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Geographical Signatures of Middle Atlantic Estuaries: Historical Layers

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ABSTRACT: Estuaries of the middle Atlantic region can be characterized and viewed broadly against the backdrop of their geomorphologic features. While geomorphology is literally at the base of every estuary, these features do not necessarily yield regional signatures. A conceptual model, with layering in time and space, is proposed as an alternative to simplistic geomorphologic characterization. Humans have altered virtually every physical, chemical, and biological feature of middle Atlantic estuaries. A basic model premise is that middle Atlantic estuaries have a base of fundamental geomorphology features. Layered, in GIS fashion, on this base are the estuaries' components: climate, nutrients, watershed soils and vegetation, producers, and consumers. These components have been so strongly influenced by humans in time and space that the signature is anthropogenic. As a consequence, best management practices, stock assessment, and restoration have replaced concepts such as ecosystem integrity and stability. The focus of the layered model is the Chesapeake Bay watershed, and although middle Atlantic estuaries differ along climatic and latitudinal gradients, all reflect the detrimental effects of a massive human presence. The ability or inability of middle Atlantic estuaries to absorb human perturbation over the last 10,000 years gives them their signatures. From the Hudson-Raritan to the Pamlico-Albemarle estuaries, we have made some progress in curbing our impacts. Nearly everything we do affects our estuaries, and our actions are proportional to the number of humans living in the watersheds. Continued population growth on our coasts and many years of abuse may be irreversible as our estuaries lose their ability to be self-regulating, biological systems.

Introduction

It is likely that this paper will differ from the other papers in the Geographical Signatures series (Conley et al. 2000; Dame et al. 2000; Emmett et al. 2000; Roman et al. 2000; Turner 2001) because my characterization of middle Atlantic estuaries has a strong historic approach and centers on human disturbance. This perspective is based on the premise that while middle Atlantic estuaries are dynamic, transient features of the landscape changing in spatial and temporal dimensions, they have historically responded to a very strong and escalating human presence. The estuaries of the middle Atlantic coastline from the tip of Long Island to Point Lookout in North Carolina (Fig. 1) are among the best studied in the world. A large number of reports, manuscripts, conference proceedings, presented papers, and studies has been promulgated about their features. These important, descriptive works are often so intensely focused on specific attributes or phenomena that the broad view is occasionally lost. Presumably, this is because we tend to rely heavily on reductionism to understand these most complex estuarine systems in narrow time frames. Consequently, we lapse into dissection rather than integration. Can a new, broader synthesis be offered to describe these estuaries?

Comprehensive, historical approaches to describing environmental phenomena are relatively rare. This could be due to the lack of concrete historical data, the questionable reliability of historic observation, the reluctance of scientists to delve into history, or a combination of these. Broad spatial perspectives have also been difficult to achieve because until recently we have lacked the analytical tools. Without these tools it has been very difficult to integrate the many pieces of information that define coastal systems. Perhaps, a broad-based overview in both time and space is necessary to characterize the estuaries of the middle Atlantic zone. The goal of this paper is to describe the estuaries of the middle Atlantic zone in this context, from a historical perspective, and to examine the layers of time and space that make these systems what they are today.

The model I wish to propose for visualizing and characterizing the middle Atlantic geographical signatures, is a layered approach. I apply this conceptual model to describe estuarine physical, chemical, and biological features through space and time. This model is also used to examine human impact, a recent signature that can be clearly seen in its own right. The model is not dissimilar to its powerful and contemporary analog, Geo-

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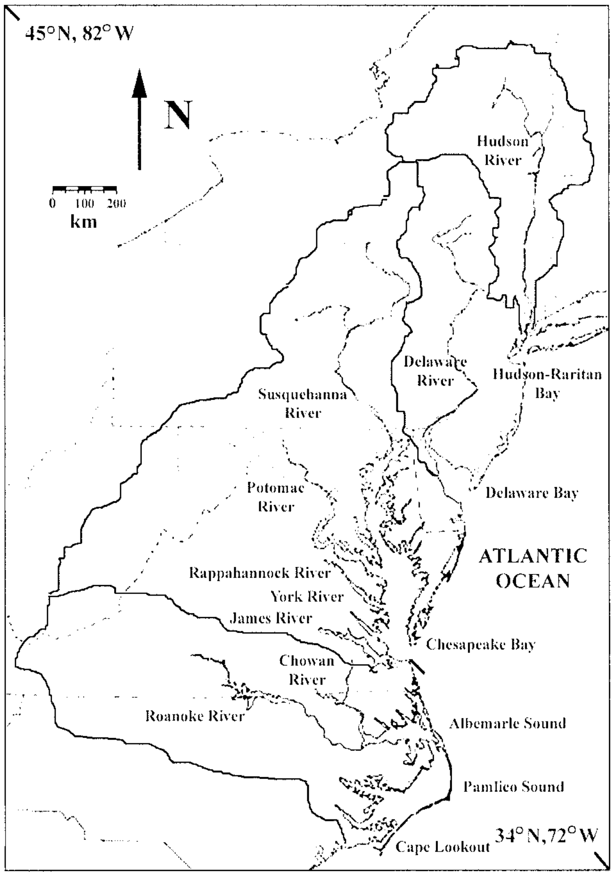

Fig. 1. Middle Atlantic estuaries and their watersheds from the Hudson-Raritan, New York, to Cape Lookout, North Carolina.

graphical Information System (GIS) technology. All estuaries and those of the middle Atlantic can be viewed broadly against the backdrop of their geomorphologic features. This physical background, against which estuaries are spatially placed, is two-dimensional and measured in latitude and longitude. The model used here presents time as a third dimension with layers of deep, geological time first, and then recent time above with its human component.

The chief indentations in the middle Atlantic coast are the Hudson/Raritan, Delaware, Chesapeake, and Pamlico/Albemarle estuaries. These share geological, geomorphological, and cultural influences that have shaped them into their present forms. Because the Chesapeake Bay is the nation's largest and richest estuary and because of its central geographical position in the middle Atlantic, it serves as the focus of this characterization. The base for the layered model is geomorphology, the substrate that holds these estuaries, and this base was defined in deep geological time.

Geomorphology

Few geographical signature papers will take you back to deep time and the formation of Pangaea at the end of the Paleozoic era, roughly 250 million years ago (mya). But this era is significant to middle Atlantic estuaries because it was at this point in the Earth's history that the supercontinents, Laurasia and Gondwana, collided. The collision uplifted the Tethys Sea forming the Appalachian Mountains and defined the western margin of the middle Atlantic watersheds (Molnar 1986; Poag 1999). What followed during the next 100 million years was a long period of climate change and intense erosion. By the Cretaceous period (140 mya) weathering had reduced the Appalachians to vestiges of their former selves and had built very thick coastal plain deposits. Tectonic movement on a regional scale tipped the entire Atlantic coast margin to the east, and regional warping created arches (high areas) and basins (embayments) in between the arches. From north to south three major depressions underlie the middle Atlantic coastal plain: the Raritan, Salisbury, and Albemarle embayments. Next, a complex set of marine sedimentation and global sea level events modified the coastal plain (Ward and Powers 1991). Recent evidence points to subsequent coastal plain modification by meteors that also hastened major extinction events. The Exmore breccia, a deep geologic deposit, indicates a huge crater from a Chesapeake Bay meteor impact. The impact, approximately 35 mya, along with subsequent subsidence, opened the mouth of the bay and modified the flow of its southern rivers (Poag 1999).

In more recent geological time during the 2 million year Pleistocene period, the middle Atlantic rivers, swollen from glacial melt water, gouged great chasms into the soft sedimentary material of the coastal plain. Several estuarine complexes occupied this reach of coastline as ice sheets advanced and retreated four times. The recession of the Wisconsin glaciers 10,000–15,000 years ago, and the flooding of the eroded river valleys by ocean water mark the beginning of the Recent epoch, and define the extent of the present coastal plain. Although all estuaries owe their existence to sea level rise (Bowden 1967), we now see sea level rise as a threat to our coasts (Day et al. 1995), and human activity is speeding the process (Cicerone 2000).

Perhaps more influential than the drowning of the river valleys is the changing width of the coastal plain from north to south. Combined tectonic and climatic events resulted in a coastal plain that is roughly triangular, narrow in the northeast and

TABLE 1. Physical characteristics of river watersheds and their estuaries in the middle Atlantic region arranged by latitude from north to south. Tidal reach of the Susquehanna watershed is the length of the Chesapeake Bay (U.S. Environmental Protection Agency 1983a; U.S. Department of Commerce 1990).

Watershed	Area (km^2)	Length of River Segment (km)			Discharge (m^3 s^{-1})
		Total	To fall line	Tidal	
Hudson	34,706	507	265	241	388
Delaware	40,275	547	409	154	411
Chesapeake					
Susquehanna	77,700	719	408	311	1,195
Potomac	36,784	655	470	185	326
Rappahannock	6,841	333	148	185	70
York	7,734	347	222	125	69
James	25,905	565	394	171	284
Albermarle	46,309	692	488	304	382
Pamlico	38,229	359	241	118	173

broader in the southeast. This has the effect of varying the inland distance of the Piedmont plateau, where the rivers have their fall lines. Consider the proximity of the sea to the Shawangunk and Palisades on the Hudson, the Watchungs and Atlantic Highlands of the Raritan, the Delaware fall line at Trenton, the Chesapeake's Susquehanna 300 km from the sea, and the long meandering paths taken by the tidal Chowan, Alligator, Roanoke, Pamlico, and Neuse Rivers. Only the Hudson, and to a lesser extent the Susquehanna, Rivers successfully penetrate the Appalachians. Indeed, the western mountains constrain the northern coastal rivers, forcing them to run due south (e.g., Hudson) or southeasterly. Their outlets to the sea are relatively close together, as the distance from the mouth of the Hudson down to Cape Henry and the Chesapeake Bay is only 400 km. As the coastal plain broadens in Virginia and North Carolina, rivers take a more easterly route (e.g., Roanoke), and the estuaries spread, backing up against barrier islands. From north to south (with only the Chesapeake and its mighty Susquehanna as exceptions), middle Atlantic estuaries have roughly equivalent tidal reaches, non-tidal river lengths, and watershed sizes (Table 1). All have gradients from full coastal ocean salinity (low 30‰ range) to freshwater; and they are mixed in various ways (Pritchard 1967). They extend with varying distances into the interior of our continent and with varying anastamosing complexity (the extent to which they interweave with the landscape). From the rather linear Hudson to the convoluted creeks and bays of the Chesapeake Bay and Pamlico/Albemarle Sounds, all share similar geomorphologic heritage deep in geologic time.

The barrier-built lagoons and sounds that lie interstitially between the large river estuaries are also important estuaries. They are both valuable and interesting systems: extraordinary nurseries, plastic systems shaped over the scale of centuries, and greatly impacted by the excesses of coastal development and shoreline hardening by erosion control structures. This run of barriers starts in the south at Cape Hatteras and the Pamlico, Albemarle, and Currituck, and inserted above the Chesapeake's mouth are the Delmarva Bays. Above the Delaware are New Jersey's barrier estuaries. Past the Hudson, the barrier lagoons begin behind Fire Island and continue on towards Montauk Point. Geomorphology and the long barrier islands give these bays dynamics that are different from the large, open, river-driven estuaries with their rapid flushing rates.

Climate

Superimposed on the middle Atlantic geomorphology base is a temperate climate layer. The temperature component of this layer reflects north to south warming with latitude and east to west cooling with longitudinal change in elevation. Winter in the middle Atlantic is of considerable importance because of its range in severity. Albany, New York has a historic mean low temperature of −11.6°C compared to Cape Hatteras, North Carolina's 2.6°C (U.S. Department of Commerce 1992). This triggers down-coast migrations of species like menhaden, striped bass, bluefish, cow-nosed rays, and Canada geese. Changes in latitude, temperature, and salinity combine to influence ice cover in these estuaries, and these are important to navigation and waterfowl. Climatic clines are also reflected in the terrestrial vegetation. Northern watersheds are more likely to have broad areas of deciduous canopy cover and forest understory, while southern watersheds have higher proportions of evergreens, with varying cycles in how they are cleared or cropped for human purposes.

In southern Pennsylvania or into the Appalachians, climate does not permit the more southern agricultural practice of double cropping (corn and soybeans in a single season). The corn season in Pennsylvania is 90 days, affecting tillage and fertilizer use, and how these systems store, release, and recycle nutrients. Northern watersheds are more likely to retain snow pack and have accentuated freshets as well, with pulsed nutrients (and contaminants) that are delivered in concert with spring plankton blooms. If these nutrient loads are excessive, large stores can be deposited in the sediments and recycled multiple times in conjunction with a later collapse of warm weather dissolved oxygen (Officer et al. 1984; Seliger et al. 1985). The storage of nutrients in sediments and its impact on habitat seem more acute further to the south and in deeper estuarine channels like the Chesapeake (Boynton et al. 1982; Jaworski 1990).

Our southeastern estuaries in the United States are more subject to tropical storms than the middle Atlantic region, but as hurricanes follow Gulf Stream waters up the coast, they can strongly influence all subsequent layers in the layered-time model. For example, Hurricane Agnes crept up the coast in June of 1972, settled over Shamokin, Pennsylvania, and dumped 45 cm of rain into the already rain-saturated Susquehanna and Potomac River watersheds. This created the worst known flooding of the Susquehanna since the earliest record keeping in 1784; floodwaters killed 117 people and caused $3 billion in damage (Bailey et al. 1975). Agnes forced the salinity of the entire Chesapeake to zero for days and caused major shifts in the lower Chesapeake macrobenthic communities (Boesch et al. 1976). It is believed that the hurricane's long-term impact has endured for years and that some species (notably the oyster) have yet to recover (Hargis and Haven 1995). In the week following the deluge, 50 years worth of sediment was deposited in the upper 40 km of the Bay (Schubel 1974; Hayes 1978). As a result, the 164,000 bushel yr^{-1} harvest of soft-shell clams (*Mya arenaria*) in Maryland prior to Agnes fell to 55,700 bushels in 1973 and has yet to rebound to pre-1972 values (U.S. Department of Commerce 1973, 1974). The hurricane's impact was probably accentuated by an already ailing fishery that had suffered from the use of the hydraulic clam dredge, a device invented in the 1950s that literally mined the soft estuarine bottoms and brought the molluscs to dangerously low numbers (Witty and Johnson 1988).

Weather delivers yet another gradient: nitrogen deposition from the atmosphere. The nitrogen sources are to the west of all the watersheds, and weather patterns shape contaminant delivery by virtue of wind direction and topography. As air masses are pushed up in crossing the mountains, condensation strips them of moisture. This causes dissolved contaminants to fall, leaving the land to the east or leeward, less directly impacted. But the rivers are still delivering contaminants, especially nitrogen (Fisher and Oppenheimer 1991). Managers seeking both to decrease loading and to blame the contamination on something other than local sources increasingly appreciate the downstream loading. Nutrient reduction goals have brought estuarine restoration groups throughout the middle Atlantic together in workgroups devoted to managing these shared resources.

Nutrients and Producers

Human activity on the land directly affects all water bodies making terrestrial systems "leaky." As nutrients leach from the soil they quickly over-stimulate algae growth and change plankton community composition. The most comprehensive accounting seems to come from the Chesapeake where deep sediment cores demonstrate the broad-scale shifts driven by European land use (Cooper 1995; Cooper and Brush 1991, 1993). Yet, the colonists' agricultural impact was slow to develop as English and other colonial settlers struggled to gain a foothold in the region. The first 150 years of colonization were characterized by inefficient hoe-based agriculture; practices that mimicked Native American methods. Tree stumps were left to decompose and acted as deterrents to erosion. Fallow fields were overgrown and soil fertility was restored because of labor shortages (Miller 1986). As a result and even as late as 1800, tobacco production (notoriously demanding on soil nutrients) in Maryland used only 1.4% of the total land area (Froomer 1978). Europeans visiting the early colonies found that farming was backward and that the implements used were inferior in number and kind to those used in the Old World (Pryor 1984). Nicholas Cresswell visiting from England saw tobacco being planted in holes dug with fingers or sticks in 1774, and he criticized the unsophisticated methods of colonial agriculture by saying "It is really astonishing that it produces anything but weeds. . ." (Cresswell 1925 p. 198).

However, what was bad news for the early colonists and brought them so often to the brink of starvation was good news for the adjacent water bodies that probably experienced little siltation at the hands of humans prior to 1800 (Miller 1986). The color of the Hudson River at the New York state capital in Albany reflects sediment loads delivered by all the tributaries. In his secret report about the potential of a new colony, Jasper Dankers, a Dutch Labadist minister who visited in 1679, remarked that crystal clear water came over the falls at Albany (Van Zandt 1971).

Clear water free of silt and sediment was soon to change forever up and down the Eastern Seaboard. In about 1760 when only one in twenty planters owned a plow (Land 1969), economic and political factors dictated a shift from cash crops like tobacco to grains such as wheat, and planting practices began to shift. Thomas Jefferson shares a lot of blame for accelerating erosion as settlement spread westward from the 13 colonies. He invented the moldboard plow that turned the soil and killed the sod (Betts 1953). Jefferson demonstrated that it was possible for moldboard plows to be mass produced on a common model and between 1800 and 1830, 124 patents where granted for plows (Bidwell and Falconer 1941). It seems that Jefferson had shown the way toward intensive plow agriculture.

By the early 1800s, Jefferson was pleading with his neighbors (who had eagerly adopted his plow) to plow contours around the hills because his own soils were being ruined and flushed into the rivers with each heavy rain. The Piedmont was also being settled in the 18th century, and large-scale deforestation took place along the Susquehanna River and its tributaries in Pennsylvania as the land was plowed for grain production (Lemon 1972). It is estimated that within 25 years of being cleared, the topsoil of the Piedmont was entirely removed and that the James River ran like "a torrent of blood" (Anburey 1791 in Miller 1986 p. 183). By 1807, many of the creeks used for anchorage off the Potomac River had silted in so badly that they had to be abandoned (Scott 1807). The shipping channel of Baltimore had to be regularly dredged after 1780 (Gottschalk 1945) and by 1800, regular dredging was done in the Potomac at Georgetown, Washington, and Alexandria (Capper et al. 1982). This coincided with the prominent tobacco ports at Joppatowne, Port Tobacco, and Upper Marlboro in Maryland being completely silted, but poor stewardship of the land continued well into the later part of the century. Joppatowne, just north of Baltimore on the Gunpowder River, once took an eight foot draft, but between 1848 and 1897, 6.04×10^6 m^3 of sediment was deposited in the upper estuary closing the port (Capper et al. 1982).

The technique of augmenting the soil with nitrogen-rich fish was borrowed from the Native Americans and was used extensively in the New World. Later in the 1840s, conventional deep-plow tillage was further complicated when nitrogen-rich Peruvian guano was imported into Baltimore for fertilizer. Fortunately for the estuary, its use was short-lived due to expense (Sharrer 1988). While nutrient subsidies continued to be necessary because of soil depletion, the real impact of soil augmentation on estuaries was not felt until the post-World War II conversion of manufacturing capacity into commercial fertilizer production and the arrival of the Green Revolution. These non-point sources are enhanced by point sources, most notably from sewage. And we now know that airborne nutrients arrive on prevailing winds from the west, outside the watersheds, to be deposited in the airsheds of our various estuaries. Twenty-eight percent of the nitrogen entering the upper Potomac River (Jaworski et al. 1992), and 40% of the total nitrogen entering the Chesapeake Bay (Fisher and Oppenheimer 1991) comes from atmospheric sources.

On the Potomac River chicken farms have replaced dairies, and Moorefield, a small riverside hamlet settled in 1777, proudly advertises itself as the Poultry Capital of West Virginia. While twenty tons of cattle manure can typically be applied to a field without excess runoff, only seven tons of nitrogen-rich chicken manure can be efficiently absorbed. Eight hundred industrial-sized chicken houses sprang up between 1990 and 1994 in the vicinity of Petersburg, West Virginia, and while the state has only 4% of the Potomac's watershed, it contributes 15% of the river's nutrient load (Palmer 1996). As Chesapeake Bay managers struggle to control nutrients from point sources, it is estimated that 66% of phosphorous and 57% of nitrogen arrived in 1996 from non-point sources (U.S. Environmental Protection Agency 1999).

In the middle Atlantic when out-of-production farmland goes on the market, developers and roadbuilders are ready to supplant agricultural runoff, and we are only learning now how much development impacts nutrient loads and how to minimize these. There is also the suggestion that when impervious (paved) surfaces in a watershed get to 10%, serious stream degradation occurs (Schueler 1994). At the 10% level stream temperatures increase (Galli 1991), stream macroinvertebrate diversity decreases (Klein 1979), and anadromous fisheries are irreversibly affected (Limburg and Schmidt 1990).

Submerged aquatic vegetation (SAV) in middle Atlantic estuaries has declined drastically. There is increasing evidence that light attenuation in the water column is the primary cause. At the root of this problem are excess nutrients that stimulate phytoplankton growth and other suspended material that inhibits the plants' photosynthetic capability. In the Chesapeake Bay, the early warning signs occurred locally as early as the 1950s (Bayley et al. 1978). Bay-wide declines of all SAV species in the late 1960s and 1970s (Orth and Moore 1983) were correlated with increasing nutrient and sediment inputs from surrounding watershed development (Kemp et al. 1983; U.S. Environmental Protection Agency 1983b). Since that time phosphorus inputs into the bay have been reduced, but it has been more difficult to curb nitrogen concentrations (Malone et al. 1993; U.S. Environmental Protection Agency 1999). Some of the success in restoring Chesapeake Bay SAV in the 1980s and early 1990s, due to nutrient reductions (e.g., Orth et al. 1996), has been reversed by unusually high freshwater discharges in the mid and late 1990s (Orth et al. 1998). Given the primacy of SAV beds in the life cycles of finfish and crabs (Setzler-Hamilton 1987; Pardieck et al. 1999; Manderson et al. 2000), declines in SAV may have serious consequences for the commercial fisheries.

Watershed Vegetation

Terrestrial vegetation in the watershed represents a layer in the middle Atlantic model that is tightly linked and responds to geomorphology and climate, and in turn influences water quality. If we have learned anything about the integrative capacity of estuaries, it is that what we do on the land has enormous consequences in the estuary. Deforestation impacts estuaries by increasing turbidity and nutrient loads as soils are carried into rivers. Parts of New York and Pennsylvania have suffered more from deforestation than other areas because of topography, and when logging completely stripped their primal forests, erosion was rampant. The same seems to have happened with agricultural land use after 1800 because estuarine sedimentation drastically increased (Brush 1989; Schneider 1996). As people moved west, massive deforestation occurred everywhere, and only a handful of Appalachian acres have been spared. By 1850 only half of the forests encountered by middle Atlantic colonists remained uncut (Clawson 1979). By 1885, the Susquehanna watershed was heavily timbered, and 226 million board feet of timber were held in the West Branch awaiting the saw at one of Williamsport, Pennsylvania's 25 saw mills (Klein and Hoogenboom 1973).

In the layered model, forest structure change first takes place in the context of geological time as forest composition shifted in response to climate change. This is well documented in the pollen record (Watts 1979; Russell et al. 1993). Superimposed much later on the climatic shift in species composition are changes from human disturbance that promoted localized and patchy forests (Russell 1980). For example, *Pinus* species have increased in areas of intensive tobacco cultivation within Maryland's Magothy and Nanticoke River basins (Schneider 1996). Changes in forest structure have also made our forests more susceptible to disease, insect infestation, and fire. The later was a factor in the 19th and early 20th centuries, when sparks from locomotives often started devastating fires in slash piles (Hough 1882). Lack of resistance of both the American chestnut (*Castenea dentata*) and balsam fir (*Abies balsamea*) to chestnut blight and the spruce budworm, respectively, was strongly influenced by their large, more-or-less monospecific stands (Swain and Craighead 1924; Kuhlman 1978; Sanders et al. 1985). While these pests probably would have killed these species anyway, both had become more common after the Euroamerican forest disturbance, and stand uniformity probably hastened their demise (Russell et al. 1993).

On the flat coastal plain of the Carolinas, monoculture on pine plantations necessitates human intervention. While the Albemarle-Pamlico watershed remains 60% forested (Stanley 1992) much of the wetland loss experienced in North Carolina includes forests: bottomland hardwood forests, cypress stands, and pocosin forests (Steel 1991). The replacement of natural forests with industrial forest plantations and wetland loss have resulted in water quality degradation. For example, pulp wood processing has contaminated finfish in this estuary and sediments reflect localized enrichment by toxic pollutants (Steel 1991; Stanley 1992). Monoculture forestry practices like clear cutting have had historic watershed impacts primarily because the trees are no longer there to filter out water-borne nutrients (Kuenzler and Craig 1986; Kuenzler 1989). One of the most dramatic losses from monoculture practices comes from forest habitat fragmentation. Interior forest habitat and the insulation that comes from being away from the edge, has dwindled to alarming levels, and forest-dwelling bird populations are declining dramatically (Terborgh 1989). Often the ecological impacts of forest disruption are not seen in the number of acres covered by forests, but rather the forests' continuity.

Deforestation changes transpiration rates, influences salinity (Brush 1986), and these have modified our estuarine fisheries. From colonial refuse in archeological sites in the James River (Jamestown), Virginia, and Lower Potomac River (St. Mary's City), Maryland, Miller (1986) has found the remains of fish exploited for food that no longer reside in these areas. The species that were once abundant and heavily consumed, such as sheepshead (*Archosargus probotocephalus*), are found in water more saline than at these sites today. Black drum (*Pogonias cromis*) remains have been recovered from a site occupied about 1660 on the Elk River near the head of the Chesapeake, well above the current range for this fish. This evidence of the early colonial diet predates the massive deforestation of the James and Susquehanna River basins, and leads Miller to speculate that the Chesapeake Bay may have been substantially more saline than it is today. Higher volumes of freshwater lost to the atmosphere, as a consequence of high evapotranspiration rates of intact forests, would reduce freshwater input into the estuary and drive salinity up. Therefore, deforestation may have exacerbated climatic patterns that had previously altered Chesapeake Bay salinity (Brush 1986).

Humans have also perturbed the vegetated borders of our estuaries, especially the salt marshes of the sounds and bays. Marsh loss in the middle Atlantic has been continuous since the arrival of Europeans, but most has been purloined by post-World War II development. In 200 years, we have lost 53% of our wetlands, a total of 4.3 million hectares. New Jersey has lost the smallest percentage (39%) within the geographical signature region, but Maryland had the largest (73%) loss between 1780 and 1980s. In terms of area, North Carolina has been the hardest hit with 2.3 million hectares of wetlands lost, more than half of all the other middle Atlantic states combined (Dahl 1990). This wetland loss coupled with wetland sensitivity to groundwater-borne contaminants have had major impacts on Atlantic coast estuaries. Wetlands filter and retain pollutants because of their restricted circulation compared to open bays. The extensive wetland loss in the southern-most part of the middle Atlantic has resulted in degraded water quality and threatened biological productivity (McMahon and Lloyd 1995; Hyland et al. 1996). Despite the draining, filling, and other insults marsh systems remain remarkably resilient, turbid, and fertile.

Consumers

Middle Atlantic estuaries have a diverse and productive set of consumers that rely on the estuary's producers. Like all other estuarine attributes, consumers have not only been altered by the human presence and suffered as a consequence, but they are indicators of the stress imposed on the individual estuarine systems. In essence, these are the final layers of the layered model and consequently integrate all levels below them, defining the estuaries and giving them their current signatures. It would be foolish to attempt a complete documentation of all the changes that have occurred in middle Atlantic consumer groups. Oysters and finfish stand out as especially illustrative of how humans have used and misused consumers, and how this exploitation has lead to more extensive estuarine alteration.

OYSTERS

The American oyster (*Crassotrea virginica*) should be the signature organism of the middle Atlantic region because it is the best documented historical example of ecosystem-level response to human consumers (Cronin 1967). Even pre-colonial impacts by Native Americans on these exceedingly abundant filter feeders have been noted because large middens (oyster refuse piles) have been found and excavated by archaeologists (Custer 1986; Kent 1986). Clear shifts in consumption patterns and exploitation have occurred across the millennia of human interaction with these molluscs (Barber 1979). Oysters play a critical role in estuaries as they act as biofilters removing phytoplankton and particulate matter, and they influence nutrient cycling (Dame et al. 1984; Dame 1996). Newell (1988) believes that at pre-1870 levels, oysters could filter the entire Chesapeake Bay's volume in 3.3 days, and that 23% to 41% of the Bay's 1982 carbon production could be removed.

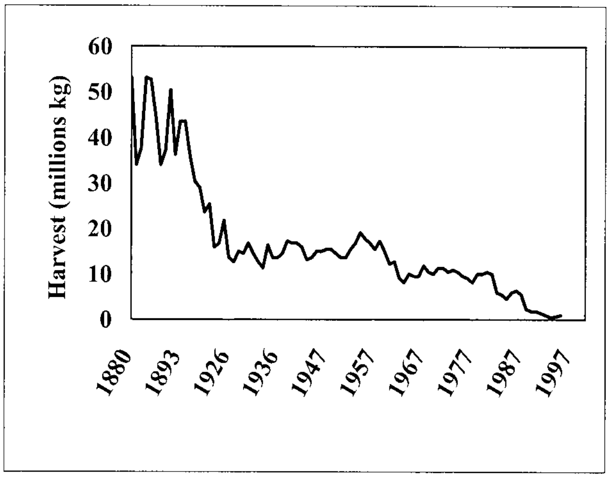

Fig. 2. Commercial oyster harvests in Virginia and Maryland waters, 1880–1995. Harvest data from U.S. Bureau of the Census (1975) and U.S. Environmental Protection Agency (1999).

Oyster reef structure, long since eradicated on the East Coast, was a huge pile of shell extending from deep water to the surface (McCormick-Ray 1998). Known as rocks because of their exposure at low tide, they were so extensive that they were hazards to navigation (Wharton 1957). Native American (10,000 years ago) through colonial harvesting of oyster reefs was slight because of low human population density. In the early 1800s, the center for early commercial oyster production was Fair Haven, Connecticut, but dwindling harvests created opportunities in New York and Baltimore (Stevenson 1894). The oyster harvest, the unbelievable harvest, begun around 1835, literally picked up steam by the time of the Civil War (Kennedy and Breisch 1981). The Baltimore and Ohio (B&O) Railroad was nearing completion in 1830, and oysters were making their way west on the rails. By 1860, the B&O was shipping more than 3 million pounds of oysters annually to western markets. Although federal confiscation of the railroad during the Civil War nearly stopped the oyster business, Baltimore's oyster houses were back in force as the post-war economy flourished (Nichols 1937). In the post-war prosperity of the 1870s the demand for oysters soon outstripped supply, pumped up prices and profits, turning bay shore villages into boomtowns, and sparking battles between Marylanders and Virginians, tongers and dredgers, oystermen and the Oyster Police (Fincham 1981).

In the Chesapeake, the oyster harvest peaked in the 1887 (Fig. 2) when nearly 20 million bushels of oysters were extracted in Maryland alone (Paynter 1996). Between 1872 and 1892 Maryland's annual oyster harvest fell only once below the 10 million bushel mark (Stevenson 1894). Oyster harvest declines between 1880 and 1905 were undoubtedly due to over-harvesting and destruction of the reefs themselves (Hargis and Haven 1995; Paynter 1996). W. K. Brooks was appointed Maryland's oyster commissioner in 1882, and his foretelling of the oyster industry's demise if harvesting went on unabated (Brooks 1891) was visionary at the time, but his pleas for conservation were ignored. Even Maryland's early legislative attempts to curb oyster export and to limit the use of the oyster dredge in 1820 failed to keep the harvests at reasonable levels. The tremendous assault on oyster beds brought a new word to fishing, management (Hennessey 1994). Although the attempt to manage the oyster industry has continued in Maryland for 180 years (Kennedy and Breisch 1983), it has had little success.

Oyster harvests in the Chesapeake have dwindled to less than 100,000 bushels in recent years, and now it is hard to imagine the harvests of the 1880s, considered the most prosperous decade in the industry's history. Equally hard to imagine is a daily train of that period pulling out of Baltimore bound for Chicago with 30 to 40 boxcars full of oysters (Nichols 1937). The ancient oyster reefs were not only dredged for the food, but for their shells as well (Rothschild et al. 1994). Stevenson (1894) estimated that the 400 million bushels of shells extracted between 1800 and 1890 would literally have sunk all the vessels in the United States at that time. Even roads were paved with crushed oyster shells; and prior to the Civil War, Edmund Ruffin, the principal agricultural journalist of the 1850s, suggested that burned and ground shells could be used to neutralize acid agricultural fields (Witty and Johnson 1988). It is also hard to believe that anyone can still be optimistic about the oyster's fate. Dave Luckett, a waterman from Glouchester, Virginia, reports, ". . . there's still a harvest out there, and eventually these problems and diseases will go away" (Ayers 1993 p. 26). Yet, watermen still resist cutting the season short, citing the fact that they have always practiced conservation (Ayers 1993). The plight of *Crassostrea virginica* even suggests to some that the Chesapeake Bay fishery is in such dire straights that it should be replaced by the Japanese oyster, *Crassostrea gigas* (Gottlieb and Schweighofer 1996).

FISH

At this point it is appropriate to cite Captain John Smith (Fig. 3) because he was the first European to take note of the middle Atlantic's biological resources. However, it must be remembered that The Virginia Company forbade Smith to speak ill of the New World, and his mission was to promote immigration rather than thwart it (Bradley 1910). Smith (1612 p. 113) comments in a 1608 journal entry that the fish were "lying so thicke with their heads above water, as for want of nets, our barge driving amongst them we attempted to catch them with a frying pan, but we found it a bad instrument to catch fish with." While Smith's account may have been self-serving and exaggerated, Miller's (1986) convincing archeological evidence gives a glimpse of abundant fish resources during the early colonization of Jamestown, Virginia (1607) and St. Mary's City, Maryland (1634). He reasons from fishing gear inventories and refuse piles that benthic-dwelling fish, like drum (*Pogonias cromis*) and croaker (*Micropogonias undulates*) caught with hand lines, were the dominant food fish. But later as these easily caught fish began to decline, a shift to pelagic plankton feeders (i.e., bay anchovy, *Anchoa mitchilli*) and filter feeders (i.e., menhaden, *Brevoortia tyrannus*) together with their equally pelagic predators (striped bass, *Morone saxatilis,* and bluefish, *Pomatomus saltatrix*) became the human quarry and were fished with nets.

Fig. 3. Portrait of Captain John Smith, "President of Virginia and Admiral of New England", from a 1614 map published in Smith 1624. The General Historie of Virginia, New-England, and the Summer Isles, and reprinted in Arber E. (see Smith 1612).

Over-fishing in the middle Atlantic region is

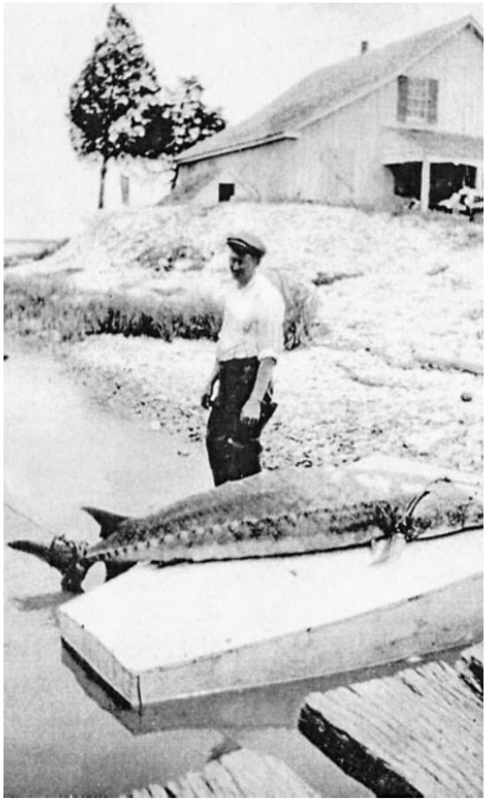

Fig. 4. Atlantic sturgeon (*Acipensor oxyrinchus*) caught in a St. Jerome's Creek trap net, St. Mary's County, Maryland. This specimen from ca. 1930 was approximately 140 kg. During the colonial period in the Chesapeake Bay sturgeon were very abundant, often 3–4 m in length, and saved the Virginia colonists from starvation during their first two winters (Smith 1612). Photograph courtesy of Historic St. Mary's City Commission.

nothing new. In 1678 the Middlesex Court in Virginia acted to conserve the county's fish because some residents had over-fished (Capper et al. 1982). Along our coasts there has been continuous human predation and overfishing of successive populations of finfish. Sturgeon (chiefly Atlantic sturgeon, *Acipensor oxyrinchus,* Fig. 4) is often mentioned by Smith in his diaries, and during 1607 and 1608 the Jamestown colonists were saved from starvation by eating sturgeon (Pearson 1942). Sturgeon was easily and heavily exploited for food, and the Delaware and Chesapeake Bays were the first and second greatest caviar fisheries, respectively, in the eastern United States (Murawski and Pacheco 1977). Between 1880 and 1890, the caviar industry was centered in Delaware Bay (Secor and Waldman 1999). But the relationship between humans and sturgeon was love-hate. Because of their size and bottom movements, some fisherman regarded sturgeon as a nuisance fish because they could easily tear through pound nets. As a result sturgeon were hunted ruthlessly to the point of near extinction with the last legally caught fish taken from the Potomac in 1970. Efforts to restore the fishery in the Hudson River, Delaware Bay, and Chesapeake Bay are underway, but sturgeon might be particularly susceptible to the new human-altered environment in these estuaries (Secor and Gunderson 1998), and as a result these efforts may have limited success.

Some middle Atlantic rivers, including the Delaware, still carry anadromous species such as American shad (*Alosa sapidissima*) and blueback herring (*Alosa aestivalis*) that live in the Atlantic but spawn in the rivers. The Susquehanna was once among the greatest anadromous fisheries in the nation. Millions of shad were netted near the mouth of the river, and single hauls of a net sometimes took days to empty, but as early as 1840, hydropower dams terminated the spawning runs (Palmer 1996). Since then the decline in shad and herring has been astonishing because over three centuries, thousands of dams, weirs, culverts, and sills have blocked anadromous migration (U.S. Environmental Protection Agency 1983a,b). While dams for power generation impede upstream spawning runs, a major initiative to build fish passages on the Susquehanna's four largest dams is nearly complete, and between 1995 and 1997, 18 smaller dams were removed (U.S. Environmental Protection Agency 1999).

Fish kills up and down the Eastern Seaboard and elsewhere are not uncommon in the summer as water temperatures soar and dissolved oxygen becomes scarce. These conditions, as well as large numbers of fish and the presence of high nutrients, perhaps from animal wastes, have triggered *Pfiesteria piscicida* blooms from Delaware to North Carolina. Historically, some fish kills may have been caused by *P. piscicida,* probably a long-time resident in these waters; but the description of this dinoflagellate, its complicated life cycle, and its implication in fish kills has only been documented recent (Burkholder et al. 1992, 1993).

The exploitation of fisheries has had an indirect effect on salt marshes. Several estuaries without massive freshwater dilution were used as sources for solar-extracted salt and the preservation of fish. Before mechanical refrigeration and in times of war, salt was the only means for preserving meat. And the short supply of salt in colonial times (Miller 1986) may have delayed the establishment of commercial fisheries (Wharton 1957).

Human Impacts—Population

Overall, human impacts are at least proportional to human population growth, and humans just living on the landscape negatively impact our estuaries. In the middle Atlantic region, these impacts

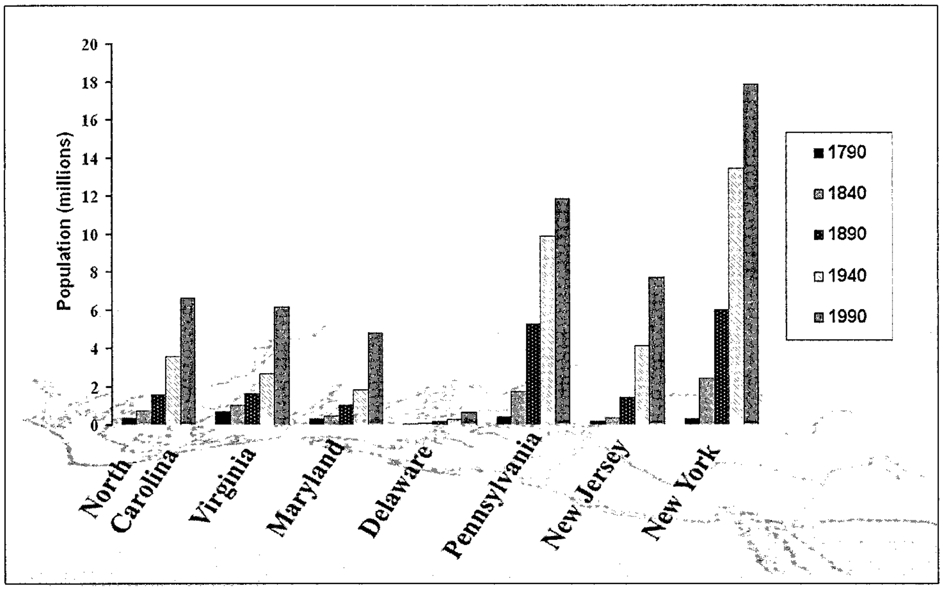

Fig. 5. Human population growth in the middle Atlantic States in 50 year intervals beginning with the first official United States census in 1790. Population numbers are in millions of people (U.S. Bureau of the Census 1975; Culliton et al. 1990).

have been going on for a long time, and they are clearly exacerbated by the region's massive population growth. To be meaningful and placed in the proper context, population growth must be viewed both chronologically and geographically (Fig. 5). Because European colonization of the middle Atlantic was centered on the coast, a north-south string of highly populated areas slowly emerged as individuals immigrated to the major ports. Even as late as 1790, the ten largest cities in the United States were all ocean ports (Forstall 1996), and then an east-to-west population movement ensued.

The primary colonization of the middle Atlantic took place in Virginia. The first English attempt with Sir Walter Raleigh's participation began in the 1580s (Bradley 1910). But the actual planting of the Virginia Colony, including John Smith, did not take place until 1607 (Smith 1612). Hendrick Hudson's trip from the Delaware Capes into Raritan Bay behind Sandy Hook took place in September of 1609, and was followed by the visit of Cornelius Jacobsen Mey to the Delaware and Cape May in 1614. It is amazing that the colonists and their sponsors so vastly underestimated the New World's harsh environmental conditions. As a consequence, the fledging colonists were not well prepared for the harsh conditions they encountered (Smith 1612). The going was especially tough in Virginia because by 1625 only 1,100 of the more than 7,500 original colonists remained (Hargis 1999). New York (more correctly, New Amsterdam) had an especially slow start with only 750 residents in 1653 (Brown 1934) while Virginia had 5,000 inhabitants (Hargis 1999). Despite all their difficulties, the tenacious middle Atlantic colonists had gained a foothold a century after the first Europeans arrived. By 1790, the year of the first United States census, nearly 2.5 million people lived along the coast from New York to North Carolina, with Virginia being the most populated state in the new nation (Forstall 1996).

One of the most significant features on the middle Atlantic landscape is the pattern of human habitation. It is estimated that by the year 2010, nearly 127 million people will live on the coasts of the United States compared to 80 million in 1960 (Culliton et al. 1990). The Chesapeake basin alone will be occupied by close to 18 million people in 2020 (U.S. Environmental Protection Agency 1999). The problem of urban sprawl is progressing southward from New York, down the Interstate highway 95 corridor through Richmond and into North Carolina, and as people move they bring their environmental impacts with them.

Human Impacts—Pollution and Exotic Species Introductions

The Maryland legislature first used the word pollution in 1808 to protect the drinking water supply of Baltimore, then a small hamlet dwarfed by Philadelphia. But the city grew tremendously becoming the third largest city in the United States in 1850. By the time of the Civil War sewage discharges made it "one of the great stenches of the world", but it was not until 1906–1915 that its sewage treatment facilities were modernized (Buckler 1872 in Capper et al. 1982 p. 24).

The big estuaries of the middle Atlantic have long been the corridors of commerce as well as conduits of people. As human society interacts with these estuaries, the problems run pretty much with their geomorphologic form. In the layered model, colonization and subsequent exploitation of middle Atlantic estuaries is population driven, and the impact is shaped by what we have done on the land or have more directly done in the water. Our initial insults were at first agricultural and linked to the quick and extractive harvesting of aquatic and terrestrial resources. These harvests have shifted in time creating a succession of resource depletions as the severity of fur, forest, food, and mineral consumption increased.

Pollution

I will use three examples of mineral resource exploitation to illustrate middle Atlantic estuarine pollution. The first, iron production in the United States, forged the country's industrial might. Bog iron was originally extracted from limonite ores precipitated on the coastal plain. John Smith sent these ores back to England for assays about 1608. The Principio Furnace in Maryland made the first iron in 1668 (Ostrander and Price 1940), and old furnaces still exist on the New Jersey Pine Barrens. Later in 1800, 167 iron furnaces were operating in Pennsylvania as the state flexed its industrial muscle. Each iron furnace consumed an acre of forest each day (Klein and Hoogenboom 1973), but the shift to coal as fuel left a lasting impression because the streams draining coal mines run at very low pH. This impact is particularly severe in the Potomac and Susquehanna basins where nearly half of the polluted river miles are due to acid mine drainage (U.S. Environmental Protection Agency 1999).

The second example also has an historical origin that dates to the Revolutionary War when soldiers were promised free land. One Maryland parcel near the Pennsylvania border was called Soldier's Delight and owned by a veteran named Reed. A sharp entrepreneur, Isaac Tyson, bought mining rights in 1808 and started the Baltimore Chrome Company in 1827 (Ostrander and Price 1940). Chromium was first used as a paint pigment, but used later in the metal plating industry. The serpentine chromite ore was transported to a heavily industrialized site on Baltimore Harbor and this site polluted the Chesapeake Bay for 140 years. The sediments of the Patapsco River and Baltimore Harbor still carry very large heavy metal loads, and chronological analysis of the sediments shows a drastic increase in contamination after 1800 (U.S. Environmental Protection Agency 1983b). The impact of these metals persists because benthos diversity is very low (Reinharz 1981), and the overall metal contamination in the Chesapeake is most acute near Baltimore (U.S. Environmental Protection Agency 1983b).

The Hudson River that contains the nation's most heavily populated urban center has been subjected to serious pollutant pressure. Organic compound (PCBs, dioxin, PAHs) transfer from the water, to the sediments, and to anadromous fish such as stripped bass continues to be a major problem in the estuary (Achman et al. 1996; Hirschberg et al. 1996). Pollution was perhaps first and worst in the Hudson/Raritan compared to other estuaries, and the contamination near New York City is so acute that Delaware River water diversion into the Hudson estuary has been considered for at least 70 years (Cronin 1967). Just to the south, serious degradation of Raritan Bay took place between the two World Wars with industrial scars and municipal wastes still very evident (Jeffries 1962). Here, habitat loss may be permanent, leading some to speculate that the lower Hudson may never recover (Cronin 1967). The Delaware perhaps follows New York as the second most polluted estuary in the middle Atlantic. The massive sewage discharges below Philadelphia/Camden and Wilmington and a history of petrochemical and toxic contamination, make restoration a very serious challenge.

Exotic Species' Introductions

Few human impacts on estuarine ecosystems loom as large as exotic species introductions (Mooney and Drake 1986), and an estimated 350 exotic species have been introduced into the coastal waters of the United States (Office of Technology Assessment 1993). It is not surprising that exotic species and their impacts have had a north-to-south spatial pattern in the middle Atlantic because as humans move, so do the organisms they bring with them. Particularly hard hit are high commercial activity areas such as the Hudson River basin where at least 113 nonindigenous species reside. The vectors of introduction are from unintentional escapes from cultivation, release of ship's ballast and ballast water, and canals (Carlton 1992; Mills et al. 1996). Canal building made the Erie (1825) and Welland (1829) Canals prime shipping lanes and linked the Great Lakes with the Atlantic. Before 1825 New York was the fifth largest port in the United States, but with the completion of the canals it became the largest port by 1840. These canals provided migratory routes for the sea lamprey (*Pteromyzon marinus*) and alewife (*Alosa pseudoharengus*) that had previously been stopped by Niagara Falls. The havoc that these species induced in the upper Great Lakes' fishery was tremendous (Beeton 1969), and it is likely that another Great Lakes' invader, the zebra mussel (*Dreissena polymorpha*), will have a considerable impact as well.

First discovered in Lake Erie in 1985 (Mackie et al. 1989), the zebra mussel may be responsible for improving water clarity in Western Lake Ontario (MacIssac et al. 1992). It made its way into the Hudson drainage by 1992 (Mills et al. 1996) and may have a similar impact in the Hudson's turbid waters by removing phytoplankton and suspended solids (Roditi et al. 1996; Caraco et al. 1997). This trend has been seen in the oligohaline segment of the Potomac River estuary where the introduced Asiatic clam (*Corbicula fluminea*) was also responsible for improving water clarity (Cohen et al. 1984). However, these invading species have also eradicated an unknown number of native bivalves. Two exotic oyster parasites, MSX (*Minchinia nelsoni*) and Dermo (*Perkinsus marinus*), do not improve water clarity because they infect and kill euryhaline oysters. MSX was most probably introduced into Delaware Bay in 1957–1958 through ballast water discharge (Haskin et al. 1966) and began its rampage as oyster production dropped from 7.5 million to less than 100,000 pounds of meat in less than a decade (Sindermann and Rosenfield 1967). By 1959, MSX was in the Chesapeake Bay where it had a serious impact in high salinity Virginia waters (Farley 1975), and its virulence continues to increase (Burreson et al. 2000). Dermo, also first seen in the Chesapeake in the 1950s (Mackin et al. 1950), has had effects similar to those of MSX and is now as far north as Martha's Vineyard, Massachusetts (Ford 1992). Together, these oyster scourges may be the final blow to the already ailing industry in the euryhaline Delaware and Chesapeake Bays. Yet, as we struggle to contain these exotic species, 90% of the ships entering the Chesapeake Bay carry live organisms in their ballasts (Chesapeake Bay Commission 1995).

Conclusions

The framework on which on which this paper rests is the consequence of human activity and human depredation through time. Geography, geology, and the biotic communities of middle Atlantic estuaries and their watersheds are the background for human exploitation that has played out in successive layers. The feature giving the middle Atlantic estuaries their characteristic signatures is human, and this feature is common to all estuaries. Therefore, the layered model is easily extended to all estuaries because all are modified to some extent by humans and have a backdrop of physical, chemical, and biological properties.

Today, estuarine scientists and managers attempt to restore, or at least remediate or mitigate, resource losses. We are probably failing to recognize the boundaries in which we expect our efforts to operate. If we look again at the model's framework with both spatial and time dimensions, time requires us to put all the good works done for these estuaries in perspective. The efforts made by local, state, and federal partners of the National Estuary Programs in the Hudson/Raritan, Delaware, Chesapeake, and Albemarle/Pamlico systems (e.g., Hennessey 1994) need to be redoubled if we are to succeed. The Chesapeake Bay Program, in place for nearly 20 years, shows real progress toward many numerical goals for nutrient and contaminant reductions. However, in all the basins the hard reality is that population continues to escalate, land and wetlands continue to be consumed, and fisheries are taxed to their limits (U.S. Department of Commerce 1990).

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