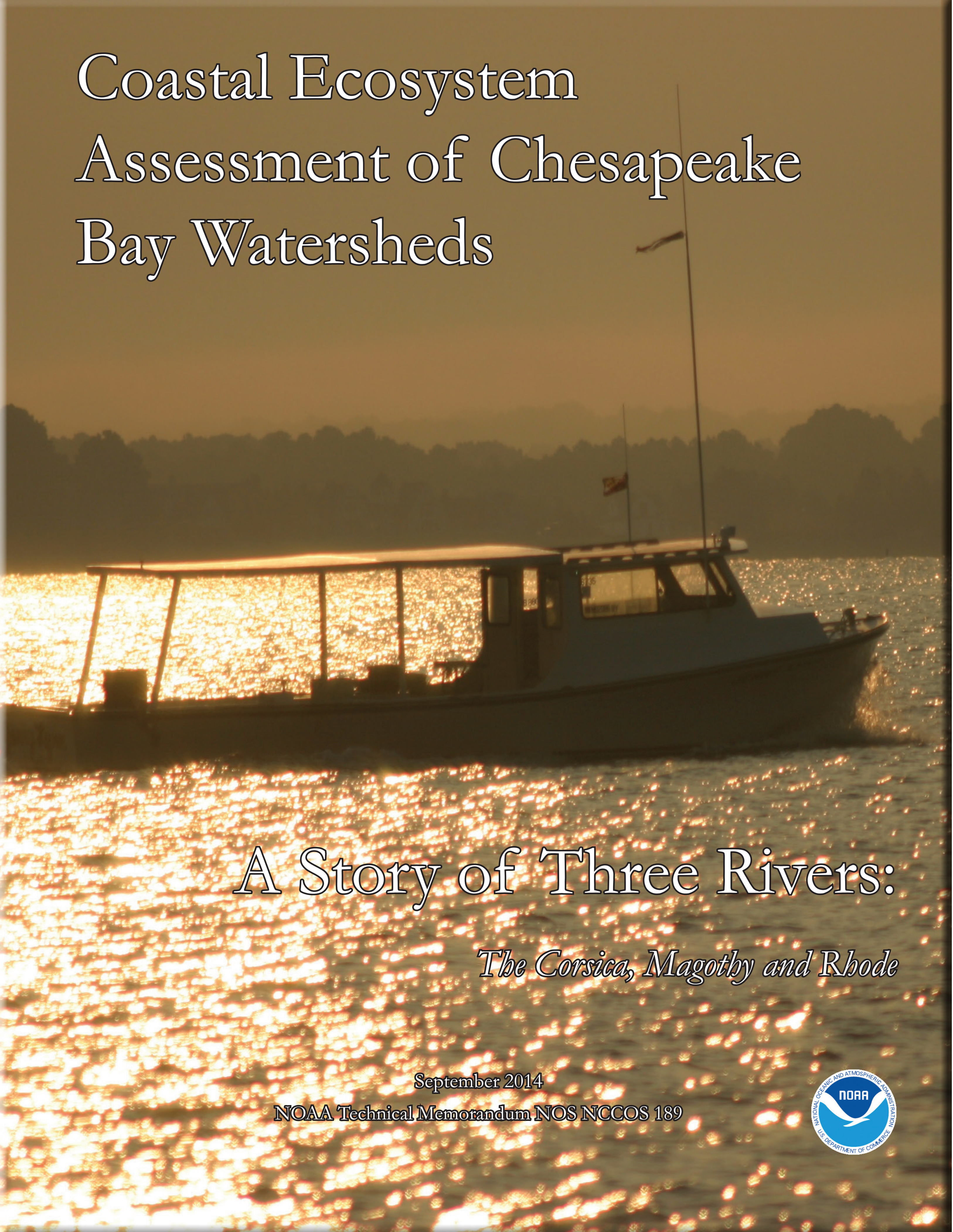
Coastal Ecosystem Assessment of Chesapeake Bay Watersheds



A Story of Three Rivers:

The Corsica, Magothy and Rhode

September 2014

NOAA Technical Memorandum NOS NCCOS 189

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Coastal Ecosystem Assessment of Chesapeake Bay Watersheds: A Story of Three Rivers - the Corsica, Magothy, and Rhode

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United States Department of Commerce	National Oceanic and Atmospheric Adminstration	National Ocean Service
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Executive Summary

Many people migrate each year to coastal and estuarine regions such as the Chesapeake Bay. Ecosystem services such as recreational and commercial fisheries, recreational boating, and ecotourism support vibrant economic sectors (e.g. seafood, hospitality, maritime transport) and provide a major contribution to economic activity in Chesapeake Bay communities. Population growth exerts continuous pressure to develop lands for housing, industry, and public infrastructure. Agriculture remains a major component of the Chesapeake Bay landscape. Together, these activities exert stress on adjacent waterways through the runoff of contaminants and sediments from developed and agricultural land.

This assessment explored linkages between land use and aquatic ecosystem health. Three watersheds (Corsica, Magothy, and Rhode rivers) with variable dominant land-use patterns (agriculture, suburban/residential, and mixed-use, respectively) were examined. The health of each habitat was assessed using a suite of observations focused on water quality and the health of aquatic organisms. Standard water quality metrics such as dissolved oxygen concentration, dissolved nitrogen/phosphorous concentration and water clarity were measured. Organismal health parameters included metrics of fish and shellfish growth, disease prevalence and severity, fish abundance, and species diversity. By analyzing these indicators of ecosystem health and their relationship to human activities within the surrounding watershed, this assessment provides insight into the trade-offs between development on land and aquatic ecosystem health. This information is necessary in order to strike a balance between supporting the needs of an ever increasing population and protecting the valuable ecosystem services that have benefited generations of Chesapeake Bay communities.

Corsica (Agricultural)

High nitrogen
Infrequent hypoxia
Abundant fish
Unhealthy fish
Healthy benthic community
Low benthic contamination

Magothy (Suburban)

Low nitrogen
Seasonal hypoxia
Low fish abundance
Healthy fish
Unhealthy benthic community
High benthic contamination

Rhode (Mixed-use)

Low nitrogen
Infrequent hypoxia
Abundant fish
Healthy fish
Healthy benthic community
Moderate benthic contamination

Climate Impacts

Climate change is expected to increase both the number and severity of precipitation events in the Chesapeake Bay region. Land development is commonly linked to increased runoff from precipitation. This study further supported that linkage. Habitat health was less varied between the three rivers during 2007, a relatively dry year for the region, than it was in 2008 and 2009, years which recorded precipitation levels at or above the regional average. This correlation indicates that precipitation increases due to climate change might be expected to further exacerbate the impacts of ecosystem stressors derived from development on land.

Environmental Thresholds and Smart Development

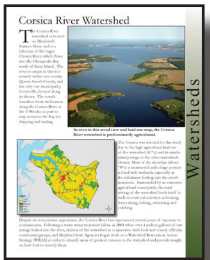
Human development on land is an unavoidable facet of population growth. The challenge for coastal managers is to balance development and the preservation of critical ecosystem services. In fact, the two are inextricably linked in this region. The economic viability of many communities depends upon readily available access to ecosystem services that are produced directly from the Chesapeake Bay. Luckily, ecosystems tend to be resilient; many are able to maintain a state of relatively strong health when faced with environmental stress. However, if pushed beyond ecological thresholds, coastal ecosystems may lose their ability to respond and be altered to a new, less favorable state. The results of this study should be used in discussions of smart development that balances environmental protection and economic growth. Smart development plans should account for environmental thresholds that when surpassed, compromise the ability of aquatic habitats to produce the ecosystem services that form the socioeconomic backbone of the region.

This document presents the findings of a 2007-2009 survey of health characteristics of three watersheds with varied land use in Chesapeake Bay. The document is divided into chapters and subchapters. The chapter title is color coded vertically on the outer margin of each page of a specific chapter. Throughout the document there are pop-out boxes that provide instructive and descriptive detail about particular issues. Figures, graphs, schematics, or maps are included when possible to enhance understanding. The error bars shown on graphs represent the standard error of the mean. Photos sources are cited only if they are from outside of NOAA.

Pop-Out Box

You will find information here that builds on topics discussed in the text or highlights related issues.

The introduction to the document provides an overview of watershed stressors in Chesapeake Bay. This chapter describes the goals of the study and the criteria for watershed selection, location of sampling sites, and temporal and spatial sampling regimes.



The Watershed chapter presents information on location, history, and land-use for each of the three watersheds. Relevant data on other land-use characteristics such as number of septic systems, oyster beds and marinas are also included to illustrate the nature of each watershed.

Four chapters provide specific results on benthic habitat condition, water quality, benthic community condition and living resources. Each of these four chapters follow a format that provides background information on the environmental component studied and why it was important to look at these components. A pop-out box in each chapter presents what was measured, how it was assessed and an explanation of what the values mean on a scale ranging from poor to good.

Document Roadmap

In order to assess each of the stressor and response variables in relation to healthy or resilient conditions, each observation was scored on an index between 1 and 5. A score of 1 means that the condition for that variable is unhealthy and a recovery from that state is difficult to achieve. A score of 5 means that the condition for that variable is in a relatively healthy state and resiliency is relatively high. Below is an example of index scores for a single metric with R=Rhode, C=Corsica and M=Magothy.

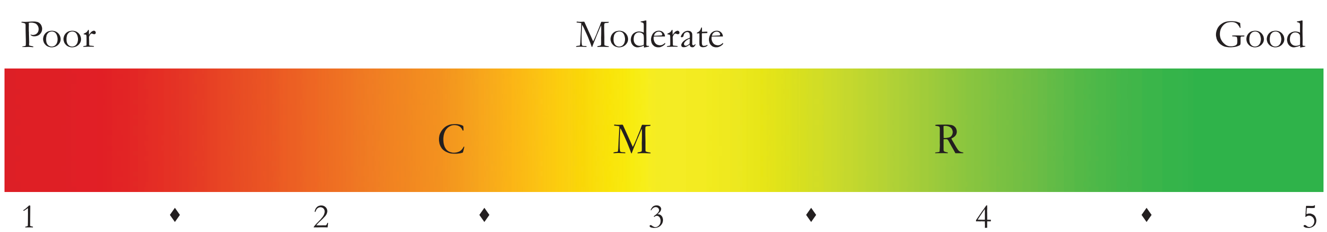
What we measured: Here you will find a description of the specific parameter that we measured.

How we assessed: This section describes the method that we used to assess the condition of each river relative to the specific parameter. If there is a well-established criterion for judging condition, then it will be presented here. If not, there will be an explanation of how we developed a way to assess condition.

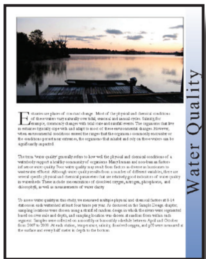
Score Example: We classified condition for each river by assigning an integer grade so that we could easily compare between rivers and parameters. Units below are for illustration.		
1	3	5
≥92μg/L	≥46 and < 92μg/L	<46μg/L

Station and River Assessment Example:

Condition	Degraded	Poor	Fair	Good
Example of Indicator Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5

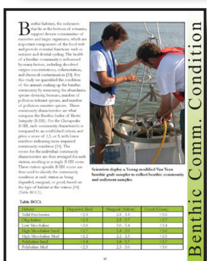


Document Roadmap

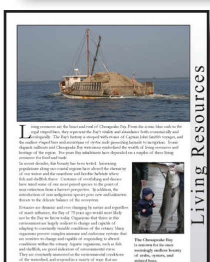


The Water Quality chapter provides information on multiple physical and chemical factors including concentrations of dissolved oxygen, nitrogen, phosphorus, and chlorophyll, as well as measurements of water clarity and indicator bacteria. Measurements were collected at 8 to 14 stations in each watershed at least four times per year.

The chapter on Benthic Habitat Condition focuses on the presence of pollutants in sediments which provide primary habitat for many aquatic organisms. Contaminants measured included metals, PAHs, PCBs and PBDEs. Sediment toxicity was measured with an assay of light production by luminescent bacteria called the Microtox® assay.



Benthic Community Condition was characterized by conducting a Benthic-Index of Biotic Integrity (B-IBI) which measures the abundance, species diversity, biomass, number of pollution-tolerant species and number of pollution-sensitive species.



The Living Resources chapter demonstrates the utility of living marine resources as bioindicators of watershed health. The premise is that living resources can provide exceptional "early warnings" of environmental alterations. Changes may occur in water quality or habitat availability, but the living resources themselves reveal the consequences of changes. The chapter is divided into fish and shellfish sub-chapters.

The Synthesis chapter is the result of comparing and analyzing data from the study and identifies distinguishing factors among the three systems. Weather related effects are also considered. Finally, implications of the results for citizens and resource managers are presented.

The document concludes with acknowledgements of collaborators and partners who generously provided resources and support. A dedication of the publication in memory of a co-worker is then presented. Lastly, literature citations are provided.

What humans do on land tends to effect what happens in adjacent waterways. Human activities such as agriculture, urban development, and industrial processes are each associated with a characteristic suite of stressors that can negatively impact aquatic environments. Generally, these stressors affect the environment by releasing four broad classes of pollutants; 1) nutrients, primarily nitrogen and phosphorous, 2) sediments, through erosion, 3) chemical pollutants, such as polycyclic aromatic hydrocarbons, and 4) biotic pollutants, such as pathogenic bacteria. In addition to the release of these pollutants, physical disturbances by humans, such as shoreline hardening and the destruction of wetlands, result in loss of critical habitat. Some common signs of these stressors include plumes of sediment washing from agricultural fields or construction sites, streams clogged with noxious algae, fish consumption advisories due to concentrations of manmade contaminants, excess nutrients resulting in low dissolved oxygen 'deadzones', and beach closures due to high levels of bacteria. The Chesapeake Bay suffers from all of these stressors.

The largest and perhaps most important estuary in the United States, The Chesapeake Bay watershed encompasses over 64,000 square miles and stretches across six states (New York, Delaware, Pennsylvania, Maryland, West Virginia, and Virginia) and the District of Columbia. It is comprised of over 150 rivers and subwatersheds that flow into it's vast drainage basin. The mixing of salt and freshwater in the Bay creates a diverse and complex ecosystem, which historically has supported thousands of migratory and resident species. These species have helped to establish a vibrant maritime economy in the Chesapeake Bay region stretching back to the 1800's. However, numbers of some commercially and recreationally important fish and shellfish have been reduced from their historic levels.

The harvest of seafood from the Chesapeake Bay, which contributes billions of dollars to local and state economies, is just one of the key aquatic ecosystem services that are threatened by land-based stressors.

The landscape of the Chesapeake Bay began to change rapidly after the arrival of European settlers en masse in the 1600's. Deforestation and large-scale agriculture were eventually followed by urbanization as the human population continued to grow. Analysis of sediment cores from the Chesapeake Bay points to a rapid increase in the amount of sedimentation and flux of nutrients into the estuary that corresponds with significant increases in human activities on land[1]. Agriculture, one of the earliest drivers of sediment and nutrient input, currently covers an estimated 25% of the Chesapeake Bay watershed [2]. Clearing forested land for the purpose of farming promotes erosion while the application of fertilizers typically increases the runoff of nutrients into rivers and streams. Additionally, pesticides applied to crops, which are toxic to many aquatic organisms, can also run off the landscape further impacting aquatic environments.

Sediment washing into the Chesapeake Bay as a result of heavy rainfall during Tropical Storm Lee (September 2011). Photo courtesy of Jeff Schmaltz MODIS Land Rapid Response Team, NASA GSFC.

Sediment Runoff

Sources: Exposed soil; agriculture areas; construction areas

Environmental Impacts: Low light penetration; aquatic plant growth; deterred oyster beds; fish eggs smothered; fish gills clogged.

Case Study: In 1972, Hurricane Agnes produced some of the worst flooding on record in the Chesapeake Bay. As a result, approximately 30 million tons of sediment washed into the Bay. Following 1972, this increase in sedimentation led to large-scale die-offs of both oysters and SAVs. [3]

Currently 17 million people reside in the Chesapeake Bay watershed, and that number is expected to reach 20 million by the year 2030[4]. Urban development increases the presence of several key stressors, including the total area of impervious surfaces (e.g. parking lots, roads, sidewalks), discharge of sewage, marine debris (trash), and direct habitat destruction as a consequence of shoreline protection efforts. These stressors promote the release of all four pollutant types (nutrients, sediments, chemical pollutants, and over production of pathogens). For example, impervious surfaces often increase fresh water runoff containing nutrients, sediments, and debris into local waterways. This runoff flows into Chesapeake Bay tributaries where it combines with similarly contaminated flows from across the watershed thus compounding the effects. High population density also results in the concentrated production of sewage. This sewage is often released directly to nearby waterways as municipal treatment systems reach their capacity during large storm events or accidental system failure.

The release of pollutants can contaminate an area for decades. Often, this pollution occurs by accident, such as the April 2000 oil spill from the Chalk Point Generating Plant that resulted in the release of 100,000 gallons of oil into a creek on the Patuxent River.

Industrial processes have impacted several key areas of the Chesapeake Bay. Factories and mines are often associated with the point-source release of chemical contaminants like heavy metals (i.e. mercury). Legacy chemicals such as polychlorinated biphenyls (PCBs) still remain in the benthic sediments of waterways impacted by high industrial development. Dams and construction activity often release large amounts of sediments into the adjacent watershed. Baltimore Harbor, Anacostia River, Elizabeth River and Middle River are all prime examples of waterways that have been negatively impacted by these types of industrial activities. Pollution from urban runoff, agriculture, and inadequate sewage treatment has caused a serious decline in water quality in Chesapeake Bay and has adversely affected the number of fish and wildlife that the Bay once supported.

Legacy chemicals such as polychlorinated biphenyls (PCBs) still remain in the benthic sediments of waterways impacted by high industrial development.

Chemical Pollution

Sources: Pesticides; electrical equipment (PCBs)

Environmental Impacts: Fish consumption advisories; toxicological effects on aquatic organisms (i.e. affects nervous system)

Case Study: A joint report published in early 2013 stated that nearly three fourths of Chesapeake Bay waterways were contaminated with toxins[5].

Accurate information on the effects of land use change in Chesapeake Bay is critical for quantifying and predicting the implications for water quality, living marine resources, and ecosystem health. These results can be used for informing land use management decisions. While large and small-scale restoration efforts abound in the Chesapeake Bay, continued human population growth and development in the Chesapeake Bay watersheds could potentially eclipse nutrient reduction and habitat protection gains. Therefore, it is critical to consider our approaches to landuse in order to ensure progress in protecting the Bay and its local watersheds. The decisions of managers should be informed by a better understanding of these land use impacts in order to assess various restoration scenarios and develop proactive management plans.

To improve our understanding of land use impacts in the Chesapeake Bay, NOAA scientists from the Cooperative Oxford Laboratory, along with a large team of partners, conducted a multiyear assessment of land use, water quality, and aquatic animal health in several small watersheds of the Chesapeake Bay. A key objective for NOAA is to protect, restore, and manage the use of coastal resources through an Ecosystem Approach to Management (EAM)[7]. An EAM considers a wide range of ecological, environmental, and human factors that may impact our ability to use our natural resources in a sustainable way. One way to build the knowledge required for an effective EAM is by conducting a comprehensive holistic study of aquatic ecosystems to provide a synthesis of analyzed data on relevant physical, chemical, ecological, and human processes in relation to specific management objectives.

Nutrient Pollution

Sources: Fertilizer on farms and lawns; septic systems; waste water treatment plant; natural sources

Environmental Impacts: Excessive algal blooms; decrease in dissolved oxygen; increase in bacteria; decrease in fish health

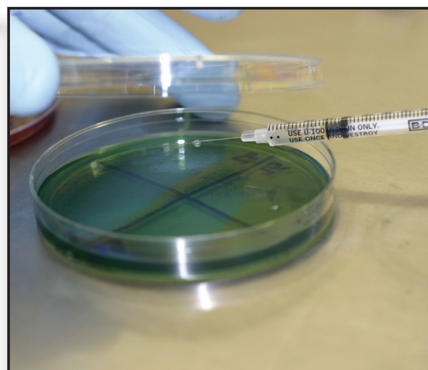
Case Study: The Chesapeake Bay experienced its largest Dead Zone, or area without sufficient dissolved oxygen, in 1998 with an estimated 30% of the Bay's water volume being affected. The average volume affected is about 22%.[6]

Bacterial Pollution

Sources: Inadequately treated sewage; failing septic systems; animal feces; and urban stormwater runoff.

Environmental Impacts: Closure of shellfish harvesting; human sickness

Case Study: In June 2013, Anne Arundel County health officials advised people with compromised immune systems or other conditions such as open cuts not to participate in the Great Chesapeake Bay Swim because of high levels of bacteria[8].



Culture media being inoculated with sample to see if bacteria are present.

Managers commonly view the environment in terms of ecosystem services, which represent the recreational, commercial, and social value of the natural resources available within a defined area. Assessing the scope of land use impacts on ecosystem services remains challenging due to the diffuse nature of non-point sources of pollution, the buffering capacity of the land, and the natural variability of ecosystems[9]. Therefore, the ecosystem health assessment study presented here utilized a cumulative stressor approach to characterize the extent of ecosystem stress. This approach analyzes the combined impact of multiple stressors on the ecosystem as opposed to the traditional view of studying individual stressors on discrete components of the environment (e.g. the effects of mercury on catfish health). This information will become critical for land-use planners and natural resource managers as the human population of the Chesapeake Bay watershed grows. Results from this study will help enable development of ecosystem condition forecasts based on variations in land-use policy or management actions.

Our Approach

The rivers included in the watershed ecosystem assessment project were chosen according to the presence of potential land-based stressors including the type of development, area of impervious surface and population. Indicators of stress included poor water quality, benthic contaminants and excessive bacterial loads while indicators of health in living resources included parasite burden, physiological parameters and presence of disease. Our integrated approach targeted various living marine resources such as fish and shellfish that occupy disparate ecological niches; this enabled measurement of diverse responses to watershed stressors. We measured conditions across a range of biological levels (cellular to community) and from numerous organisms.

Watersheds within the Chesapeake Bay were selected based on the following criteria:

1. Divergent land-use patterns plus a balanced reference site;
2. Watersheds without extensive upstream hydrology (20-30,000 acres);
3. Salinity range 6-12ppt;
4. Accessibility by small boat;
5. Availability of historic and/or other monitoring data.

The Chesapeake Bay watershed encompasses a large area of land stretching from parts of New York, Delaware, Pennsylvania, Maryland, West Virginia, Virginia and the District of Columbia.

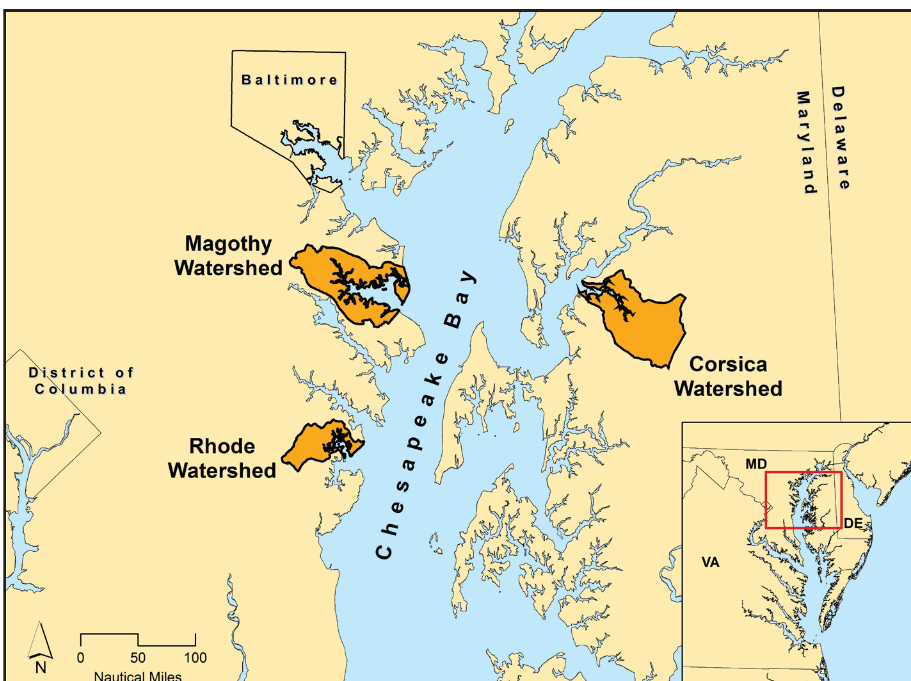


Figure Intro1. Locations of selected watersheds.

Watershed boundaries (12 digit Hydrologic Unit Code (HUC)) were overlaid on the 2001 National Land Cover Dataset[10]. After combining landuse categories into urban, forest, agricultural, wetlands, or barren and restricting salinity range to 6-12ppt to allow for habitat consistency, watersheds in Maryland's Chesapeake Bay were compared, and ultimately, the Corsica was chosen as agricultural, the Magothy as developed, and the Rhode as a balanced reference system with a mixture of forest, development, and agricultural uses (Figure Intro1).

The goal of the project was to compile the most comprehensive picture of the aquatic ecosystem in each watershed. To this end, the sampling design encompassed shallow water and deep water habitats, low salinity as well as high salinity sites, and organisms that inhabit each habitat.

Each river was stratified using a 6ft contour to separate shallow, nearshore habitats from deepwater habitats. Head waters have lower salinities due to freshwater inputs while the salinity at the mouth is greater due to tidal influences. These salinities vary throughout the day due to tidal fluctuations. To account for these fluctuations, the sample design took into account the salinity gradient that exists in each river and each river was divided into three sections according to mile marker: head, middle, and mouth (Figure Intro2).

This stratification scheme divided each river into distinct sampling areas (nearshore and deepwater areas in the headwaters, main stem and lower/mouth reaches). Most variables were sampled from one station in each of these areas, whereas others (e.g. crabs and oysters) were sampled where the organisms could be found. There were three primary sampling events each year in which all variables were measured (Figure Intro3). Variables that were expected to fluctuate more often than would be captured by these three primary sampling events, such as water quality and fish community composition, were sampled with greater frequency (Table Intro1). For each sampling event, all three rivers were sampled within a two week window to allow for direct temporal comparison.

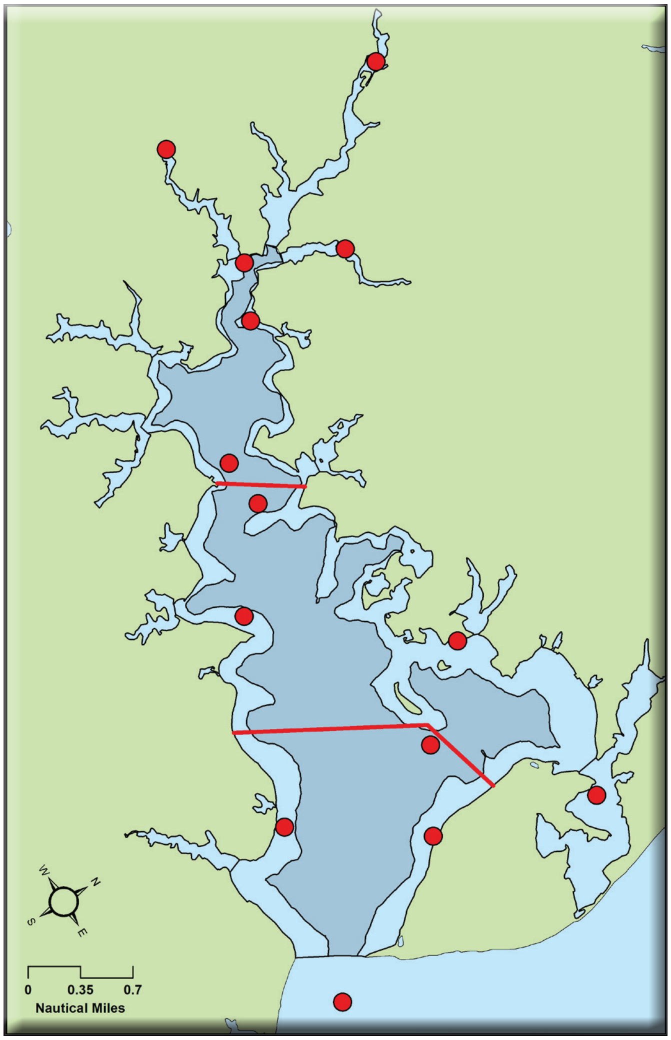


Figure Intro2. Example of sampling design framework from the Magothy River. The 6ft contour line divided shallow water (light blue) from deepwater (darker blue). River mile segments (red lines) were used as a proxy for salinity gradient. Water quality sampling stations are represented by red dots.

Shoreline of the Rhode River

The sampling design encompassed shallow water and deep water habitats, low salinity as well as high salinity sites, and organisms that inhabit each habitat.

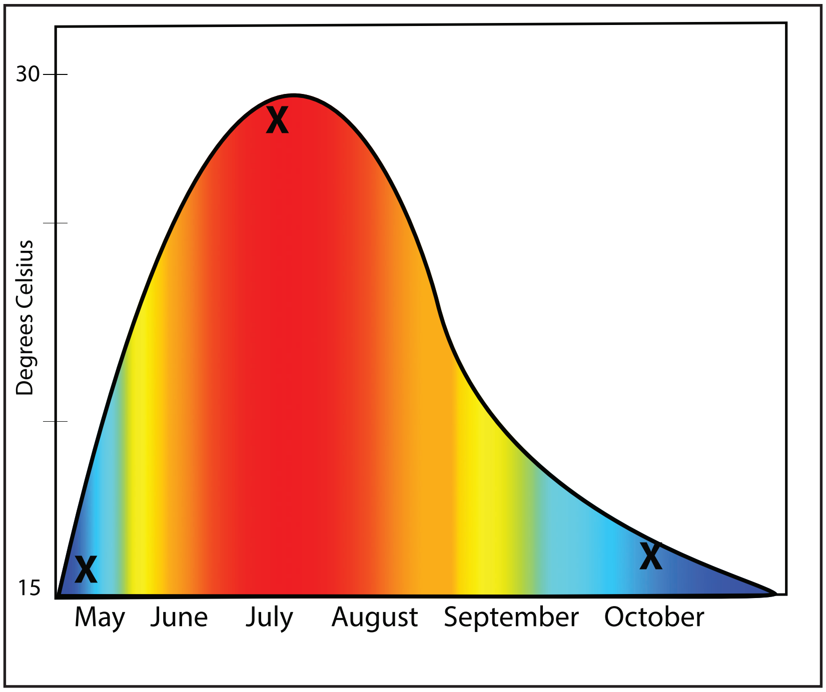


Figure Intro3. Schematic showing the relationship between seasonal water temperatures and the three sampling periods when all variables were measured.

Sampling Timeline								
Month/ Sampling Event	May	May-June	June	July	August	August	September	October
	1	2	3	4	5	6	7	8
Water Temperature								
Fish Community Compostion	X	X	X	X	X	X	X	X
Water Quality Sampling	X		X*	X		X*		X
Targeted Fish	X			X				X
Clams	X			X				X
Crabs				X				X
Oysters								X

Table Intro1. Table showing sampling timeline for each component. * Denotes sampling in 2008 and 2009 only.

Corsica River Watershed

The Corsica River watershed is located on Maryland's Eastern Shore and is a tributary of the larger Chester River, which flows into the Chesapeake Bay north of Kent Island. The river is unique in that it is entirely within one county, Queen Anne's County, and has only one municipality, Centreville, located along its shores. The town's founders chose its location along the Corsica River in the 1790s due in part to easy access to the Bay for shipping and trading.

Photo courtesy of Ben Longstaff, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

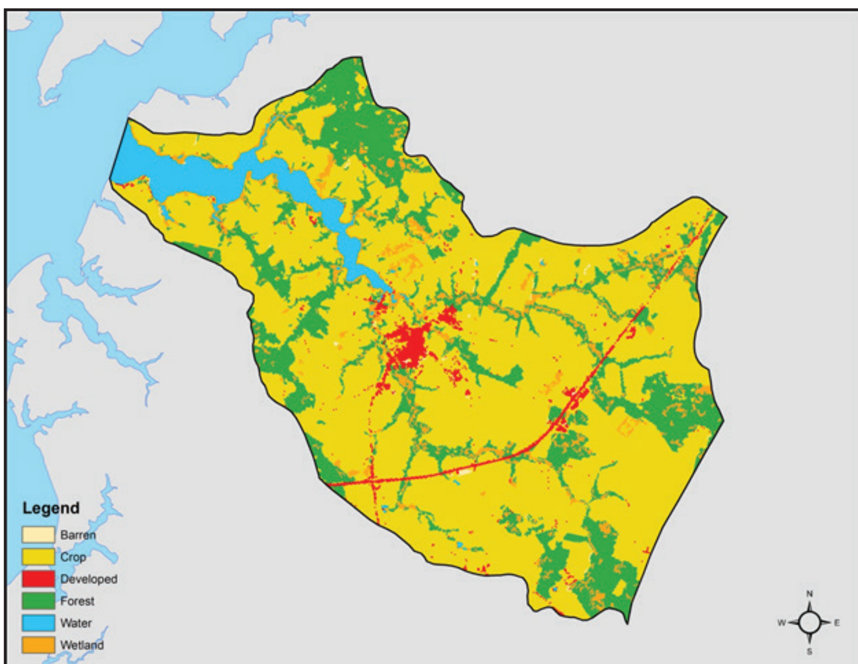


Figure WS1. As seen in this aerial view and landuse map, the Corsica River watershed is predominantly agricultural.

The Corsica was selected for this study due to the high agricultural land use of the watershed (70%) and its similar salinity range to the other watersheds chosen (Figure WS1). Most of the shoreline (about 70%) is unarmored and a large portion is lined with wetlands, especially in the tributaries feeding into the river's mainstem. Surrounded by an extensive agricultural countryside, the rural setting of the watershed lends itself to such recreational activities as boating, water-skiing, fishing, swimming and crabbing.

Despite its near pristine appearance, the Corsica River has experienced several years of exposure to contaminants. Following a waste water treatment failure in 2003 when over 1 million gallons of raw sewage leaked into the river, citizens of the watershed in conjunction with local and county officials, community groups, and Maryland state agencies began work on a Watershed Restoration Action Strategy (WRAS) in order to identify areas of greatest concern to the watershed and provide insight on how best to remedy them.

In 2004, the watershed and river were designated as impaired by local and state agencies. Excess nutrients, fecal bacteria, sediments, and toxins have all contributed to the decline of the water quality within the watershed and led to the Corsica being listed on Maryland's impaired waters list [11].

Following the support gained by the WRAS, the Corsica River was made Maryland's "targeted restoration watershed" in 2005. Local volunteer conservation groups such as the Corsica River Conservancy sample water quality, place oyster cages on their docks and work to restore the river. Centreville has been operating a state of the art waste water treatment plant since 2004, but the river remains on the list of impaired waters in 2013. One potential source of pollution is the 740 septic systems, which are located mostly on the upper reaches of the river, outside of the town of Centreville. Another source is nutrient-rich run off from the surrounding agricultural fields. At the mouth of the river, historical oyster bars are now virtually non-existent.

Centreville has been operating a state of the art waste water treatment plant since 2004, but the river remains on the list of impaired waters in 2013.

Corsica River

303d Environmental Impairments

Nitrogen

Phosphorus

Fecal Coliform

Total Suspended Solids

Biological Impairment

PCBs [12]

Corsica River Watershed At A Glance

Agricultural (%)[a]	70
Urban (%)[a]	3
Forest (%)[a]	21
Wetland (%)[a]	6
Armored Shoreline (%)[b]	30
Impervious Surface (%)[a]	2
# Chicken houses[c]	15
# Marinas (> 10 berths)[c]	4
# Docks (<10 berths)[c]	78
Watershed Population[d]	4,368
# Septic Systems[e]	740
# Historic Oyster Beds[f]	6
Approximate Acres of Historic Oyster Beds[f]	196
Acres of Sub-aquatic Vegetation (Average 2007-2009)[b]	0

Data sources: [a]National Landcover Dataset 2006, [b]Virginia Institute for Marine Sciences, [c]Google earth, [d]US Census, [e]Maryland Department of Planning, [f]Maryland Department of Natural Resources

Magothy River Watershed

The Magothy River watershed is located on the western shore of Chesapeake Bay in Maryland south of the Patapsco River and north of the Severn River in Anne Arundel County. It was originally named the "Magoty" or "Maggotty" River possibly due to the presence of mosquito larvae. Throughout its history, the Magothy has been coveted by its shore's residents from the mid-1800s as prime waterfowl hunting areas [13] to the 1940s when residents opposed the Navy's intention to use the river as a base for naval seaplanes [14]. It was this opposition that led to the founding of the Magothy River Association, which still actively monitors the river and engages residents in restoration projects.

The Magothy River was chosen due to its high level of development in its watershed boundaries and its similar salinity range to the other two watersheds (Figure WS2). It has been heavily altered by humans with urban and suburban development making up about 38% of the land use overall and 75% of the land abutting the river in residential use.

Photo courtesy of Ben Longstaff, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

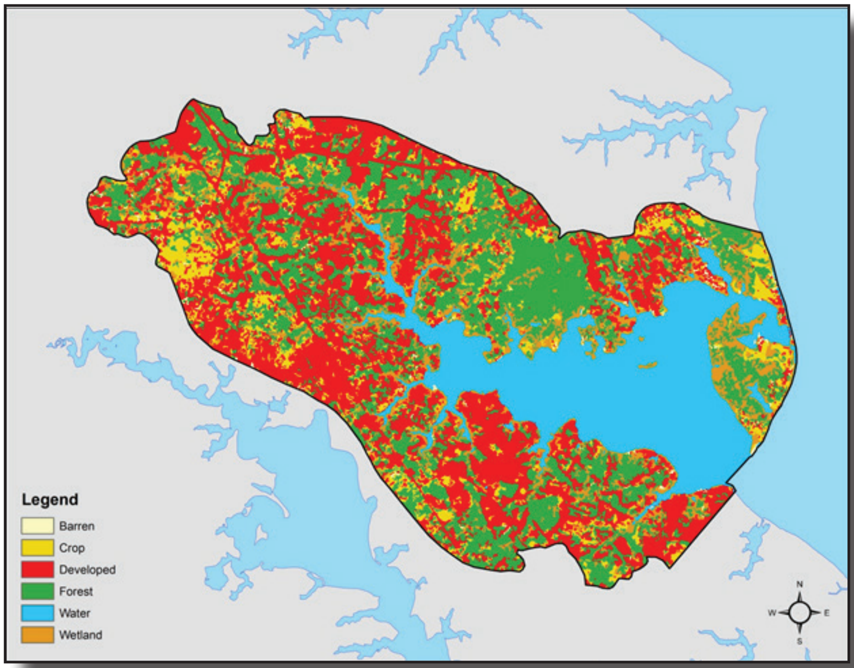


Figure WS2. Thirty-one percent of the Magothy River watershed is urbanized with over 30,000 people residing in the area and over 9,000 septic systems in use.

There are greater than 9,000 residences with septic systems, the majority of these on the northern side of the river. Recreational boating is very popular in the Magothy River, with over 30 marinas and 1,700 boat docks lining the mainstem and tributary creeks. There has also been a large amount of shoreline alteration with approximately 60% of the shoreline being armored by rip-rap, groins, or bulk-heading. It is slightly larger (22,641 acres) and deeper (about 12 ft on average in the mainstem channel) than the other two watersheds.

Development in the Magothy River watershed has come with consequences. In March 2005 a contractor mistakenly drilled through a sewage pipe and 120,000 gallons of raw sewage spilled into Cypress Creek, a tributary of the Magothy. Mill Creek, another tributary, experienced over three million gallons of sewage and sediment spillage in December 2005 when a sewer line corroded and broke [15]. The resulting increase in sediments raised the creekbed and altered the entrance to the creek to boaters [16].

In 2013 Anne Arundel County is one of nine highly urbanized counties in Maryland to enact a stormwater utility fee. Collected monies will be utilized by local governments to fund projects and programs that improve waterways by reducing sources of nitrogen, phosphorus, and sediment and thus meet State and Federal laws mandating the reduction of such stormwater pollutants. Funded projects may include establishing rain gardens, restoring urban streams, and developing or maintaining proper stormwater infrastructure [17].

Magothy River

303d Environmental Impairments

Nitrogen

Phosphorus

Total Suspended Solids

Biological Impairment

PCBs

Fecal Coliform Violation Determined After 2007-2009 Study Period [12]

Magothy River Watershed At A Glance

Agricultural (%)[a]	11
Urban (%)[a]	38
Forest (%)[a]	37
Wetland (%)[a]	14
Armored Shoreline (%)[b]	60
Impervious Surface (%)[a]	23
# Chicken houses[c]	0
Marinas (> 10 berths)[c]	36
Docks (<10 berths)[c]	1785
Watershed Population[d]	30,016
# Septic Systems[e]	9472
# Historic Oyster Beds[f]	7
Approximate Acres of Historic Oyster Beds[f]	227
Acres of Sub-aquatic Vegetation (avg. 2007-2009)[b]	58

Data sources: [a]National Landcover Dataset 2006, [b]Virginia Institute for Marine Sciences, [c]Google earth, [d]US Census, [e]Maryland Department of Planning, [f]Maryland Department of Natural Resources

In 2013 Anne Arundel County is one of nine, highly urbanized counties in Maryland to enact a stormwater utility fee.

Rhode River Watershed

The Rhode River watershed is located on the western shore of the Chesapeake Bay in Maryland, south of Annapolis, MD. Evidence of human activities extends back 6,000 years although permanent Native American settlements did not appear until about 2,400 years ago. The area around the Rhode River proved to be ideal land for hunting, fishing, and growing crops. During the Colonial Era (1650-1776), forested land was cleared for cash crops such as tobacco, a nutrient-depleting crop that forced farmers to continuously clear large holdings of forest. The Rhode was home to several farms and plantations until the early 19th century when farms were divided into smaller farms with more diverse crops. The 19th century also brought the age of the steamboat to the Rhode with four steamboat wharves where local farmers and fishermen could ship their harvests throughout the region. As a result, the communities around the river grew and waterfront development became more popular[18].

Photo courtesy of T. Gill

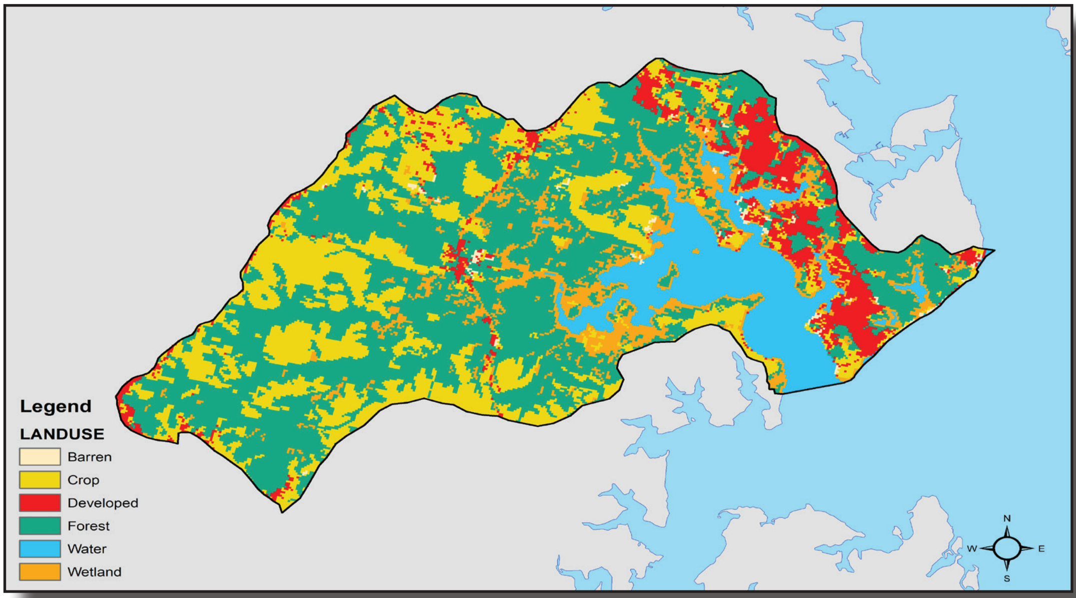


Figure WS3. The balanced land use of the Rhode River watershed is reflected in its diverse shorelines, from tree-lined beaches to waterfront homes and marinas.

Today, land use is considered mixed, with a significant amount of forest (about 51%) and urban development making it a good reference system to compare to the Corsica and Magothy watersheds (Figure WS3). Much of the urban land development is located along the northern shore near the river mouth. Most of the remaining portions of the river are lined with forest and low-density housing, with about 25% of the shoreline armored by rip-rap, bulkhead, or groins. The majority of the approximately 11 marinas are located in the tributary creeks. Recreational boating and swimming are popular, particularly in summer due to the presence of several youth camps located along the river.

Rhode River

303d Environmental Impairments

Nitrogen

Phosphorus

Fecal Coliform

Insufficient Data Exists to Determine if Violations for Biological Impairment and Total Suspended Solids Have Occurred [12]

The West/Rhode Riverkeepers Association actively engages the community in monitoring and restoration projects. For example, the Association has led efforts to plant submerged-aquatic vegetation, grow oysters off existing docks, and coordinate with engineers and electric company officials to restore a stream along a transmission line right of way.[19]

Rhode River Watershed At A Glance

Agricultural (%)[a]	28
Urban (%)[a]	9
Forest (%)[a]	51
Wetland (%)[a]	11
Armored Shoreline (%)[b]	25
Impervious Surface (%)[a]	7
# Chicken houses[c]	0
# Marinas (> 10 berths)[c]	11
# Docks (<10 berths)[c]	262
Watershed Population[d]	9,246
# Septic Systems[e]	447
# Historic Oyster Beds[f]	9
Approximate Acres of Historic Oyster Beds[f]	90
Acres of Sub-aquatic Vegetation (Average 2007-2009)[b]	0

Data sources: [a]National Landcover Dataset 2006, [b]Virginia Institute for Marine Sciences, [c]Google earth, [d]US Census, [e]Maryland Department of Planning, [f]Maryland Department of Natural Resources

Estuaries are places of constant change. Most of the physical and chemical conditions of these waters vary naturally over tidal, seasonal and annual cycles. Salinity, for example, commonly changes with tidal state and rainfall events. The organisms that live in estuaries typically cope with and adapt to most of these environmental changes. However, when environmental conditions exceed the ranges that the organisms commonly encounter or the conditions persist near extremes, the organisms that inhabit and rely on these waters can be significantly impacted.

The term 'water quality' generally refers to how well the physical and chemical conditions of a waterbody support a healthy community of organisms. Many human and non-human factors influence water quality. Poor water quality may result from factors as diverse as hurricanes to wastewater effluent. Although water quality results from a number of different variables, there are several specific physical and chemical parameters that are relatively good indicators of water quality in watersheds. These include concentrations of dissolved oxygen, nitrogen, phosphorus, and chlorophyll, as well as measurements of water clarity.

To assess water quality in this study, we measured multiple physical and chemical factors at 8-14 stations in each watershed at least four times per year. Sampling locations were chosen using a stratified random design in which the rivers were segmented based on river mile and depth, and sampling location was chosen at random from within each segment. Samples were collected on a monthly or bimonthly schedule between April and October from 2007 to 2009. At each station, temperature, salinity, dissolved oxygen, and pH were measured at the surface and every half meter in depth to the bottom.

Dissolved Oxygen

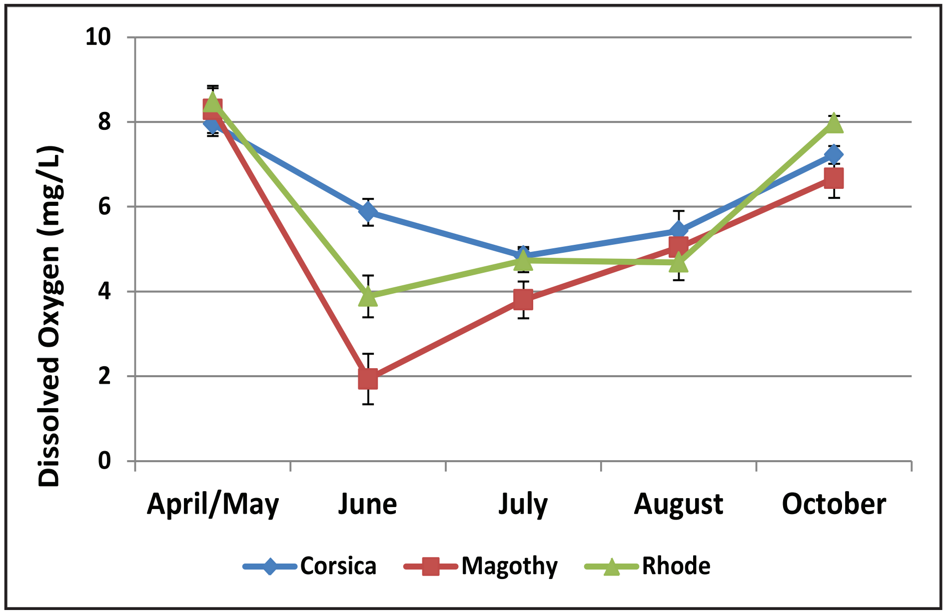
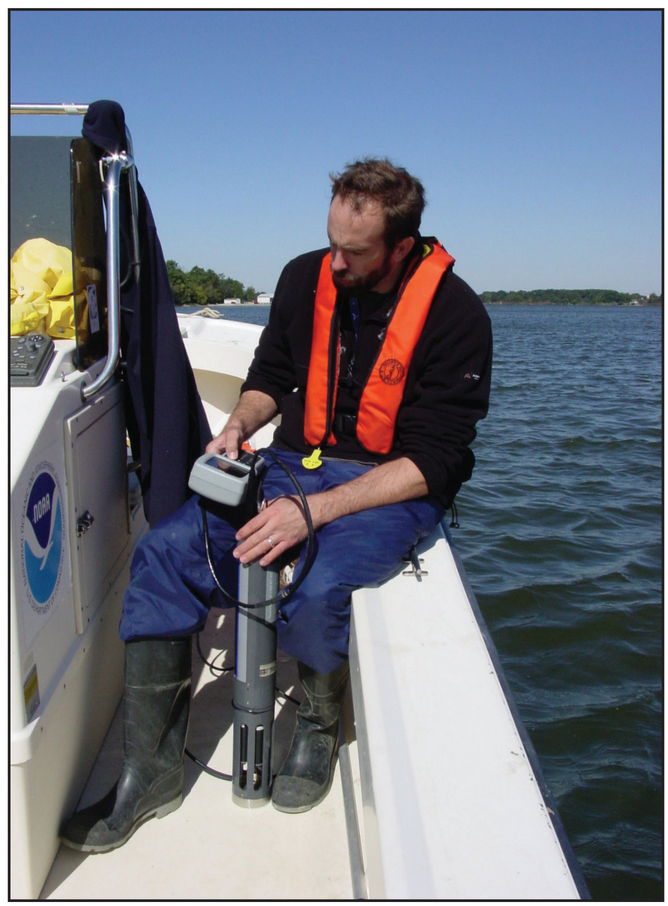


Figure WQ1. Average dissolved oxygen concentrations in bottom waters for each river, by sampling period.

Most aquatic organisms are aerobic and need sufficient amounts of dissolved oxygen in the water for respiration. Oxygen in natural water bodies diffuses from the overlying air, is mixed into the water column with wind and waves, and is also produced by plants and some bacteria. It is consumed by most other organisms and may become depleted in the aquatic environment. Stratification of water (i.e strong horizontal layering) and/or excess nutrients often lead to decreased oxygen levels in bottom waters. In large estuaries such as the Chesapeake Bay, stratification of the water column occurs in the mainstem and the lower portions of some tributaries in late Spring through late Summer as water temperatures rise and storm frequencies decrease. For this reason, most assessments of water quality take into account seasonality of dissolved oxygen concentrations.



The US EPA has suggested levels of dissolved oxygen sufficient to support aquatic life in the Chesapeake Bay [20]. Because organisms that reside in different sub-habitats of the estuary require different concentrations of dissolved oxygen, the EPA established dissolved oxygen thresholds specific to each sub-habitat of the Chesapeake Bay [20]. For example, fish that live in surface waters (i.e. within a couple meters of the surface) are used to having relatively high concentrations of oxygen, while benthic organisms often experience much lower oxygen levels and are better adapted to those low oxygen conditions. The sub-habitats defined by the EPA which are relevant to this study are presented in Table WQ1. with the associated dissolved oxygen criteria and the time of year for each.

Designated Use	Criteria (mg/L)	Dates
Open Water	≥ 5.0	Year-round
Deep Water	≥ 3.0 ≥ 5.0	June 1 – September 30 Oct 1 – May 31
Deep Channel	≥ 1.0 ≥ 5.0	June 1 – September 30 October 1 – May 31

Table WQ1. Values used to assess dissolved oxygen concentration thresholds.

Dissolved oxygen levels were measured at 0.5m increments at each station using a datasonde. Significant differences in dissolved oxygen concentrations were detected with year, season, river section, and depth in the water column. In general, dissolved oxygen concentrations were high enough in all three rivers to support the organisms living there. However, oxygen levels in bottom waters of the Magothy were lower than the other two rivers in June and July (Figure WQ1) and fell below the 1.0mg/L criteria in about 38% of sample compared to 23% and 19% in the Corsica and Rhode Rivers, respectively (Figure WQ2). Anoxic bottom water (i.e. the lack of any measureable oxygen) in the Magothy River may be related to slightly greater water depths compared to the other two watersheds and high nutrient concentrations (which were found in all three rivers).

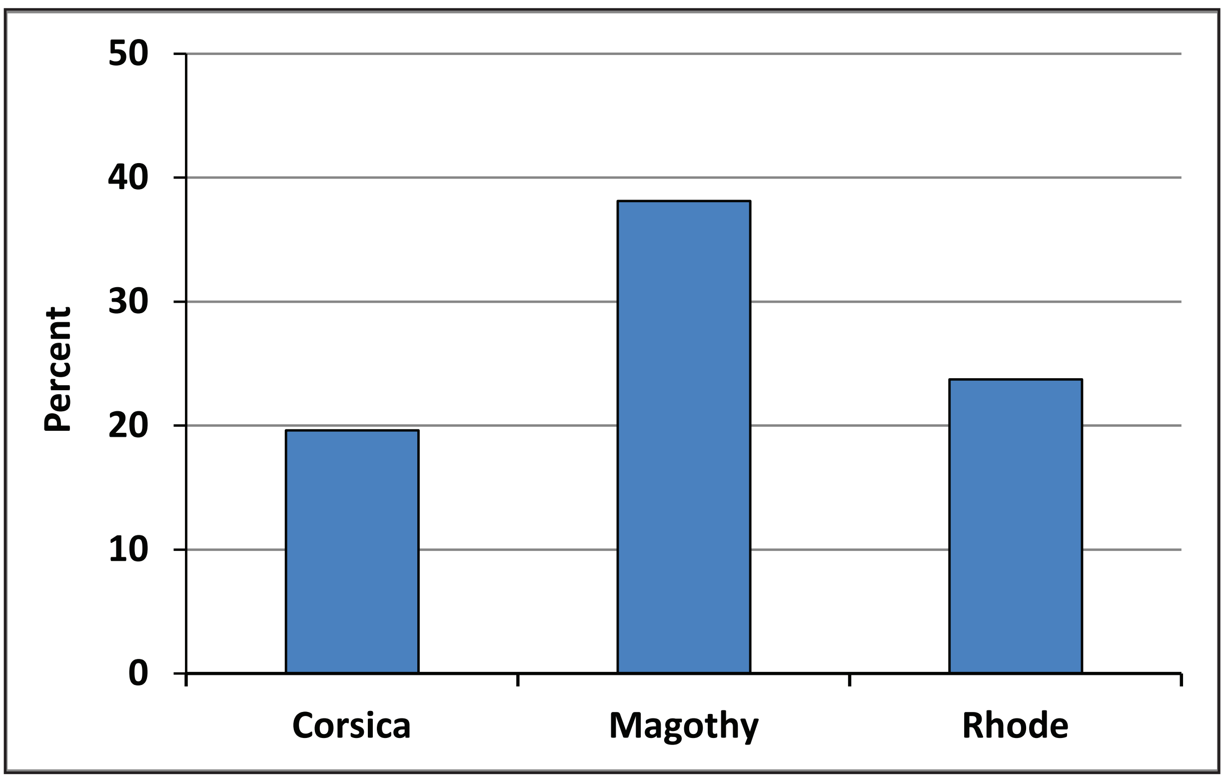


Figure WQ2. Percent of all dissolved oxygen readings for each river below EPA criteria in bottom waters.

Dissolved Oxygen Summary

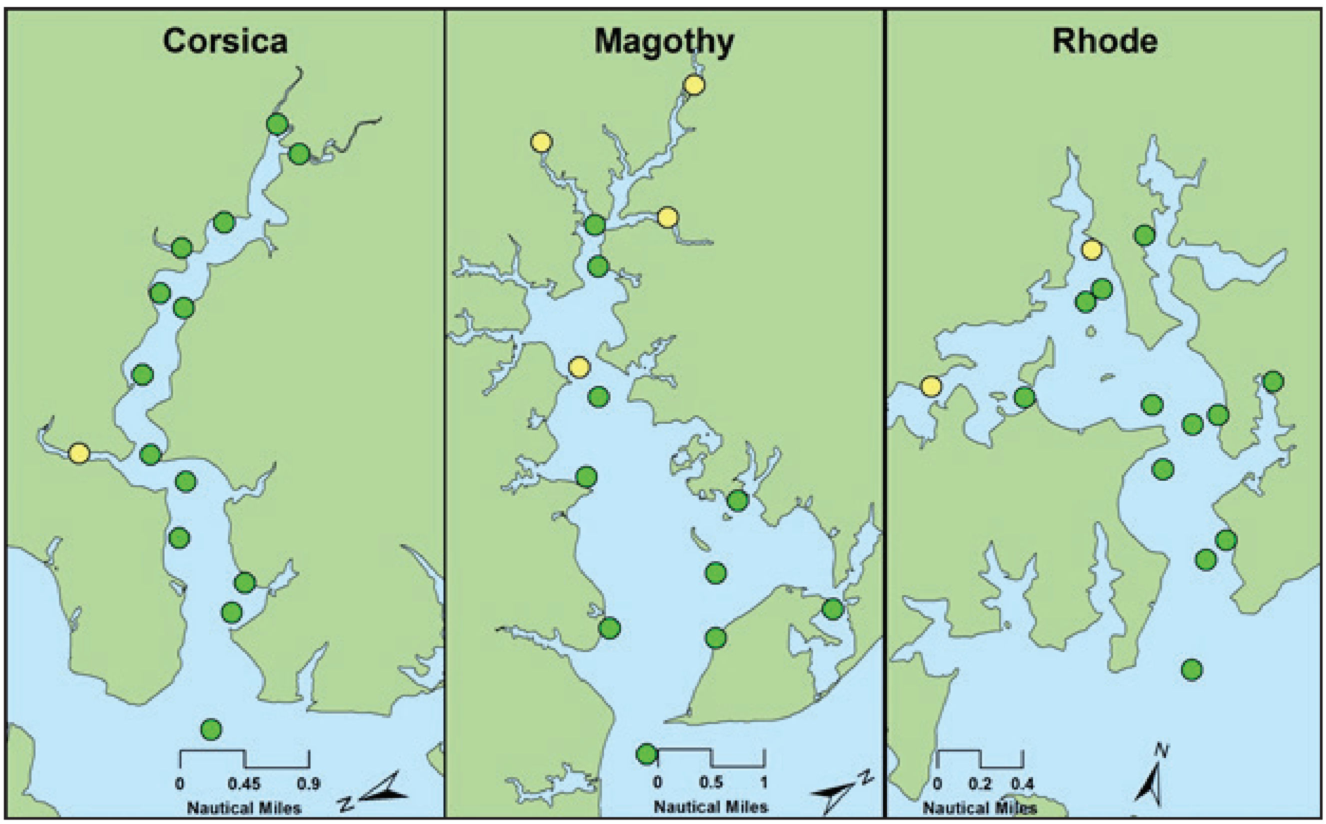
What we measured: Oxygen concentrations (milligrams of oxygen per liter of water (mg/L))

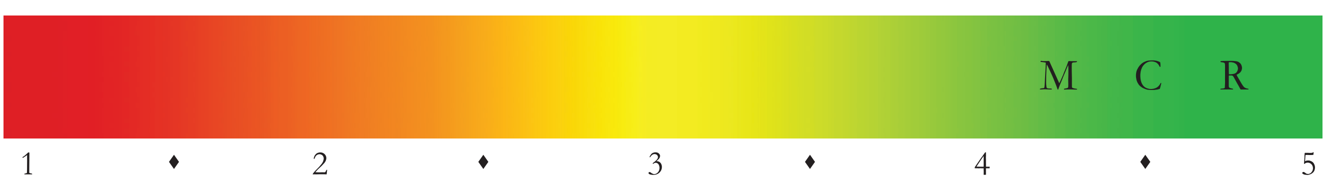
How we assessed: Oxygen concentrations were compared to published thresholds (Table WQ1) for Chesapeake Bay, based on natural resource dissolved oxygen requirements in various water bodies [20].

Each dissolved oxygen measurement was compared to the relevant criteria and scored as 1 if below that criteria or as 5 if it exceeded the threshold. These individual scores were averaged to obtain station and river conditions, and the average was assessed as degraded, poor, fair or good based on where it fell between 1 and 5.

Station and River Assessment:

Average Dissolved Oxygen Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5
Index Condition	Degraded	Poor	Fair	Good





Nitrogen

Nitrogen is a necessary nutrient for all organisms. Nitrogen gas (N_2) is the most common gas found in the atmosphere and dissolves naturally in water. However, most organisms cannot use nitrogen gas to build organic molecules and therefore rely on the presence of fixed nitrogen in their environment. In estuaries, inorganic nitrogen often runs off land or flows through groundwater. It is possible for there to be an excess amount of nitrogen. High concentrations of nitrogen often result in the rapid and excessive growth of plants and bacteria, even leading to overproduction. In the Chesapeake Bay, high levels of nitrogen may cause dense phytoplankton blooms in surface waters during Spring and Summer. As these phytoplankton die they sink to the bottom, where bacteria consume them and use up dissolved oxygen, leading to low dissolved oxygen conditions. Although restoration efforts tend to focus on lowering the amount of nutrients such as nitrogen entering the water (nutrient load), concentrations of nutrients in the water act as an indicator of water quality and habitat condition.

For our study, water samples for nitrogen analysis were collected just below the surface using acid-washed 500mL plastic bottles. In order to compare nitrogen concentration in our samples with established water quality criteria, we combined inorganic and organic nitrogen compounds, in both dissolved and particulate forms.

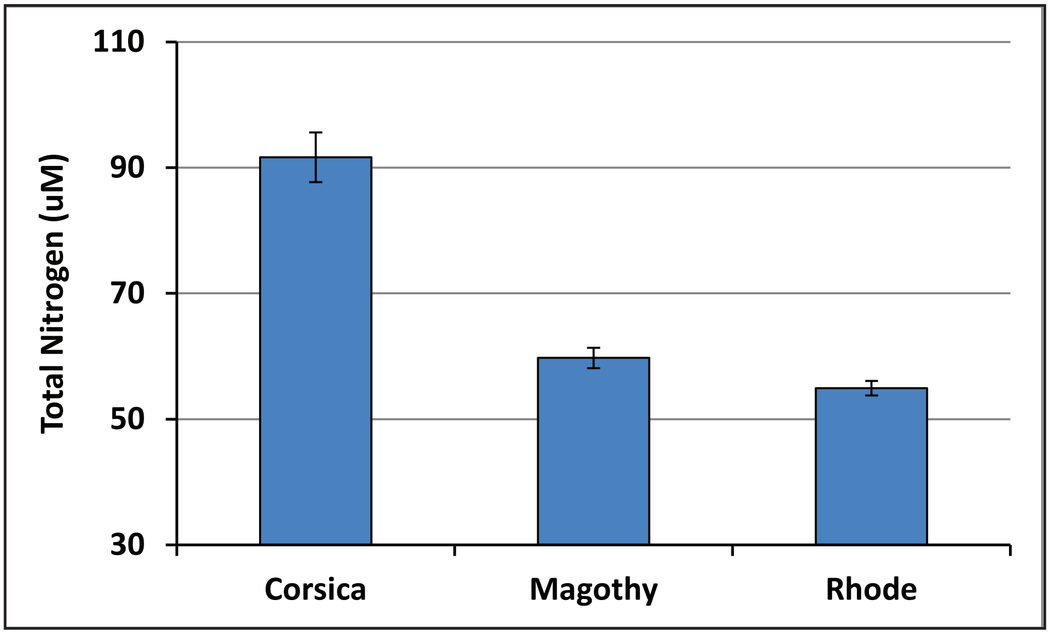


Figure WQ3. Average concentrations of total nitrogen in surface waters.

We found that nitrogen concentrations were statistically higher in the agriculturally dominated Corsica River watershed than the other two watersheds, and lowest in the Rhode River (Figure WQ3). Nitrogen was also significantly different between years and seasons. Although nitrogen levels might be expected to be highest in spring when rain showers cause nutrient runoff, in this study we found highest levels of nitrogen in summer.

N_2

In estuaries, organic nitrogen often runs off land or flows through groundwater.

Nitrogen Summary

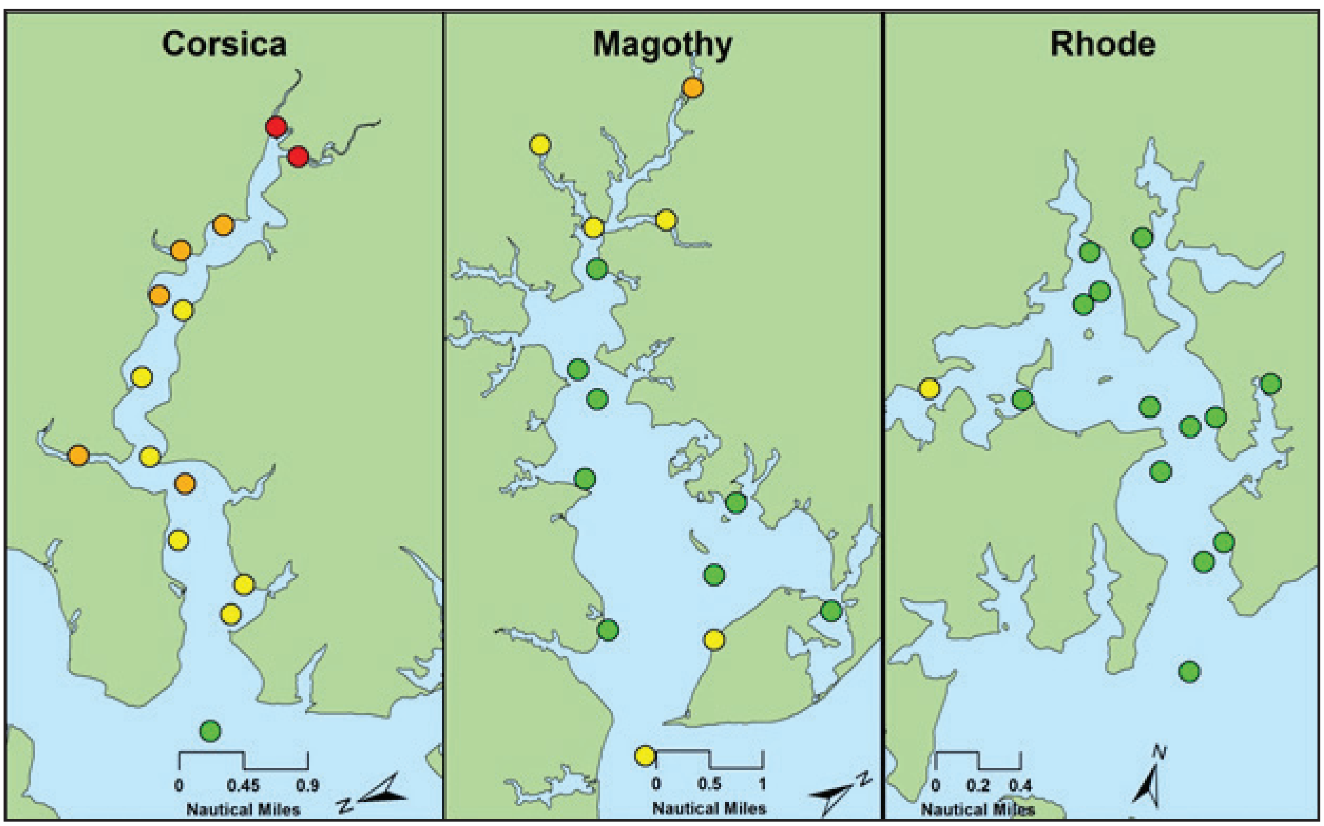
What we measured: Total nitrogen concentrations (micro molar (uM)); includes dissolved organic and inorganic as well as particulate organic nitrogen compounds.

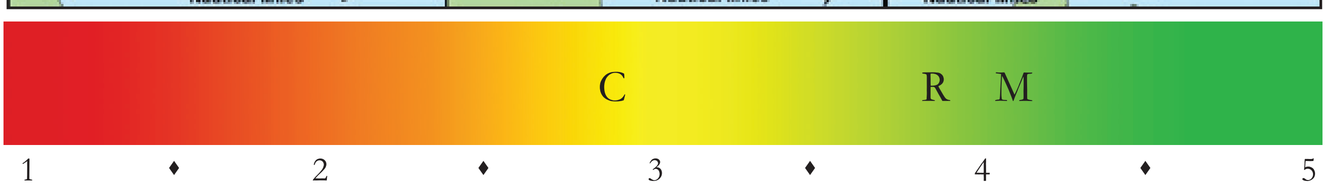
How we assessed: We compared our findings to an established threshold (46uM) for the health of seagrass beds [21], and a value double that level (96uM) reflective of very high concentrations. The nitrogen measurement from each water sample was compared to the relevant criteria and scored as 1, 3 or 5. These individual scores were averaged to obtain station and river conditions, and the average was assessed as degraded, poor, fair or good based on where it fell between 1 and 5.

Score		
1	3	5
≥92uM	≥46 and < 92uM	<46uM

Station and River Assessment:

Condition	Degraded	Poor	Fair	Good
Average Nitrogen Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5





Phosphorus

Like nitrogen, all organisms depend on external sources of phosphorus. Both natural and anthropogenic sources of phosphorus compounds occur in most aquatic systems. However, many estuaries and watersheds suffer from the effects of high levels of anthropogenic phosphorus input, leading to overproduction of plants and bacteria resulting in poor water clarity and low dissolved oxygen. In Chesapeake Bay, excessive phosphorus comes from a variety of sources, including agricultural application, wastewater treatment, urban runoff, and atmospheric deposition.

Phosphorus compounds in aquatic systems are often bound to particles suspended in the water or in the bottom sediments and therefore have slightly different distribution patterns than nitrogen. Erosion and overground runoff tend to contribute a large proportion of phosphorus transport into Chesapeake Bay [22].

Water samples for phosphorus analysis were collected just below the surface using acid-washed 500mL plastic bottles.

Phosphorus concentrations, like nitrogen, were highest in the agriculturally dominated Corsica River watershed. In fact, all three watersheds differed from one another based on phosphorus levels, with the Magothy River having the lowest concentrations (Figure WQ4). Like nitrogen, concentrations of total phosphorus were highest in the late summer and lowest in the early spring and fall (Figure WQ5).

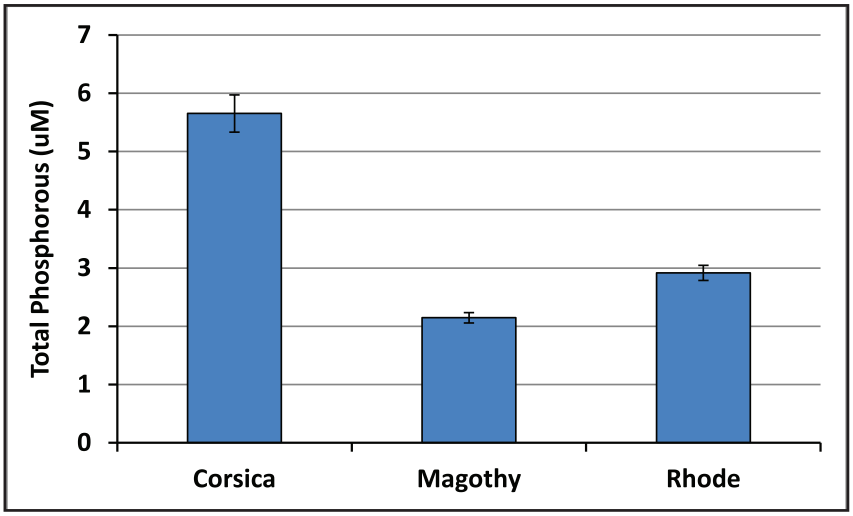


Figure WQ4. Average concentrations of total phosphorus in surface waters.

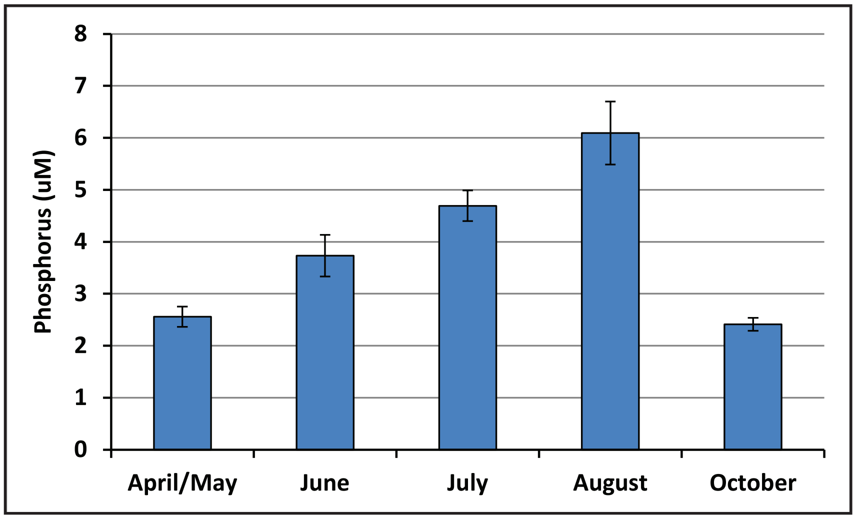


Figure WQ5. Average concentrations of total phosphorus in surface waters by month.

P In Chesapeake Bay, excessive phosphorus comes from a variety of sources...

Water Quality

Phosphorus Summary

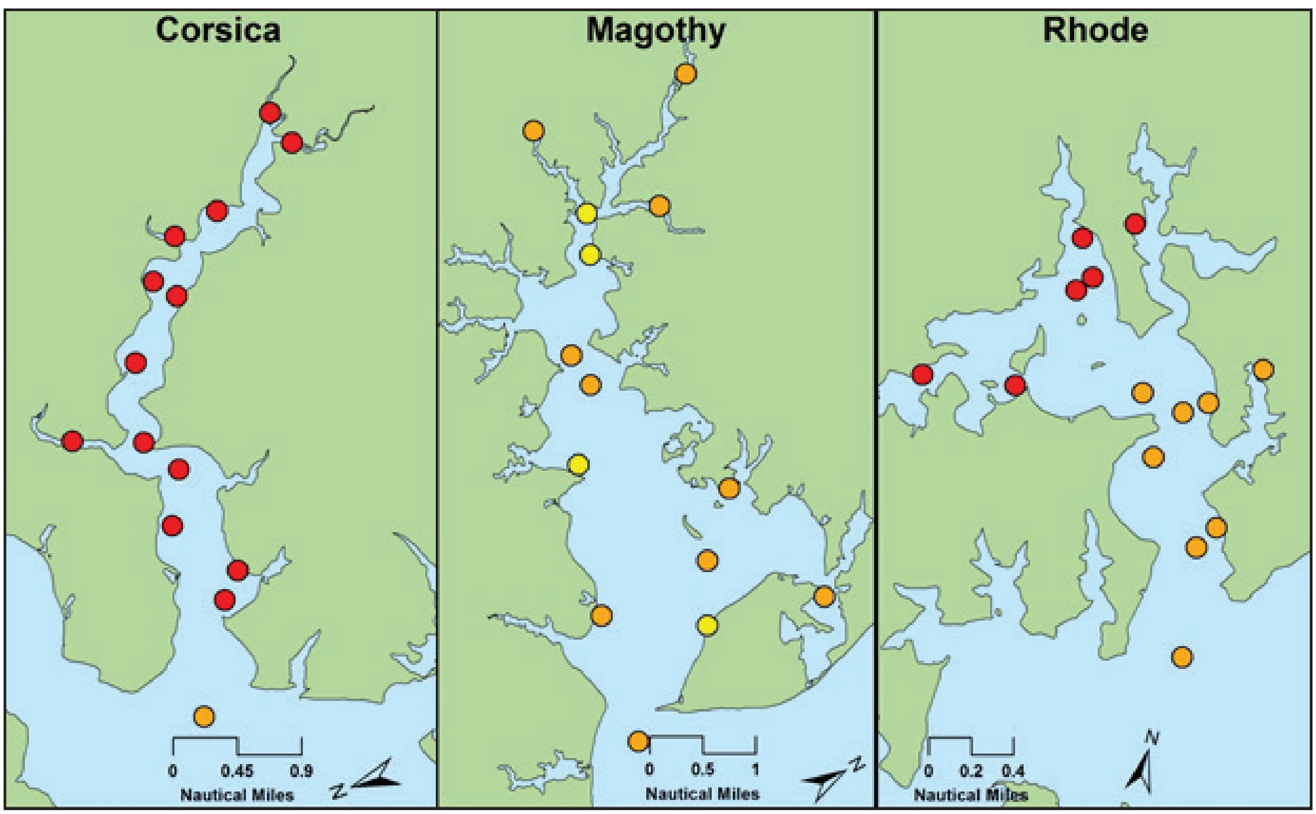
What we measured: Total phosphorus concentrations (micro-moles per liter of water(uM/L); includes dissolved organic and inorganic as well as particulate organic phosphorus compounds from all samples, all seasons.

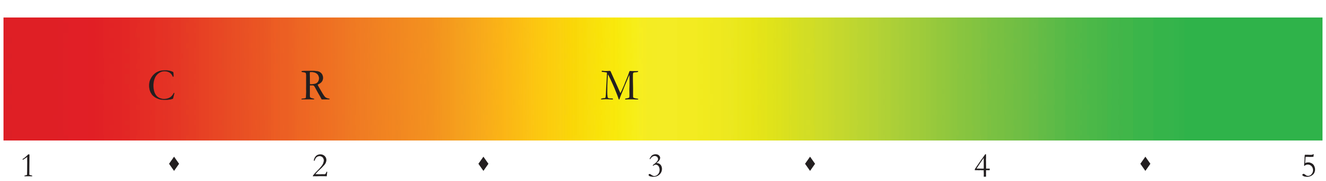
How we assessed: We compared our findings to an established threshold (1.2uM) for the health of seagrass beds [21], and a value double that level (2.4uM) reflective of very high concentrations. The phosphorus measurement from each water sample was compared to the relevant criteria and scored as 1, 3 or 5. These individual scores were averaged to obtain station and river conditions, and the average was assessed as degraded, poor, fair or good based on where it fell between 1 and 5.

Score		
1	3	5
≥2.4uM	≥1.2 and < 2.4uM	<1.2uM

Station and River Assessment:

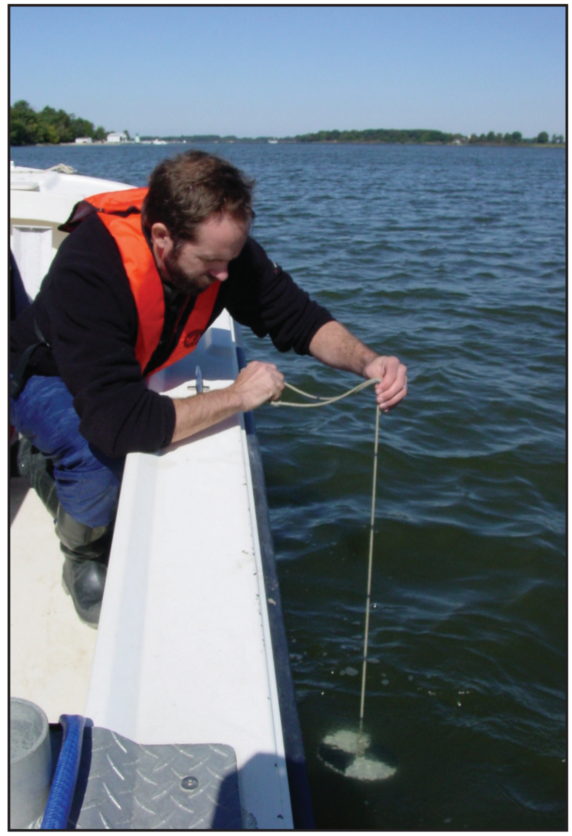
Condition	Degraded	Poor	Fair	Good
Average Phosphorus Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5





Secchi Depth

Water clarity is affected by many variables, but is primarily related to the amount of suspended material in the water. This material can be living organisms (e.g. phytoplankton), organic detritus, or inorganic particles. Water clarity directly relates to how far sunlight penetrates into the water column and the quality of light (i.e. which wavelengths) reach various depths. Because most organisms that create organic molecules from inorganic matter use sunlight as their source of energy, water clarity is an important component of water quality and of ecosystem condition. For these reasons, most estuarine and marine condition assessments include some measure of water clarity .



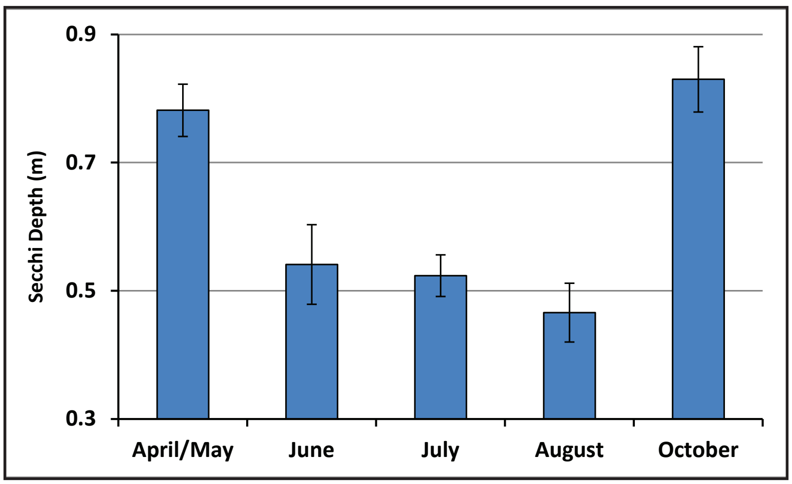


Figure WQ6. Water clarity was significantly lower in the Summer than in Spring or Fall. (Data for all three rivers combined).

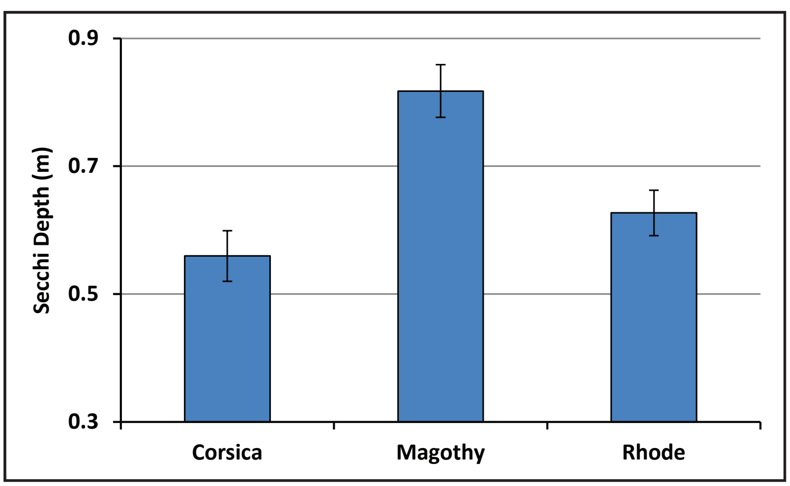


Figure WQ7. Water clarity was significantly lower in the Corsica River watershed than in the Rhode or Magothy.

We measured water clarity at each water quality sampling station using a Secchi disk. This sampling device was designed by Pietro Angelo Secchi in the mid-1800's. The observer lowers the disk into the water and measures the depth at which the pattern on the disk is no longer visible. Secchi depth readings are influenced by sun angle, cloud cover, and other factors that impact lighting. Therefore this method provides only a coarse assessment of turbidity.

We detected differences in water clarity based on season/month (Figure WQ6) and between rivers (Figure WQ7). Water clarity was significantly better in the Magothy than in the Corsica or Rhode. However, when compared to the water quality standard, all three rivers had relatively poor water clarity.

Secchi Depth Summary

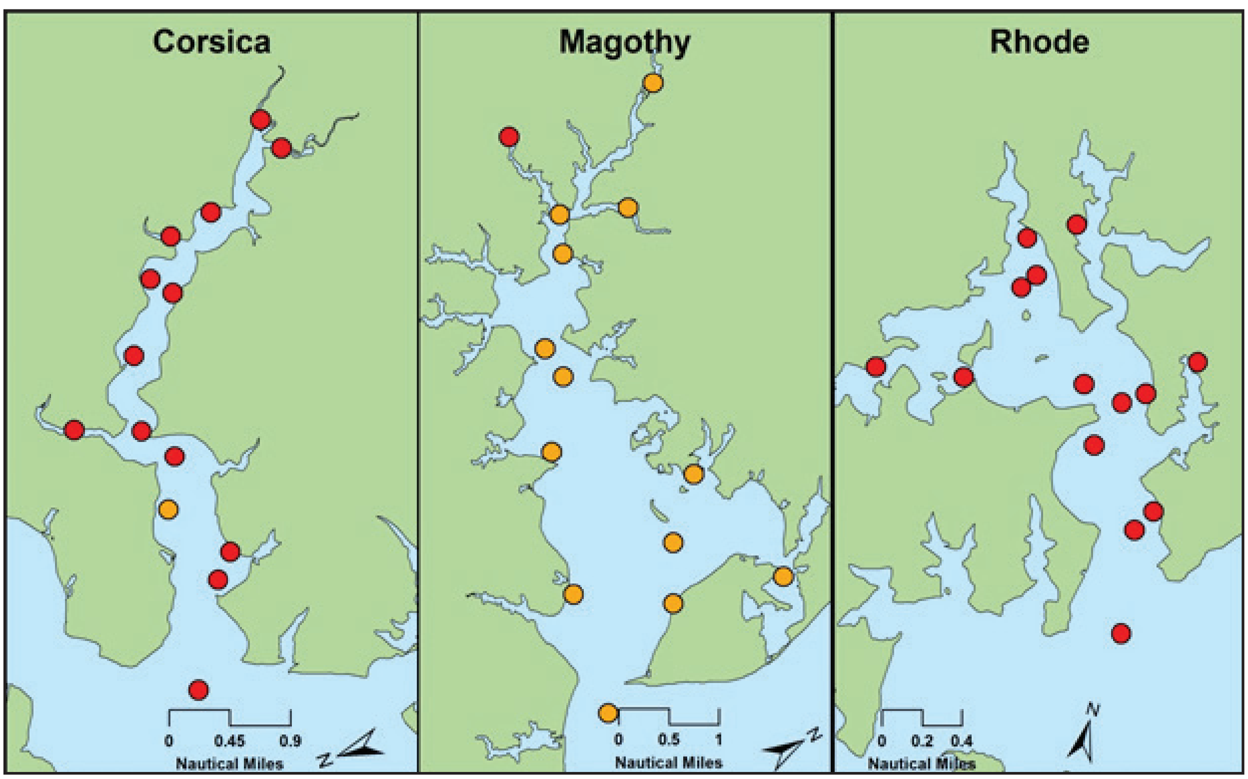
What we measured: Water clarity as estimated by the maximum depth which a Secchi disk could be read in the water.

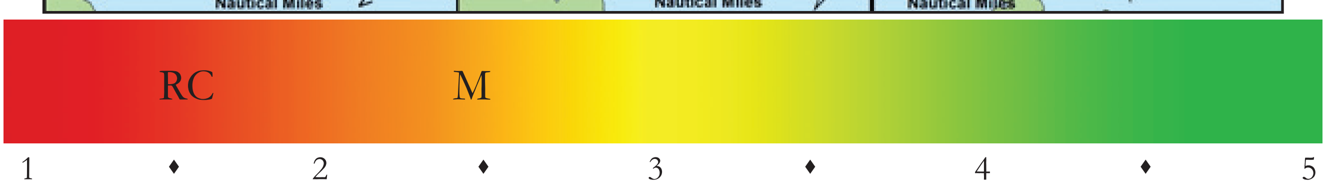
How we assessed: Water clarity was compared to the published thresholds of 0.65m (oligohaline waters) and 1.63m (mesohaline waters) for phytoplankton health in Chesapeake Bay [23]. The Secchi measurement from each water sample was compared to the relevant criteria and scored as 1, 3 or 5. These individual scores were averaged to obtain station and river conditions, and the average was assessed as degraded, poor, fair or good based on where it fell between 1 and 5.

	Score		
Habitat	1	3	5
Oligohaline (salinity ≤ 5.0ppt)	≤0.325m	>0.325 and ≤0.65m	>0.65m
Mesohaline (salinity > 5.0 and ≤ 18ppt)	≤0.815m	>0.815 and ≤1.63m	>1.63m

Station and River Assessment:

Condition	Degraded	Poor	Fair	Good
Average Secchi Depth Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5





What happens when it rains?

Nutrients are washed into the water from a variety of sources, including wastewater outfall, agricultural land, and the atmosphere (Figure WQ8). Excessive nutrients in the water (eutrophication) leads to algal blooms in warm months, which can clog the surface waters and block sunlight from reaching the plants that grow on the bottom. When the algae die they sink to the bottom where they are eaten by bacteria, which use up most of the oxygen in the water, causing oxygen-depleted 'dead zones' in the deeper waters.

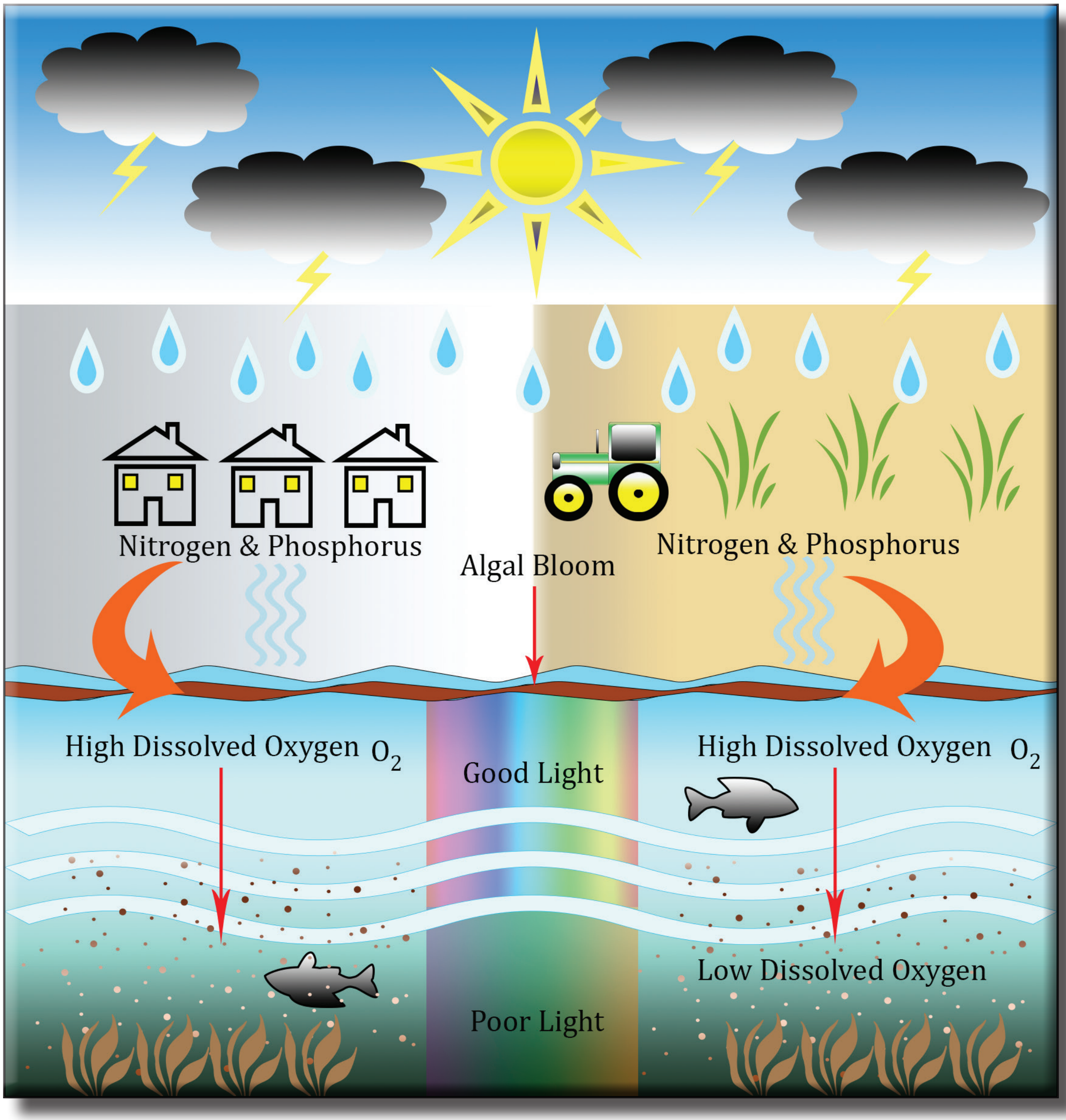


Figure WQ8. Eutrophication in Chesapeake Bay

Water Quality

Chlorophyll a

Although primary production by plants and photosynthetic bacteria represents an integral component of almost all habitats, the presence of unusually high levels of these organisms often indicates a system out of balance. Because the majority of photosynthetic organisms contain the light-capturing pigment Chlorophyll a, concentrations of this pigment have been used to estimate their densities in natural waters. The amount of Chlorophyll a varies between photosynthetic organisms and even within species depending on light availability and other environmental conditions. However, as discussed in the previous chapter components on nitrogen and phosphorus, high levels of Chlorophyll a are a sign of excess nutrients, favorable temperatures and salinity conditions to support the growth of dense populations of phytoplankton.

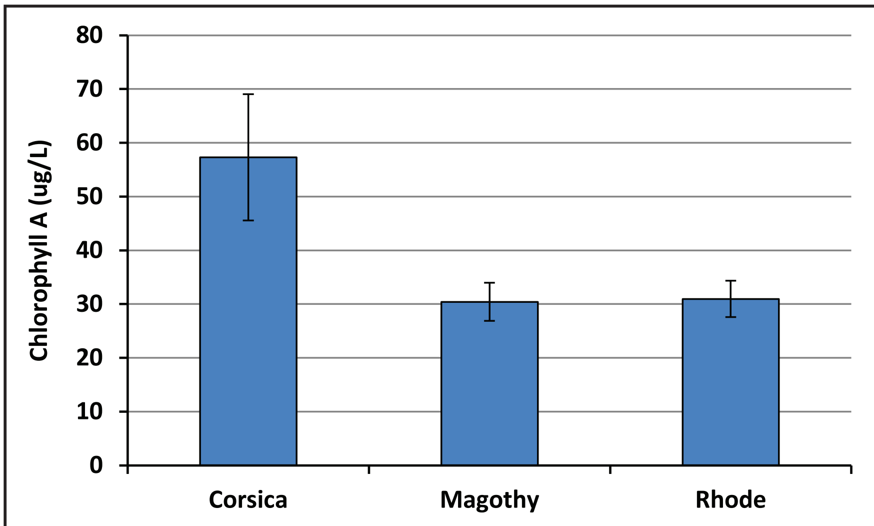
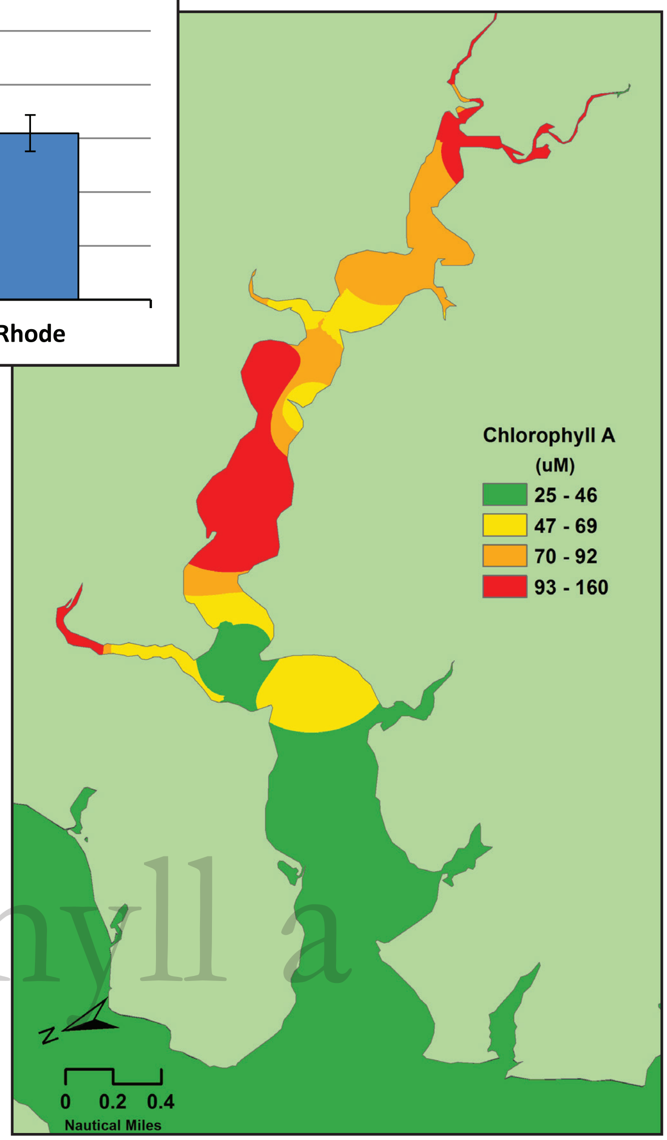


Figure WQ9. Average Chlophyll a by river

We measured Chlorophyll a in surface water samples by filtering 50-100mL of water through a pre-rinsed 0.7µm filter. The filters were stored on dry ice in the field and in a -80°C freezer in the lab. Chlorophyll a concentrations were measured from the filters using high performance liquid chromatography.

Chlorophyll a



Spatially estimated Chlorophyll a concentrations in the Corsica River for April-June of 2007-2009.

Chlorophyll a Summary

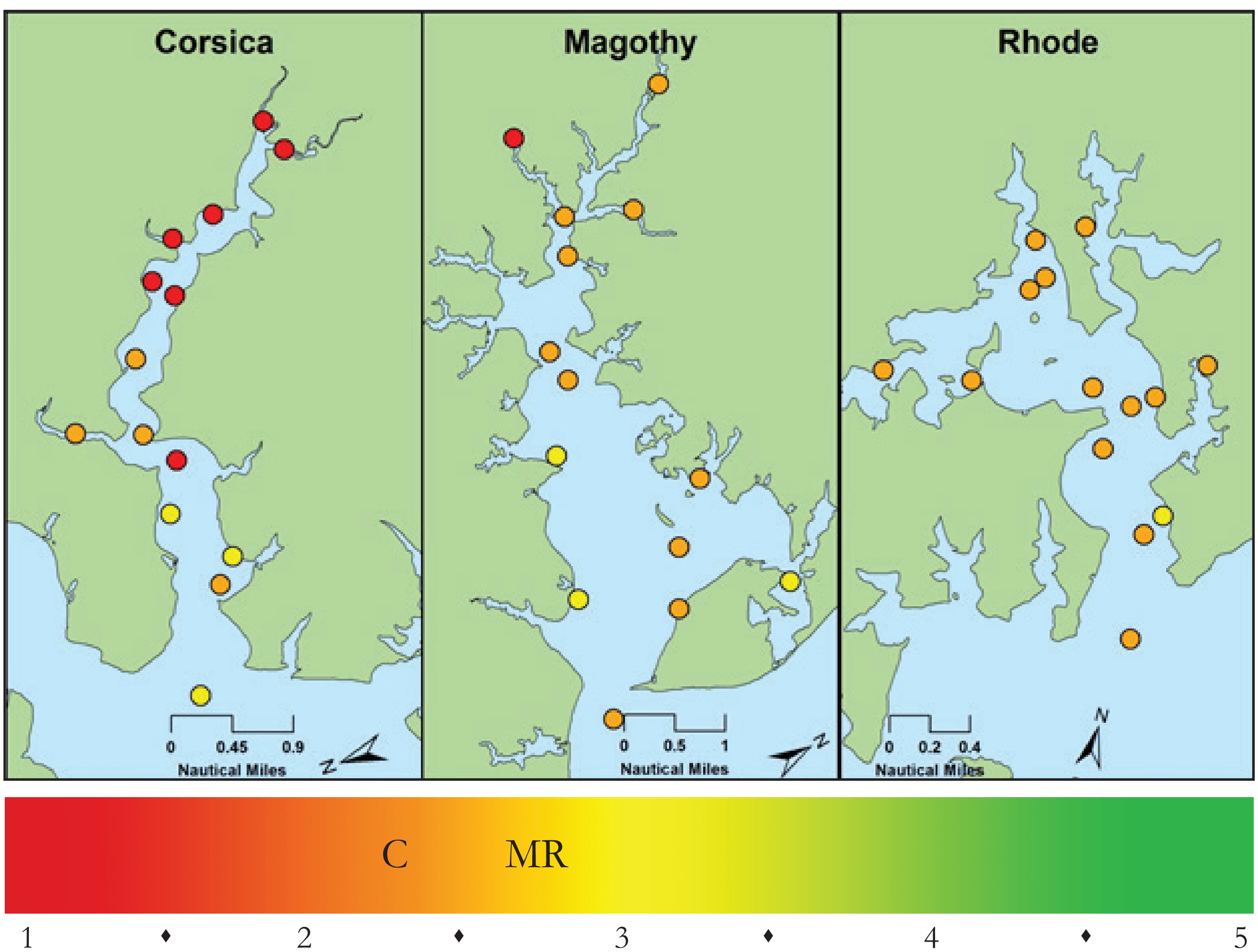
What we measured: Chlorophyll a concentrations in micrograms per liter (μg/L)

How we assessed: We compared our findings to an established threshold [21] for the health of seagrass beds (15μg/L), and a value double that level (30μg/L) reflective of very high concentrations.. The Chlorophyll a measurement from each water sample was compared to the relevant criteria and scored as 1, 3 or 5. These individual scores were averaged to obtain station and river conditions, and the average was assessed as degraded, poor, fair or good based on where it fell between 1 and 5.

Score		
1	3	5
≥30μg/L	≥15 and < 30μg/L	<15μg/L

Station and River Assessment:

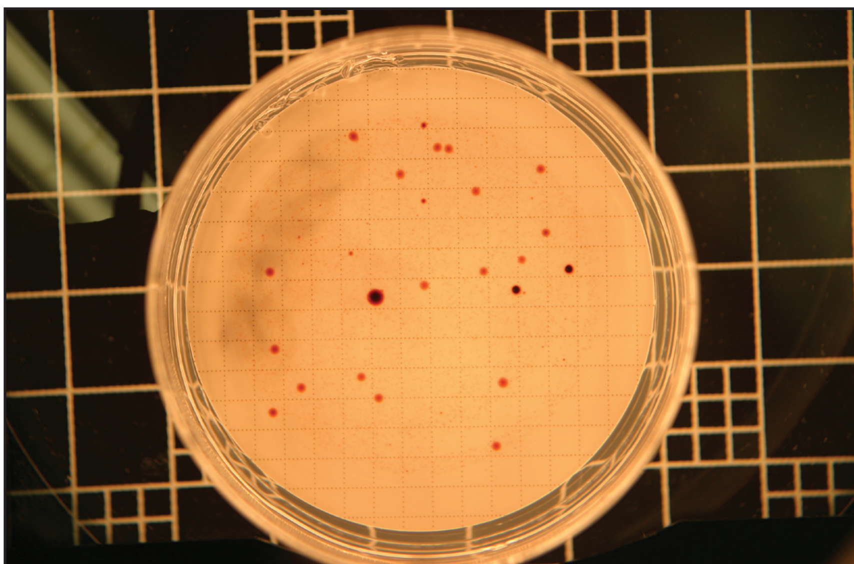
Condition	Degraded	Poor	Fair	Good
Average Chlorophyll Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5



Indicator Bacteria

An important component of water quality includes the presence and concentration of pathogens that are harmful to humans. Humans may contract an illness from estuarine environments by contact with polluted water while swimming or fishing, or from the consumption of raw or undercooked contaminated shellfish. Monitoring natural water bodies for potential pathogens is not feasible due to the large number and diversity of potential pathogens. Instead, fecal bacteria concentrations, such as *Enterococcus* spp., are measured in targeted waters or seafood to indicate the likelihood of human illness. Based on epidemiological studies, the US EPA has developed threshold criteria for densities of fecal bacteria and the resultant rates of illness from swimming in or eating shellfish from contaminated natural waters.

Enterococcus spp.



Petri dish with bacterial colonies that were isolated from a surface water sample.

Indicator bacteria act as sentinels of human pathogen presence in surface waters.

For this study, *Enterococcus* spp. bacteria were isolated using standard methods [24], which involve filtering sample water, incubating filters on specific culture media, counting bacteria colonies on the media and comparing numbers to the threshold criteria recommended by EPA. For marine and estuarine waters, the US EPA criteria involving *Enterococcus* spp. are for beaches used for swimming. Most agencies that monitor beaches used for swimming use a geometric mean of weekly samples collected during warm months. Although our samples were not collected at beaches, swimming associated with children's camps and boating activities occur regularly in all three watersheds. Therefore, we chose to use the US EPA criteria for "designated beach area" as a lower threshold and the "moderate" swimming use criteria as an upper threshold.

Indicator Bacteria Summary

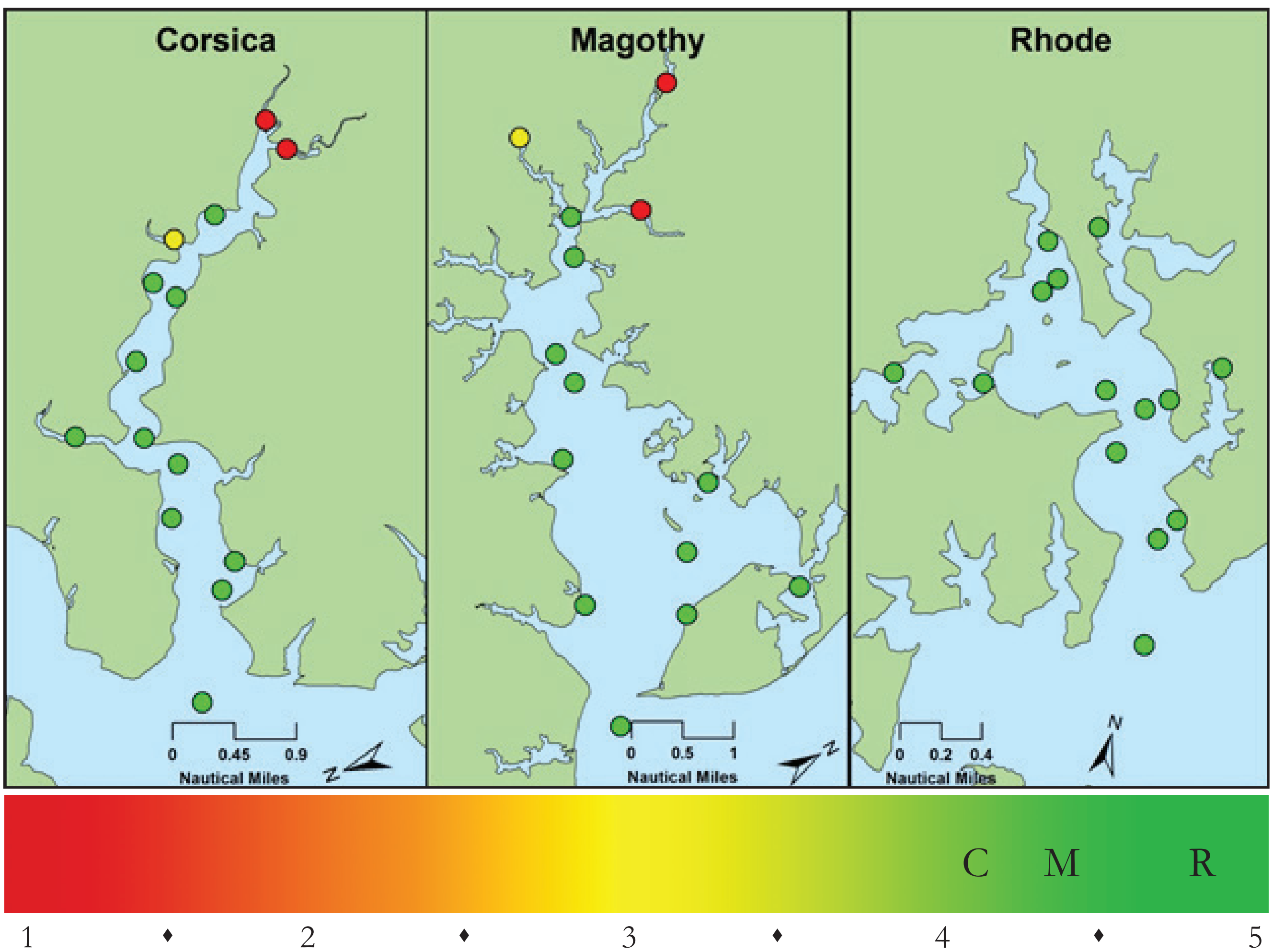
What we measured: Densities of *Enterococcus* spp. bacteria in surface waters from each of the water quality sampling stations.

How we assessed: Percent of samples where the density of *Enterococcus* spp. bacteria was lower than the US EPA criteria for a :designated beach area (104 colonies per 100 milliliters (mL) of water)) and for “moderate” swimming use (158 colonies per 100 milliliters (mL) of water) [25]. The bacterial density measurement from each water sample was compared to the relevant criteria and scored as 1, 3 or 5. These individual scores were averaged to obtain station and river conditions, and the average was assessed as degraded, poor, fair or good based on where it fell between 1 and 5.

Score		
1	3	5
≥158 colonies/100mL	≥104 and < 158 colonies/100mL	<104 colonies/100mL

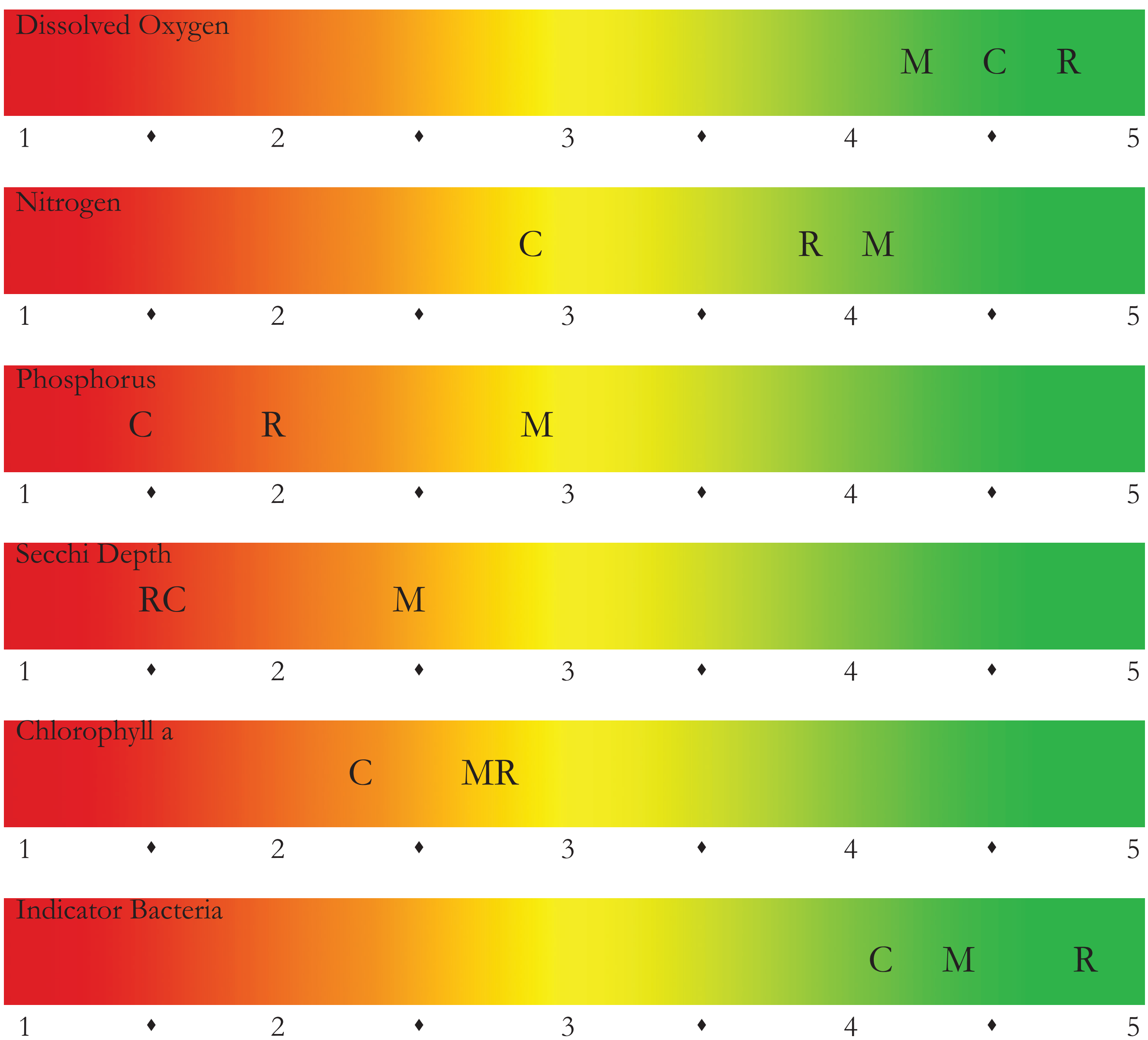
Station and River Assessment:

Condition	Degraded	Poor	Fair	Good
Average Indicator Bacteria Scores	≥ 1 and ≤ 2	> 2 and ≤ 3	> 3 and ≤ 4	> 4 and ≤ 5



Water Quality Summary

Many watersheds suffer from poor water quality, often due to anthropogenic stressors. Stormwater from urban and suburban areas can carry high concentrations of nutrients, bacteria and suspended sediments. Agricultural practices can have similar inputs, both in surface runoff and in groundwater. We did note some informative trends in water quality among the three rivers. First, there was a clear trend in nutrients with the agriculturally dominated Corsica having the highest concentrations of nitrogen and phosphorus compounds, and the more urbanized Magothy having the lowest concentrations of nutrients. However, nutrient concentrations, particularly phosphorus, exceed water quality criteria in sections of all three rivers. Secondly, dissolved oxygen concentrations were notably low during summer in the bottom waters of the heavily urbanized and slightly deeper Magothy. Nitrogen and indicator bacteria densities showed the most variability within the watersheds, with upper tributary stations having very high numbers compared to downstream stations. Some metrics such as water clarity and Chlorophyll a were poor for all three rivers, indicating that they may be linked to similar sources across all three watersheds.



Many of the pollutants that impact estuarine systems, including some toxic chemicals and pathogens, collect in the sediments that lie at the bottom. These benthic sediments serve as important habitat for many organisms that either live there or rely on the benthic community of organisms for food. These include many commercially important species, such as crabs and oysters, as well as the less well known worms and other small invertebrates that serve as food for larger organisms. Depending on the concentrations and types of pollutants in the sediments, these organisms may suffer from sublethal impacts, such as less successful reproduction, or they may die.

Land Management

Sources

Agriculture
Lawn Care
Erosion Control

Contaminants

Pesticides
Metals
Fuel Exhaust
Bulkhead Chemicals

Marine Activities

Sources

Boating, Boat Repair
Dredging
Docks/Marinas

Contaminants

Fuel Exhaust, Fuel Leaks
Paint Chipping, Zinc Anode
Shedding, Metal Rust,
Waste Tank Chemicals

Figure BH1. Examples of contaminant sources and types of contaminants from land management and marine activities

Pollutants in the sediments may also be stirred up into the water column, especially after large wind storms or heavy rainfalls, directly exposing organisms that live in the water column. Because of the importance of the benthic habitat for coastal aquatic organisms and the fact that it is a deposition site for many pollutants, the concentrations of chemical contaminant and sediment toxicity levels were measured in the rivers examined in this study. Established criteria exist for both sediment contaminant levels and toxicity for classifying degraded versus non-degraded condition.

Sediment Chemical Contaminant Analysis

Several large-scale studies, both in the Chesapeake Bay and in other estuaries, have found strong relationships between chemical contamination and the level of development on the adjacent land [26-28]. Sources of these contaminants are numerous, but include industrial processes, fossil fuel burning by power stations and gas-powered vehicles, electrical cooling equipment, household chemicals, land management and marine activities (Figure BH1). Introduction to the estuary may occur by direct input from waste pipes, overground runoff following rain storms, groundwater flow, and atmospheric deposition.

In this study, sediment contaminant concentrations were measured to determine whether they were above concentrations known to impact benthic organisms. The criteria include two risk levels 1) higher risk level, based on contaminant concentrations which were harmful to benthic organisms in 50% of studies, and 2) lower risk level, based on concentrations that were harmful to benthic organisms in 10% of studies. [29]. Concentrations of burnt fuel byproducts (called PAHs), chlorinated coolants (called PCBs), pesticides, flame retardants (called PBDEs), and metals were measured using analytical chemistry methods [27].

Photo courtesy of Jane Hawkey, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

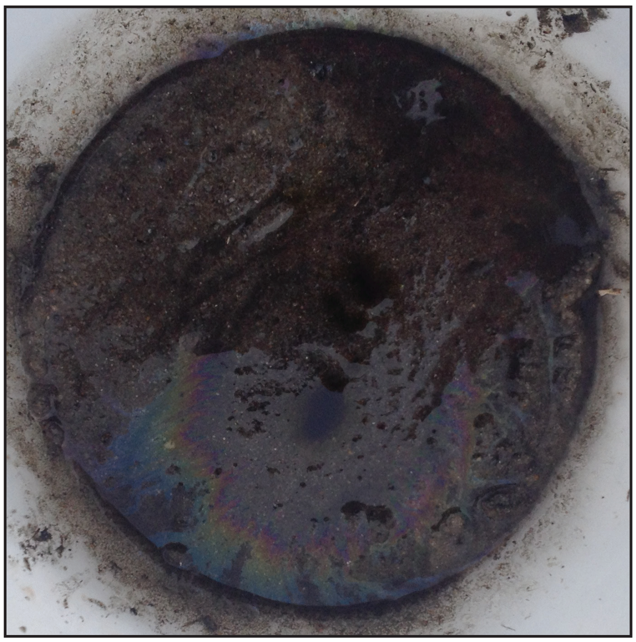
Chemical contaminants were detected at numerous sites in all three systems. Table BH1 shows the number of measurements, grouped by type of contaminant, that exceeded their respective risk criteria. There were numerous sites that exceeded risk criteria for metals and fuel byproducts. Chlorinated coolants were rarely encountered at notable levels and only exceeded the lower level criteria at one station in the Magothy River. There were 12 stations (spread across all three rivers) where the pesticide DDT exceeded the lower risk criteria, despite the fact that it has not been used in agriculture for decades.

PAHs are some of the most widespread pollutants in soil and sediments, and may be carcinogenic, cause genetic mutations, or cause developmental abnormalities.

Contaminant Group	Criteria Exceeded					
	Adverse effects in 50% of studies			Adverse effects in 10% of studies		
	Corsica	Magothy	Rhode	Corsica	Magothy	Rhode
Metals	0	7	1	6	48	40
PAHs	0	5	0	3	62	17
PCBs	0	0	0	0	1	0
Pesticide (DDT)	0	0	0	3	7	2

Table BH1. Number of measurements that exceeded the relative risk criteria, organized by river and type of contaminant. For example, there were eight measurements of metal concentrations, regardless of station or type of metal, that exceeded the higher criteria level.

The most ubiquitous contaminant exceeding the lower risk criteria was the metal arsenic, which was measured at adverse levels for 49% of all stations sampled, and 79% of stations in the Rhode River. However, zinc was by far the most common contaminant found at levels exceeding the higher criteria level. This occurred at seven stations, all in the Magothy River.



Oil slick on sediment

PAHs are some of the most widespread pollutants in soil and sediments, and may be carcinogenic, cause genetic mutations, or cause developmental abnormalities. We detected elevated levels of PAHs at numerous stations, primarily in the Magothy River watershed. Tributary stations in the headwaters of the Magothy had particularly high PAH concentrations, with four measurements exceeding the higher risk criteria. Sediments in the Rhode River contained PAH concentrations that exceeded threshold values in 17 cases. In contrast, the Corsica River watershed stations contained only three PAH concentrations above threshold values.

Almost all chemical contaminants that exceeded risk criteria were found in the Magothy, particularly at stations in the middle and upper reaches of the river. In the Rhode River, contaminants exceeding contaminant criteria occurred most frequently at stations along the northern, developed shoreline. In the Corsica, stations that exceeded risk criteria were more geographically widespread, with no obvious trends in strata.

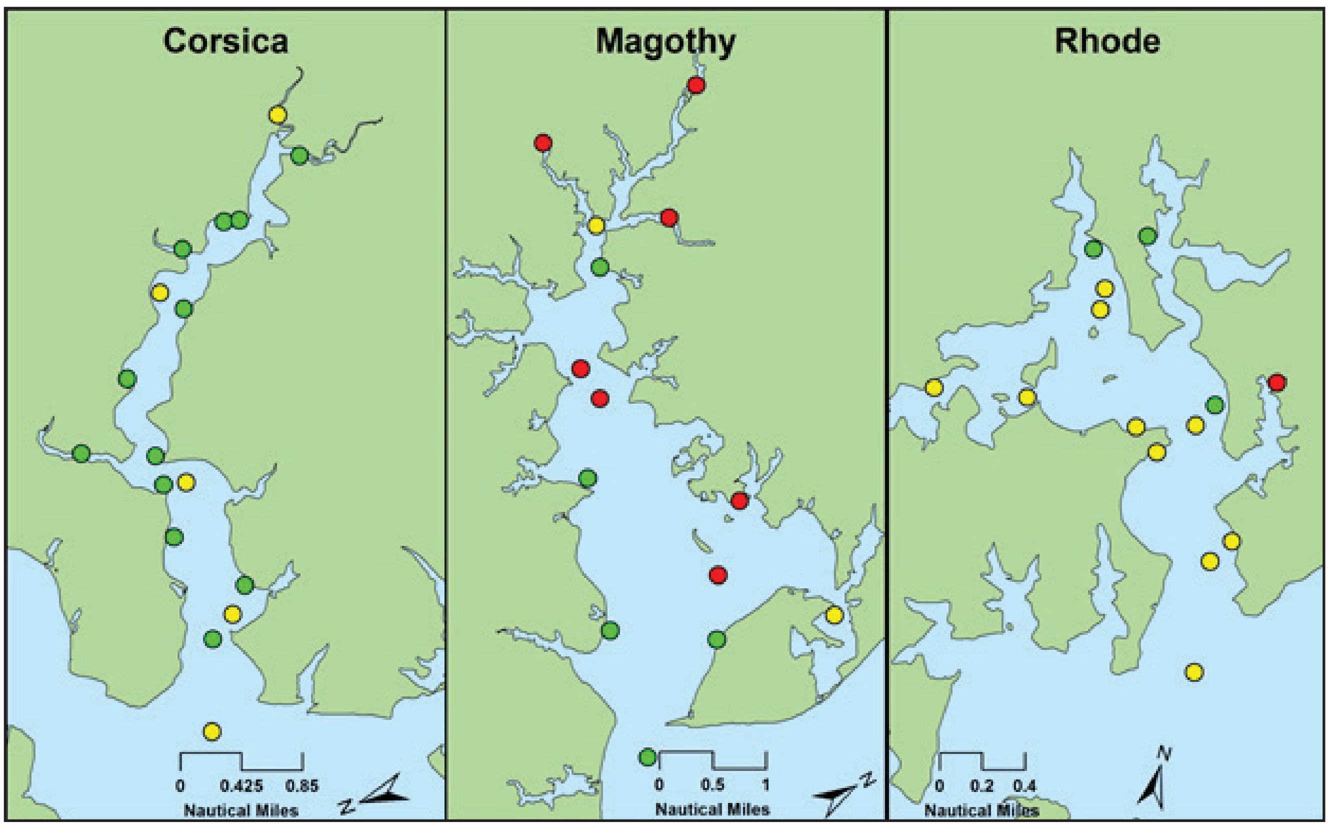
For 70% of the stations in the Corsica River all contaminant concentrations were below risk criteria, while 64% of Magothy stations and 79% of Rhode stations contained at least one contaminant exceeding risk criteria. However, 50% of Magothy stations contained one or more contaminants exceeding the high risk criteria. Overall, the Magothy River had more contaminant measurements (Table BH1) that exceeded the risk criteria than the Rhode, which was in turn higher than the Corsica.

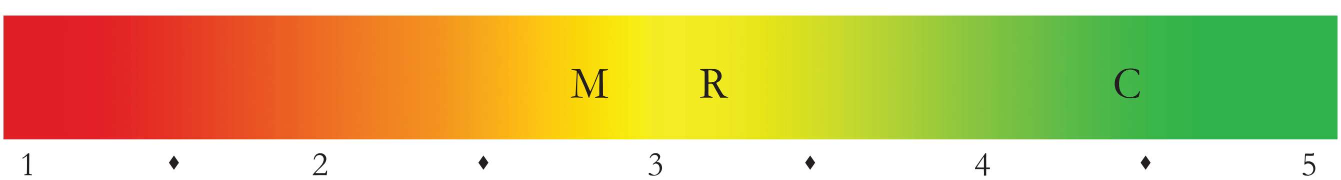
Sediment Chemical Contaminant Analysis Summary

What we measured: Concentrations of burnt fuel byproducts (PAHs), chlorinated coolants (PCBs), pesticides, flame retardants (PBDEs), and metals. Sediment samples were collected from the top 2-3cm of sediment from 14 sites per watershed during the summer of 2007.

How we assessed: Contaminant concentrations were compared to well established risk criteria [26, 30] We used a fairly conservative threshold for marginal effects, with one or more exceedances indicating at least a marginal condition.
Degraded (red): One or more contaminant measurements exceeding the high risk criteria; score = 1
Marginal (yellow): One or more contaminant measurements exceeding the lower risk criteria; score =3
Good (green): No contaminants found at levels exceeding any risk criteria; score=5

Station and River Assessment:





Toxicity

As discussed above, chemical contaminants within benthic sediments may be toxic to aquatic life. However, simply measuring the concentrations of chemical contaminants in benthic habitats does not provide sufficient evidence to determine how toxic the sediment will be to the organisms that live there. Some chemicals may not be easily taken up by living organisms and mixtures of chemicals may be more or less toxic than the sum of their individual toxicities. Sediment toxicity is determined not only by what materials comprise the sediment but also how conducive the sediments are to sustaining a healthy benthic community. Most toxicity testing occurs in a laboratory setting and involves exposing particular organisms to sediment samples.

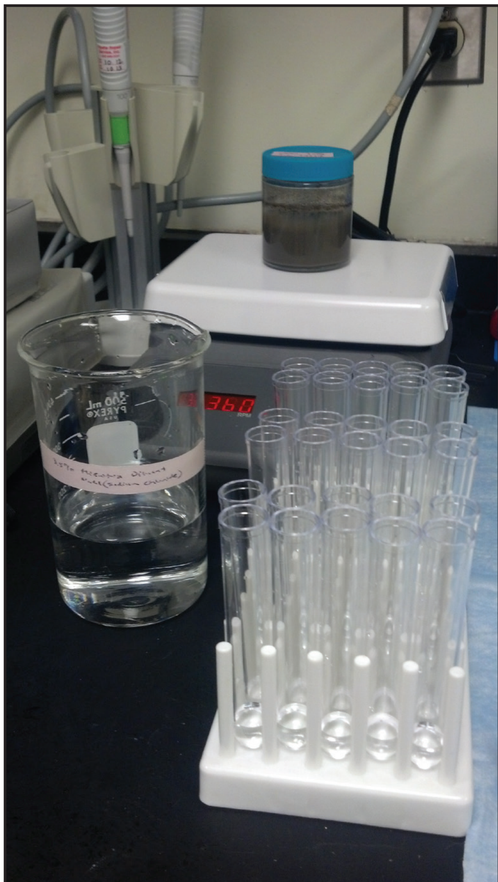


Figure BH2. Sediment being prepared for addition to test tubes. After this step, luminescent bacteria will be added.

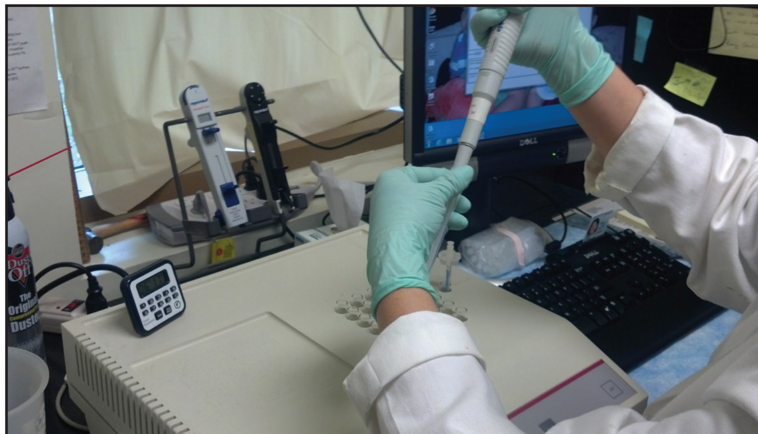


Figure BH3. Toxicity testing of sediment, using Microtox Assay ®

Many different toxicity tests have been developed and standardized[31]. For this study, we chose an assay that involves measuring light production by luminescent bacteria during and after exposure to sediment samples from the three rivers (Microtox Assay ®; Strategic Diagnostics Inc., CA) (Figures BH2 & BH3). Although this test occurs in an artificial setting and with an organism that may not be endemic to the study area, when results from previous studies using this assay were compared to toxic impacts in organisms from the particular study area, the Microtox assay was shown to be reasonable indicator of toxicity risk [32].

Forty-three percent of sampling sites, mostly from tributary and deep water sites, in the developed Magothy River watershed were toxic. Eighteen percent of sites in the agricultural Corsica River watershed were determined to be toxic and were from deep, main channel sites. The reference Rhode River only had four sites considered to be toxic, and there was no trend in the location of these sites.

Toxicity Summary

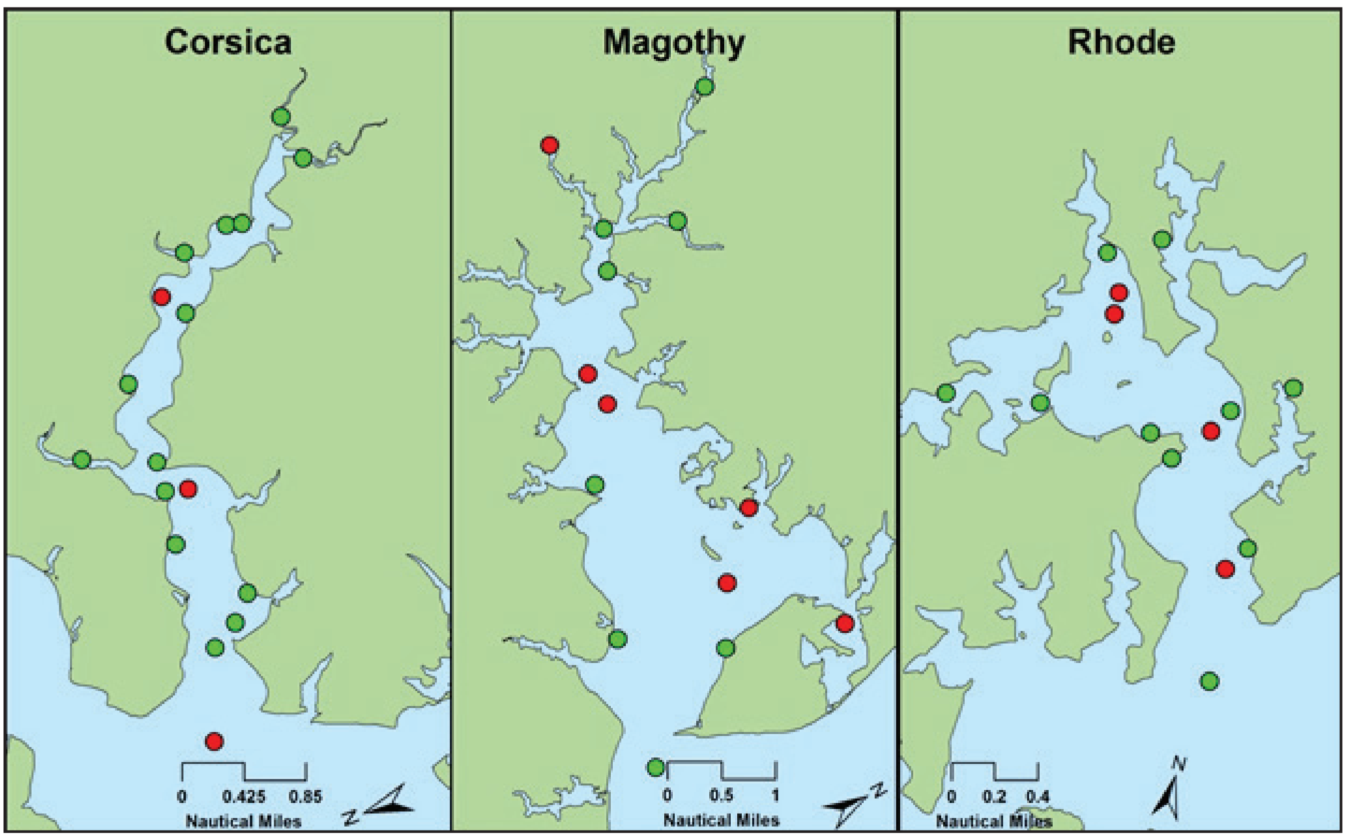
What we measured: Microtox assays were conducted using luminescent bacteria (*Vibrio fisheri*). An EC50 (the sediment concentration that reduces light output by 50% relative to controls) value was calculated for each sample.

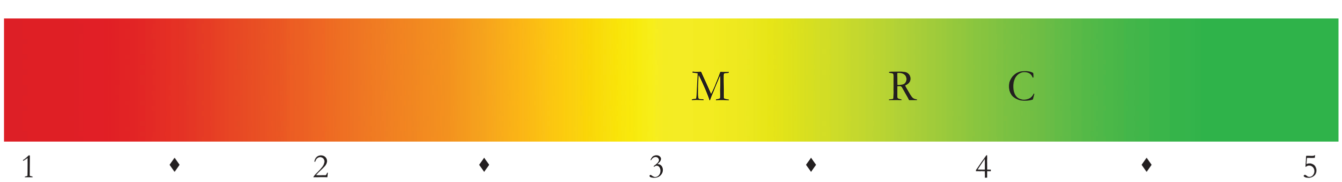
How we assessed: Results from each station were compared to criteria (shown in table below) developed by Ringwood et al.[32]. Light reduction below the EC50 is considered evidence of toxicity likely to harm organisms that might live in the sediment being tested.

Toxicity Criteria
Silt and clay content > 20% EC50 = 0.2%
Silt and clay content < 20% EC50 = 0.5%

Degraded (red): EC50 less than threshold; score =1
Good (green): EC50 above threshold; score=5

Station and River Assessment:





Benthic habitats, the sediments that lie at the bottom of estuaries, support diverse communities of microbes and larger organisms, which are important components of the food web and provide essential functions such as nutrient and detrital cycling. The health of a benthic community is influenced by many factors, including dissolved oxygen concentrations, sedimentation, and chemical contamination [33]. For this study we quantified the condition of the animals making up the benthic community by measuring the abundance, species diversity, biomass, number of pollution-tolerant species, and number of pollution-sensitive species. These community characteristics are what comprise the Benthic-Index of Biotic Integrity (B-IBI). For the Chesapeake B-IBI, each community characteristic is compared to an established criteria and given a score of 1,3, or 5, with lower numbers indicating more impaired community condition [34]. The scores for the individual community characteristics are then averaged for each station, resulting in a single B-IBI score. These station-specific B-IBI scores are then used to classify the community condition at each station as being degraded, marginal, or good, based on the type of habitat at the station [34] (Table BC1).

Scientists deploy a Young modified Van Veen benthic grab sampler to collect benthic community and sediment samples.

Table BC1. Thresholds for classifying benthic community condition, based on habitat (i.e. sediment type and salinity) [34]

Habitat	Degraded (Red)	Marginal (Yellow)	Good (Green)
Tidal Freshwater	<2.5	2.5 - 3.5	>3.5
Oligohaline	<2.5	2.5 - 3.7	>3.7
Low Mesohaline	<3.0	3.0 - 3.4	>3.4
High Mesohaline Sand	<2.7	2.4 - 3.0	>3.0
High Mesohaline Mud	<2.2	2.2 - 2.5	>2.5
Polyhaline Sand	<1.8	1.8 - 3.7	>3.7
Polyhaline Mud	<2.3	2.3 - 3.0	>3.0

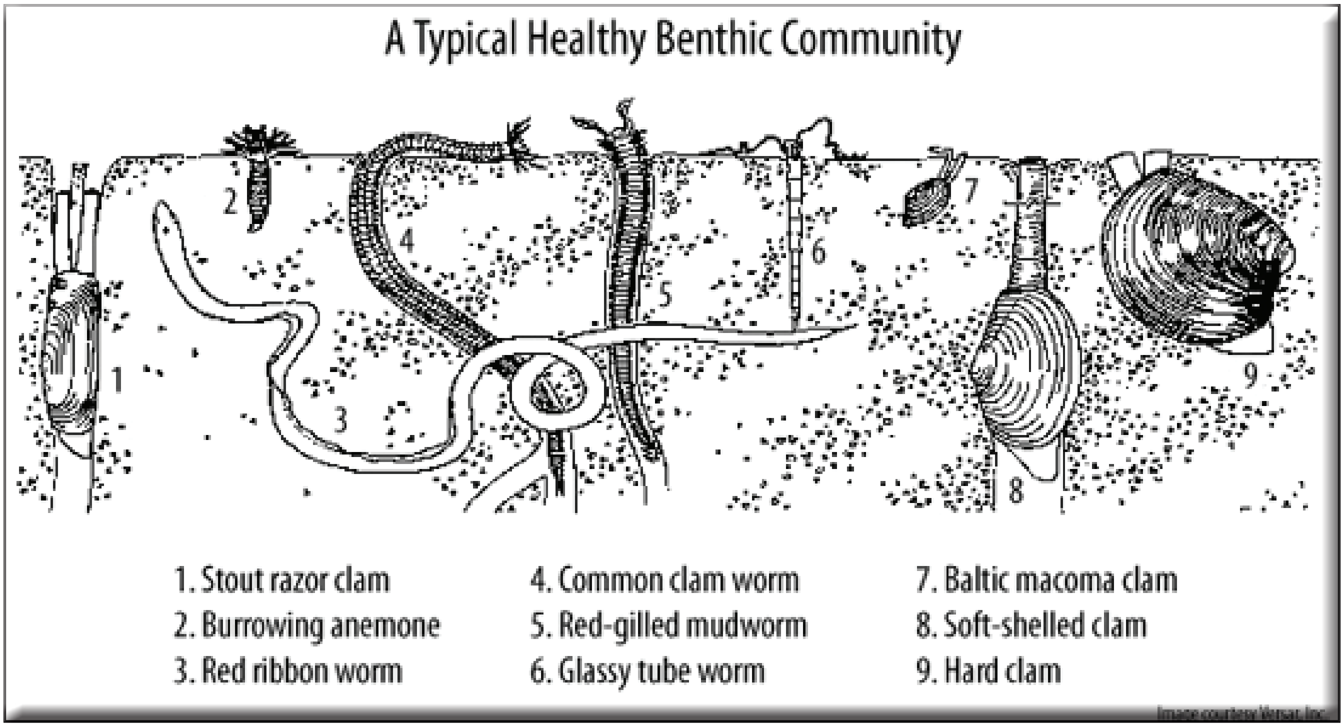


Image courtesy of Versar, Inc.

It is expected that areas with high levels of contaminants and high toxicity, in addition to areas that are highly scoured and poorly oxygenated, will have poor benthic community health and low B-IBI values. We tested this expectation for the three rivers in this assessment.

Sediment samples were collected at the same time and in the same way as the sediments for the benthic contaminant and toxicity testing. Sediments were collected at each of the water quality stations in 2007 (described in the Introduction), using a $0.044 m^2$ surface area Young grab. Sediments for the benthic community analysis were filtered through a screen with a half of a millimeter mesh size. All organisms were preserved and later identified, counted and weighed. Three additional stations were included in the Corsica River where water quality is routinely measured by the Maryland Department of Natural Resources, bringing the total number of stations to 45. Sampling occurred in all systems over a 2 day period in late August of 2007. Results of this study also appear in Leight et al [35].

The benthic faunal community was impaired at a majority of sampling sites in all three watersheds. The relative health of the benthic macrofauna was poorest for the Magothy River and all sites in the Magothy scored as degraded. Impaired benthic communities were also found at 94% of the Corsica River stations and 64% of the stations in the Rhode River. Overall B-IBI scores were significantly lower further upriver than the stations closer to the mouth in both the Magothy and Corsica.

In all three watersheds, benthic community condition related significantly with the type of sediment (silt and clay) and the salinity of the overlying water but not to bottom dissolved oxygen. Abundance (# organisms/m^3), biomass, and the number of species were highest in the Rhode and lowest in the Magothy. Abundance was significantly greater in the Corsica and Rhode as compared to the Magothy. Additionally, biomass was significantly greater in the Rhode than the Magothy.

Benthic Community Condition Summary

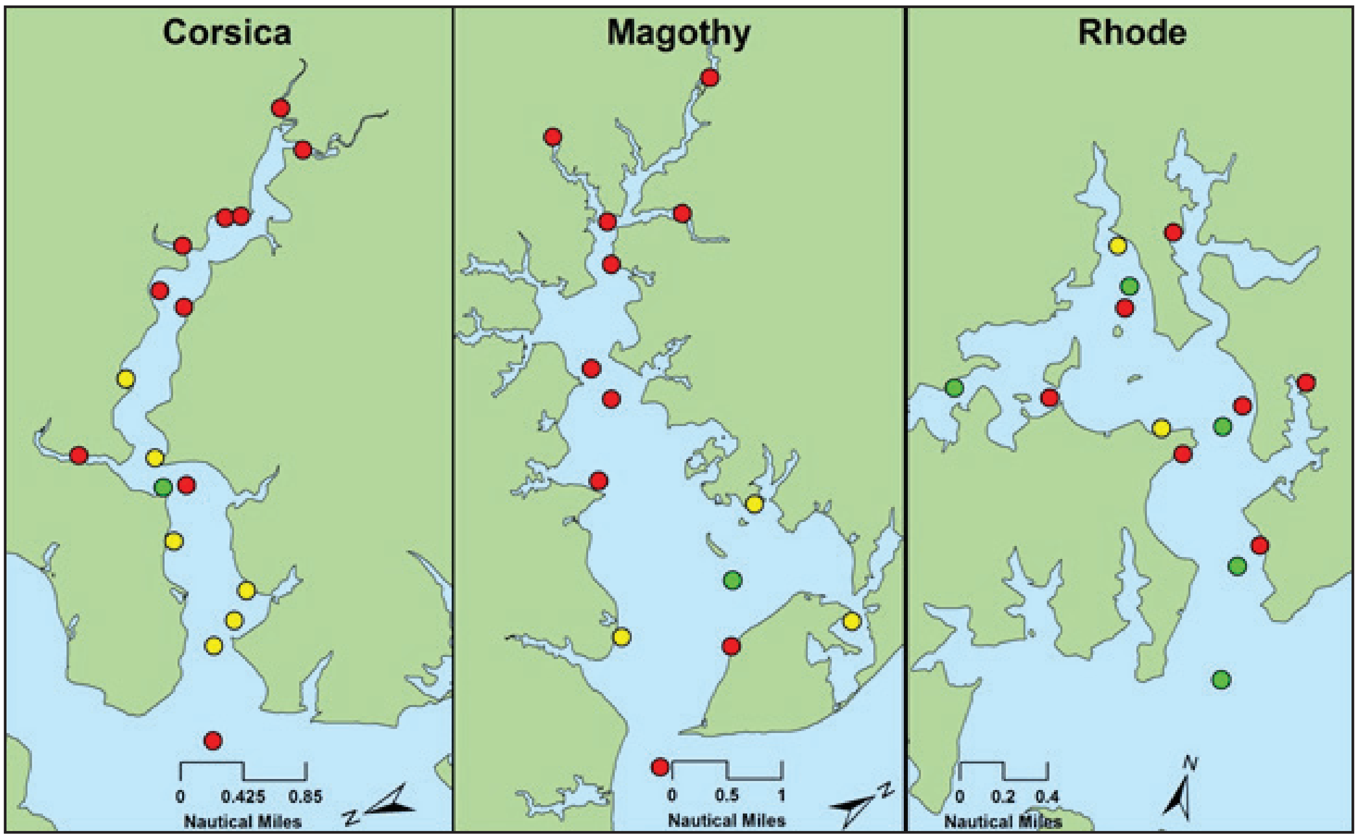
What we measured: Sediment samples were collected from the top 2-3 cm of sediment from 14 sites per watershed during the summer of 2007. Benthic fauna were collected from the sediment and identified to the lowest practical taxonomic level, usually to genus or species and counted.

How we assessed: Community condition was determined using the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) [34], taking sediment composition and salinity zone into account.

Degraded (red): B-IBI classified as degraded, Index score =1

Marginal (yellow): B-IBI classified as marginal, Index score = 3

Good (green): B-IBI classified as non-degraded, Index score = 5



1 ♦ 2 ♦ 3 ♦ 4 ♦ 5

Looking at both benthic habitat condition (contaminants and toxicity) and benthic community condition provides a way to characterize the overall state of the benthic environment in these watersheds and identify effects in the organisms from stressors. Stations that had high contaminant and toxicity levels tended to have degraded benthos. This was particularly true for the more urbanized areas of the Magothy and Rhode. There were however, several stations where the benthic community was impaired despite relatively low chemical contamination and toxicity, possibly as a result of other stressors such as low dissolved oxygen or physical disturbances to the bottom.

Living Resources

Living resources are the heart and soul of Chesapeake Bay. From the iconic blue crab to the regal striped bass, they represent the Bay's vitality and abundance both economically and ecologically. The Bay's history is steeped with stories of Captain John Smith's voyages, and the endless striped bass and mountains of oyster reefs presenting hazards to navigation. Iconic skipjack sailboats and Chesapeake Bay watermen symbolized the wealth of living resources and heritage of the region. For years Bay inhabitants have depended on a surplus of these living resources for food and trade.

In recent decades, this bounty has been tested. Increasing populations along our coastal regions have altered the chemistry of our waters and the nearshore and benthic habitats where fish and shellfish thrive. Centuries of overfishing and disease have taxed some of our most prized species to the point where numbers are too low to support a viable commercial fishery. In addition, the introduction of non-indigenous species pose new and unknown threats to the delicate balance of the ecosystem.

The Chesapeake Bay is renowned for its once seemingly endless bounty of crabs, oysters, and fish.

Estuaries are dynamic and ever-changing by nature and regardless of man's influence, the Bay of 75 years ago would most likely not be the Bay we know today. Organisms that thrive in this environment are largely resilient to change and capable of adapting to constantly variable conditions of the estuary. Many organisms possess complex immune and endocrine systems that detect change and are capable of responding to altered conditions within the estuary. Aquatic organisms, such as fish and shellfish, are good indicators of environmental stress. They are constantly immersed in the environmental conditions of the watershed, and respond in a variety of ways that are measureable.

These responses occur at all levels of biological organization. Intermittent stressors can cause changes in gene expression driving altered physiological responses. If a stressor persists, the structure and function of tissues can be affected. Finally, chronic or prolonged habitat degradation or stress can lead to broad scale changes in fish and shellfish populations. By measuring responses at each level of biological organization, a holistic picture of the quality of the environment for supporting sustainable fisheries emerges [36]. Often these responses to environmental stressors can be observed before population level changes can be noted (Figure LR1).

In the following chapter, we demonstrate the utility of using living resources as bioindicators of the state of the estuary. The premise is that living resources provide an exceptional "early warning" system of alterations to their environment. Changes may be noted in water quality or habitat availability, but the living resources themselves answer the question "so what "?

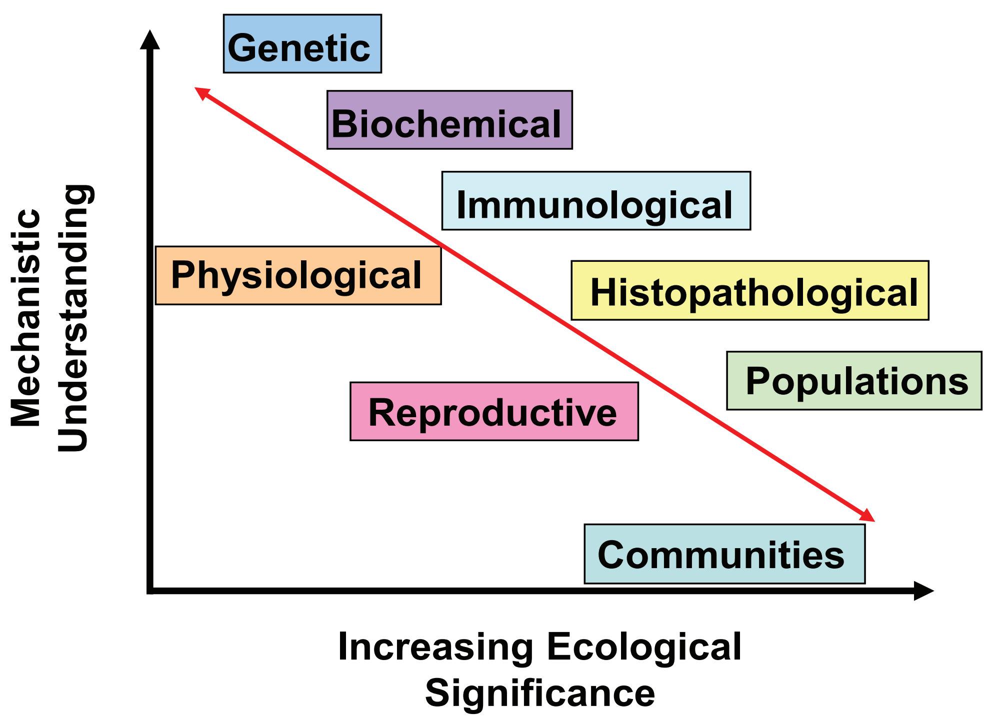


Figure LR1. Scientists can better understand how to best manage ecosystems by getting a "big picture" view of how each level of biological organization responds to environmental stress.

Fish

Estuaries are dynamic environments by nature, and the fishes that thrive in such environments are generally capable of adapting to a wide range of conditions. An effective indicator organism must be sensitive to change, well distributed, and primarily reside within the system under study. In Chesapeake Bay, the white perch (*Morone americana*) serves as an ideal indicator organism because of its ubiquitous distribution in the region and it's mid-level trophic position. Individual white perch largely remain in the same river, and occupy both near shore and open water habitats thus offering a composite picture of estuarine conditions. A second species, the mummichog (*Fundulus heteroclitus*) is also used to capture local effects and represent lower trophic positioning. With a 50 meter home range and well documented susceptibility to a variety of chemical contaminants, it serves as a good indicator of local pollution sources.

In the following pages, we demonstrate the utility of using fish as bioindicators of stress in estuarine systems and note the differential response from multiple levels of biological organization among watersheds.

Seining is an effective way to capture fish in shallow water environments to determine abundance and diversity.

Abundance and Diversity

Healthy ecosystems support an abundance of fish and a diversity of species. Changes in the size and structure of fish communities are good indicators of habitat or environmental impacts. However, they alone do not lend insight into the cause of change.

Fish abundance was greatest in Corsica and lowest in the Magothy (Figure LRF1). Abundance in the nearshore, shallow sites was more variable between years, while open waters were generally less productive with fewer numbers of fish in upper reaches of the river.

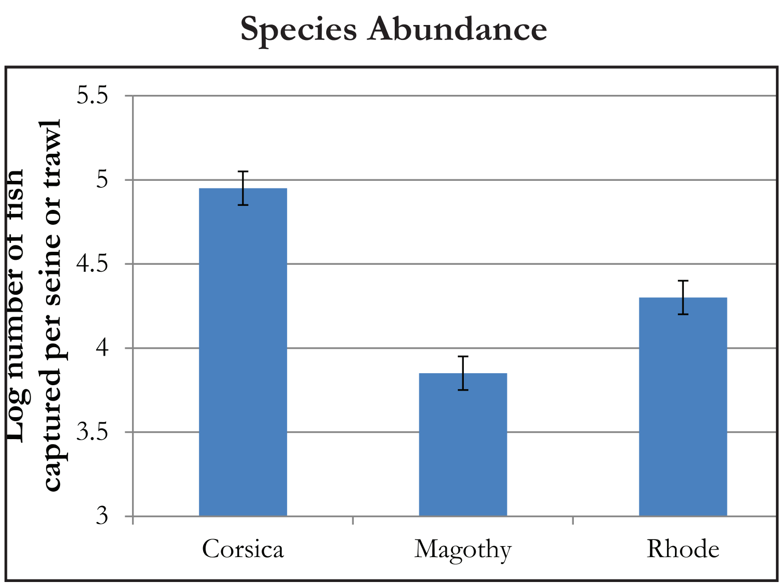


Figure LRF1. Overall fish abundance was consistently lower in the Magothy River in both shallow and deep waters.

The number of fish species, or species richness, captured in nearshore and open waters of the studied systems was generally lowest in the Magothy River, and relatively equal in the Rhode and Corsica. Annual changes in the number of species present was also apparent as was a trend of lower diversity in upper sections of the rivers compared to down river stations.

The abundance and diversity of fish species was consistently lower in the Magothy than in either the Corsica or Rhode. This trend is in general agreement with the literature where systems that have extensive development and greater amounts of impervious surfaces suffer from habitat loss and reduced fisheries [37].

In all three rivers, white perch, spot, and Bay anchovy were among the five most dominant species. However, the abundance of white perch in the Corsica River watershed far exceeded both the Rhode and Magothy (Figure LRF2).

Another way to look at the data is in terms of evenness of distribution. Ecologists use a number of indices to simultaneously describe both the number of species present and how many of each species are present. A perfectly balanced system theoretically would have equal numbers of many species. We used the Shannon-Weiner diversity index to calculate species evenness as a relative measure of community health. Evenness ranges from 0 – 1 with 1 being a perfectly balanced system.

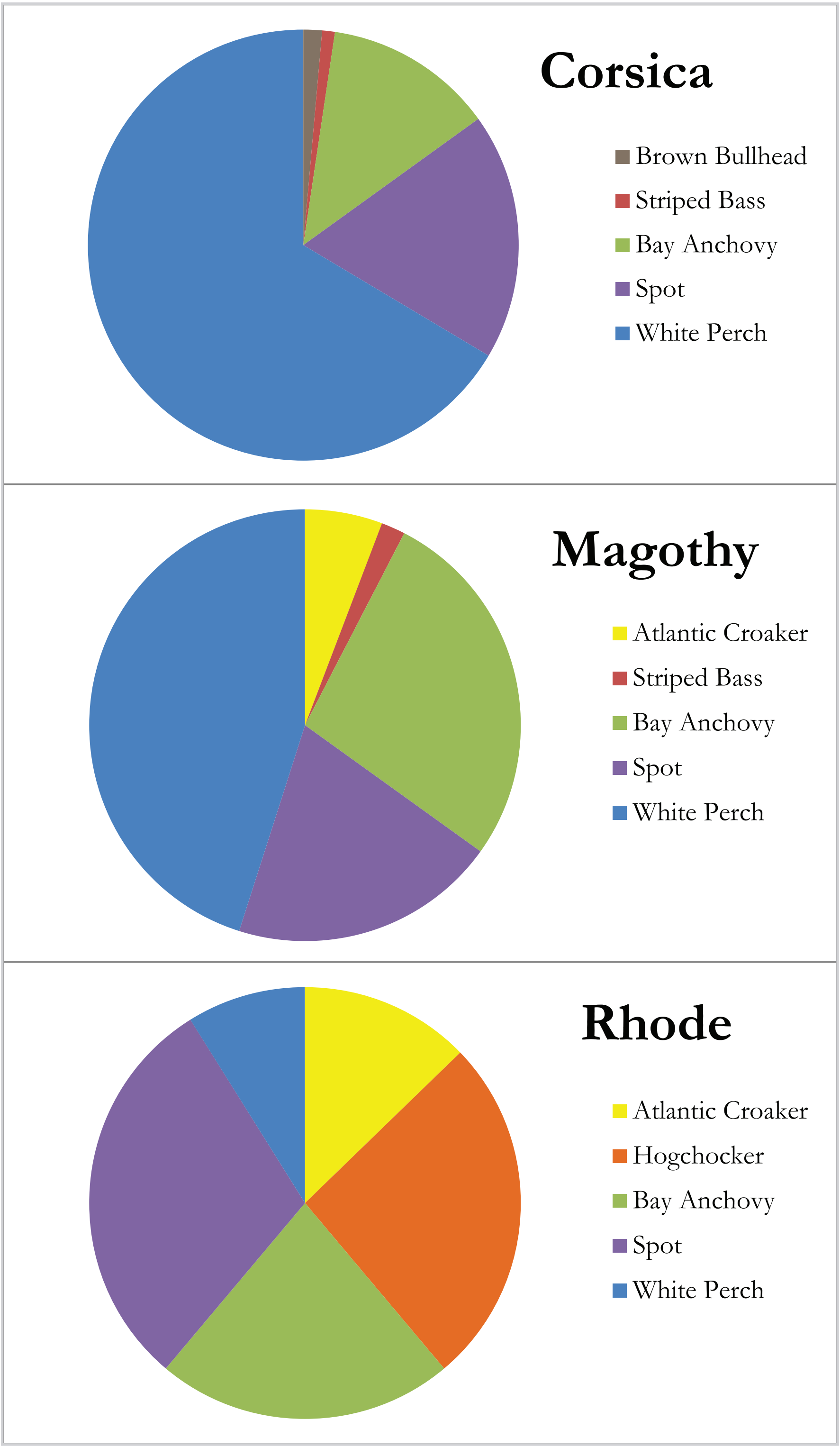


Figure LRF2. The relative abundance, within each river, of the five most dominant fish species. White perch dominated the Corisca, resulting in lower evenness for that river.

The story that emerges from the three rivers is one of resiliency. Nearshore habitats in all three rivers supported a diverse and evenly distributed number of species. The Magothy displayed the greatest evenness, likely due to the diversity of habitat present (grasses, salinity range). Deep waters show a different story largely due to low oxygen as exemplified by empty trawls in the Magothy, although all rivers were generally in a healthy range.

In general, the Magothy had the lowest overall abundance and diversity of fish but still showed a great deal of balance or evenness. White perch dominated the catch in the Corsica and were present in every trawl. However, occasionally empty trawls in the Rhode occurred for unknown reasons.

Abundance and Diversity Summary

What we measured: A 100 ft beach seine and 16 ft otter trawl were used to sample sites throughout each river six times per year. Seine and trawl were deployed in a standard fashion with the number of individuals in each species counted.

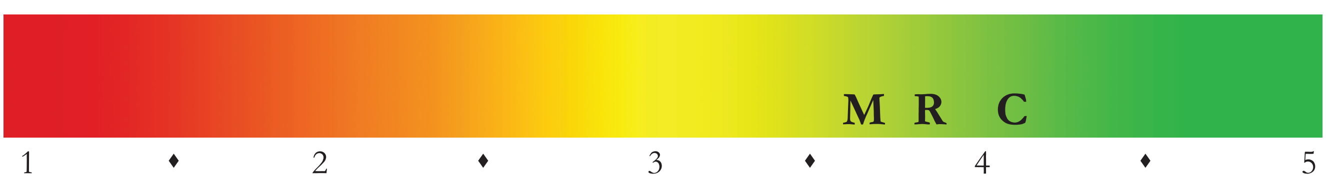
How we assessed: Species evenness as a relative measure of community health was calculated using the Shannon-Weiner diversity index. Evenness ranges from from 0 – 1 with 1 being a perfectly balanced system. For the purpose of our index development, evenness scores were adjusted to a 1-5 scale. Values are presented for both nearshore (seine data) and mid-river (trawl data) habitats.

Shannon-Weiner Evenness Score	0 (No Balance)	0.5 (Somewhat Balanced)	1 (Perfectly Balanced)
Index Score	1	3	5

River Assessments:

Nearshore (Shallow) Waters

Mid-River (Deep) Waters



Growth and Fitness

While population level changes can reflect long term impacts to a system, prey availability and appropriate habitat conditions are reflected in the growth and fitness of the population. Several methods such as RNA/DNA ratio, weight, and body fat content in fish were used to measure both short term (days) to long term (weeks to months) changes in the growth and condition of individuals.

White perch usually stay within in a river, are abundant, and long-lived making them a good indicator species to determine how land use affects aquatic organisms.

Instantaneous Growth Potential

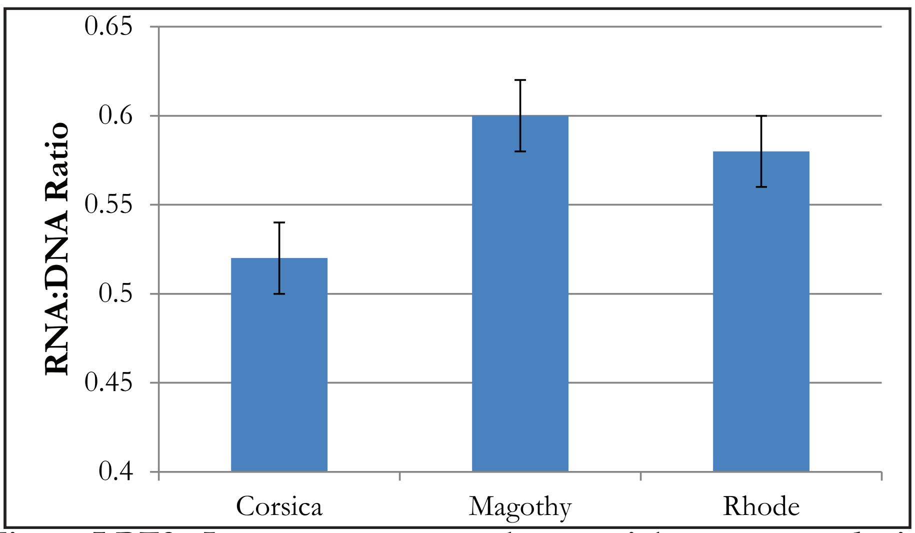


Figure LRF3. Instantaneous growth potential, as measured with RNA:DNA ratios, was consistently lower in the Corsica River.

Ribonucleic acid (RNA) is transcribed in the process of protein synthesis and thus increases during periods of active growth or mobilization of resources for spawning or repair. Deoxyribonucleic acid (DNA) remains relatively constant within a cell. Therefore the ratio of RNA:DNA is widely applied as an indicator of growth [38]. A high RNA: DNA ratio is an indicator that a fish is actively feeding and growing while a low ratio suggests the opposite. Because much energy is expended on reproduction in the spring, only summer and fall data are used for the index.

We examined RNA:DNA ratios in white perch and found them to be significantly lower in the Corsica River than the other two rivers and generally greater in upriver sites than downriver (Figure LRF3). There were significant changes between years in all three watersheds with white perch sampled in 2007 possessing the lowest RNA:DNA ratios.

Relative weight offers a convenient means for measuring fitness of an individual fish. Much like pediatricians chart the weight and height of children against a national database, relative weight compares the weight at any given length of a fish to a standard derived from a large pool of fish sampled across the country. A score of 90, or weighing 90% of the standard weight for a fish's length, is considered acceptable, while less than 80% denotes lack of proper feeding, environmental stress, or other issues [39].

Average relative weight for all rivers followed a similar trend as RNA:DNA ratios with the Corsica being lower than all other systems. Annual variability was again apparent in all systems, with relative weight overall increasing from 82% in 2007, to 84% in 2008, and 92% in 2009. Over the three year period, all systems fell below the 90% threshold at least once (Figure 4).

Finally, we measured the presence of fat in the abdominal cavity of fish. Like many species, white perch accumulate abdominal fat reserves in preparation for winter. Storage lipids are easily identified as an off white, glossy substance intertwined with the visceral organs. The presence of these reserves is an indication that the fish is consuming more calories than are needed for normal activities and bodily functions, which is indicative of sufficient prey [40]. As seen in Figure LRF5., white perch in the Corsica River had reduced fat reserves compared to fish from the other two watersheds.

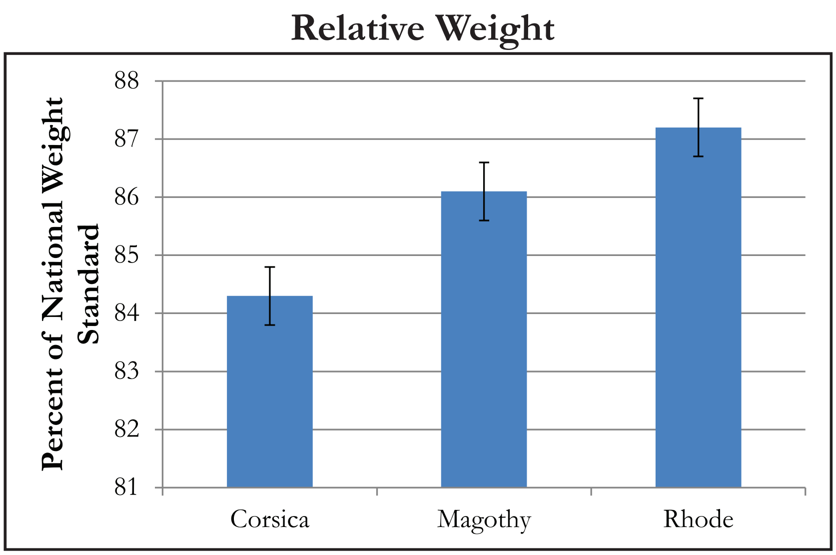


Figure LRF4. Relative weight followed a similar trend as RNA:DNA with values being the lowest in the Corsica River watershed.

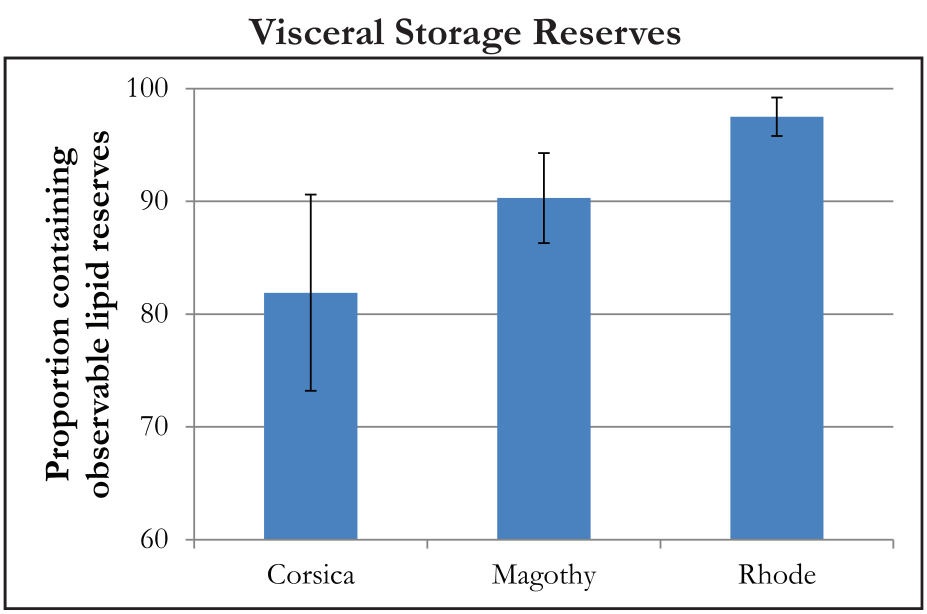


Figure LRF5. Abdominal fat reserves were also lowest in the Corsica showing that although abundance in this system was highest, condition was lowest.

Overall, the picture that emerged is one of reduced condition in the agriculturally dominated Corsica River watershed as compared to the other rivers. This reduction in condition may be due to a combination of factors. First, higher density of white perch in the Corsica River leads to competition for resources. As we will see later in this chapter, other factors such as parasite burden and disease prevalence may also play a role.

Growth and Fitness Summary

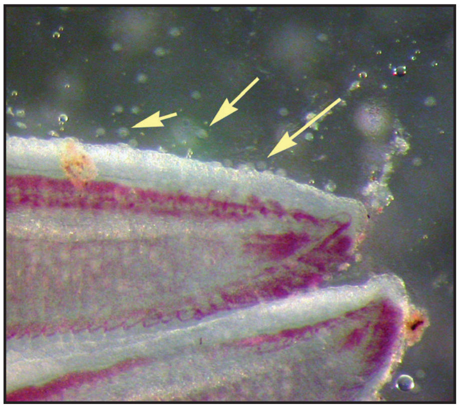
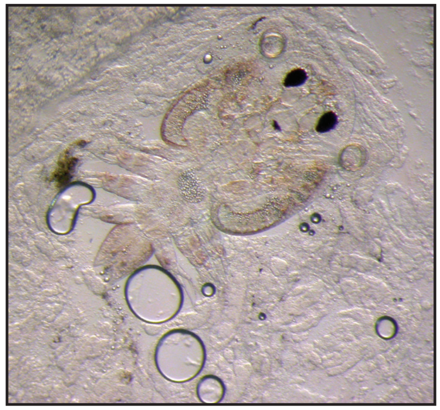
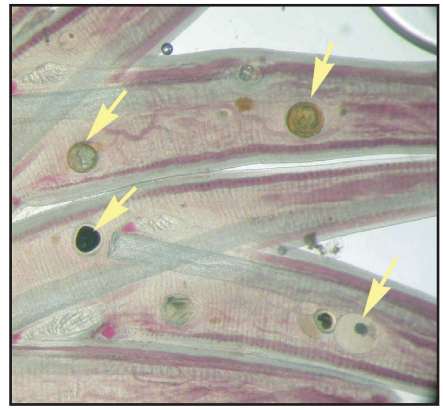
What we measured: While several indicators were used to measure growth and fitness, relative weight was chosen for index development because of the existence of general criteria for classification. White perch were collected from all rivers with either seine or trawl and immediately weighed (g) and measured (TL,cm). Weight at length was then assessed relative to a standard weight derived from white perch collected around the US.

How we assessed: Individual relative weights were scored according to the following table and average condition over the course of the study used for final index. A score above 90% is generally considered healthy, while scores less than 80% represent unfavorable foraging conditions.

Relative Weight	< 80%	80-90%	> 90%
Index Score	1	3	5

River Assessments:

External Fish Parasites

Although low quantities of external parasites on the gills and skin are normal, a high number of parasites can be an indication that the animal is stressed.

The abundance and diversity of fish parasites serves as a general indicator of environmental stress. They are influenced by several factors, including water quality and contaminants, abundance of intermediate hosts (principally benthic macroinvertabrates), and the physiological status of the individual fish.

External parasites were observed more frequently and at higher density in white perch from the Corsica River then the other rivers (Figure LRF6). The principal parasites observed were found on gills and included a ciliated protozoan, *Trichodina* spp., encysted flatworm, (digene cysts), and gill flukes (*Dactlygyrus* spp.). Internal parasites followed a similar pattern as external parasites, and were largely encysted worm larvae (trematode metacercaria). In general, internal and external parasite prevalence was correlated and remained at similar levels during the first two years of the study. In 2009, however, prevalence dropped slightly.

Parasites are a normal part of functioning ecosystems and their presence alone does not necessarily indicate degraded condition. However extremely high prevalence and intensity of parasites can be harmful to fish.

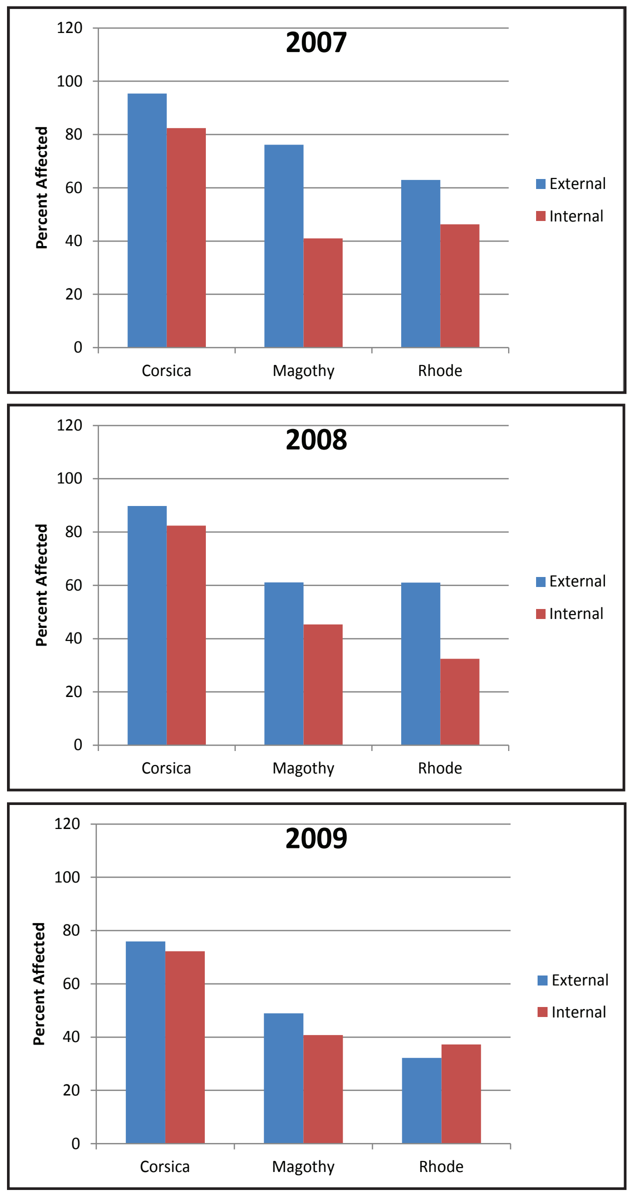


Figure LRF6. Parasite prevalence varied slightly annually but was consistently higher in the Corsica River.

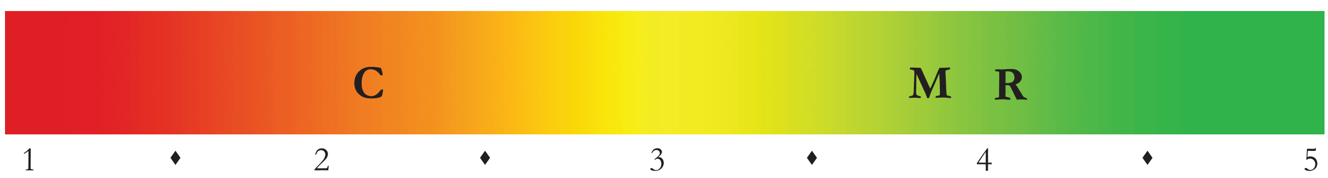
External Fish Parasites Summary

What we measured: In the field, small sections of gills and samples of the mucous scraped from the skin were taken from fresh fish. External parasites were counted and identified to genus by microscopic examination.

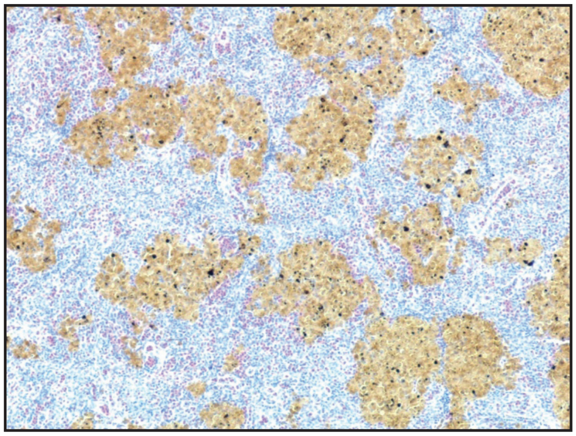
How we assessed: The intensity, or number of external parasites counted, was used to create a relative index of external parasite burden as shown below. As with all indices in this chapter, a score of 5 represents the preferred condition.

No. of parasites per section	> 3 parasites	1-3 parasites	< 1 parasite
Index Score	1	3	5

River Assessments:



Macrophage Aggregates

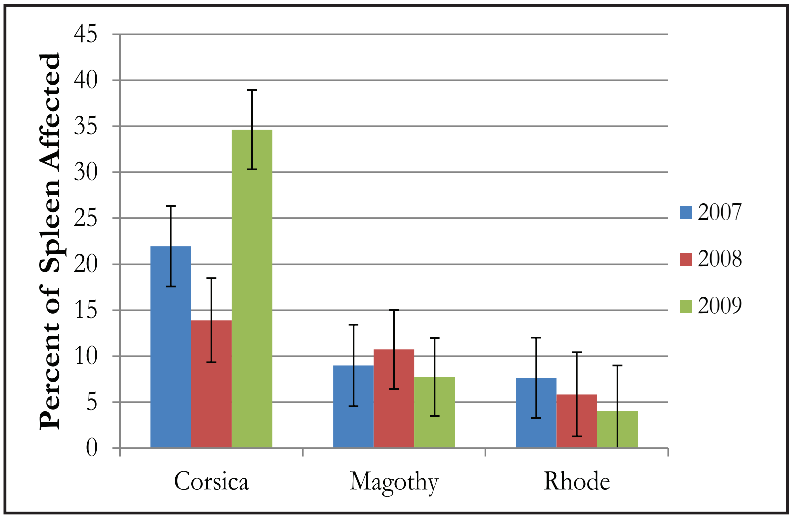


Macrophage aggregates of white blood cells occur when organisms are exposed to contaminants, heavy metals, and parasites.

Macrophages are aggregations of white blood cells involved in the capture, transport, and destruction of foreign materials, such as contaminants, heavy metals, parasites and dead cells. They accumulate in focal centers for the destruction of foreign materials and reclamation of useful tissues and cells. The size, density, and pigmentation are known to be affected by fish health status, age, and environmental contamination. Greater than 40 macrophage aggregates per square millimeter (MA/mm^2) is considered representative of impaired waters while less than 15(MA/mm^2), fish are considered healthy [41].

Macrophage aggregate density and percent affected spleen was significantly greater in white perch from the Corsica River watershed than the other rivers (Figure LRF7), with some annual variability noted, particularly in the Rhode and Magothy Rivers. The percentage of tissue affected followed a similar pattern with white perch from the Corsica again having a greater area of the tissue involved. Thus, in general, the Corsica River tended to have more fish with aggregates affecting a larger proportion of organs than fish from the other rivers.

While the indicator suggests a greater degree of environmental degradation in the Corsica River, only 5% of the fish exceeded the 40 MA/mm^2 criteria for degraded systems. However, only 16% fell in the low category (less than 15 MA/mm^2) characteristic of healthy systems in comparison to 48% and 58% for the Rhode and Magothy respectively.



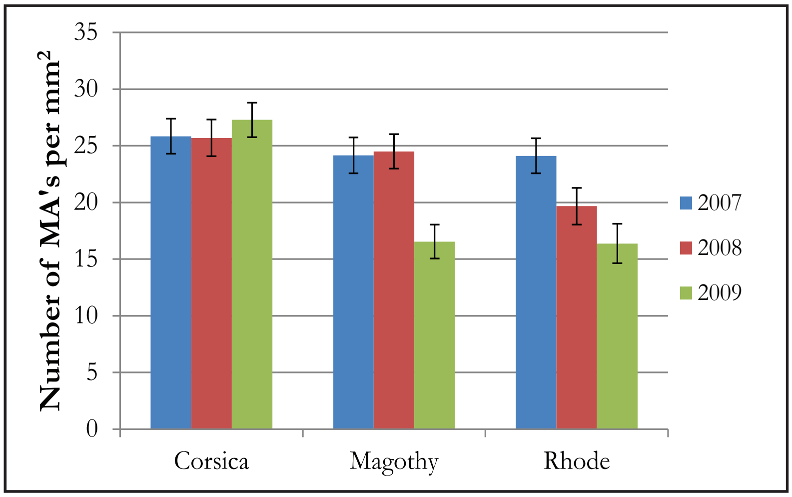


Figure LRF7. Although the density of macrophage aggregates was higher in the Corsica River, only 5% of these fish exceeded the criteria for degraded systems.

Living Resources Fish

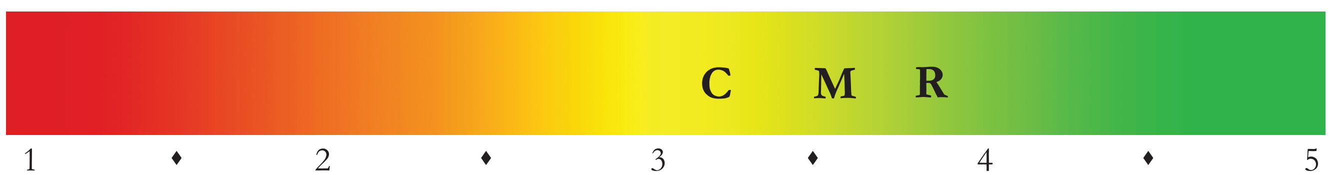
Macrophage Aggregate Summary

What we measured: White perch spleens were embedded in paraffin, cut to 5 microns, stained using Mayer's hematoxylin-eosin-phloxine, and prepared as slides. Slides were examined with the aid of image analysis software to determine the density of macrophage aggregates per mm^2 for a minimum of four sections per fish.

How we assessed: Calculated macrophage density was compared to established standards where greater than 40 macrophage aggregates/mm^2 is indicative of impaired systems while less than 15 aggregates/mm^2 indicates a healthy system.

Macrophage Density (MA/mm^2)	> 40 Threshold for Impaired System	15-40	< 15 Healthy System
Index Score	1	3	5

River Assessments:



Fish Disease

Another potential indicator of system degradation is the prevalence of disease. Disease in aquatic organisms is commonly considered in the context of host, pathogen, and environment. In theory, environmental conditions that are stressful to organisms, or favor pathogen proliferation can lead to increased incidence of disease.

The major disease in white perch collected in this effort is mycobacteriosis, caused by the presence of several species of bacteria of the genus Mycobacterium. The disease resulting from infection is characterized by inflammation in the spleen and the formation of granulomas, or capsules formed by the body as a means of defense to wall off the bacteria. The disease has been at the forefront of management issues in the Chesapeake region because of a high prevalence in a key species, striped bass. In addition, some of the bacteria associated with the disease are capable of causing infection in humans.

Prevalence of mycobacterial disease was greatest in the Corsica River, where 30-50% of fish were affected (Figure LRF8). The concentration of bacteria cultured was also significantly higher in the Corsica River, being nearly ten times higher per milligram of tissue. Of interest, the primary species cultured is *Mycobacterium triplex* which differs from the main isolates associated with striped bass.

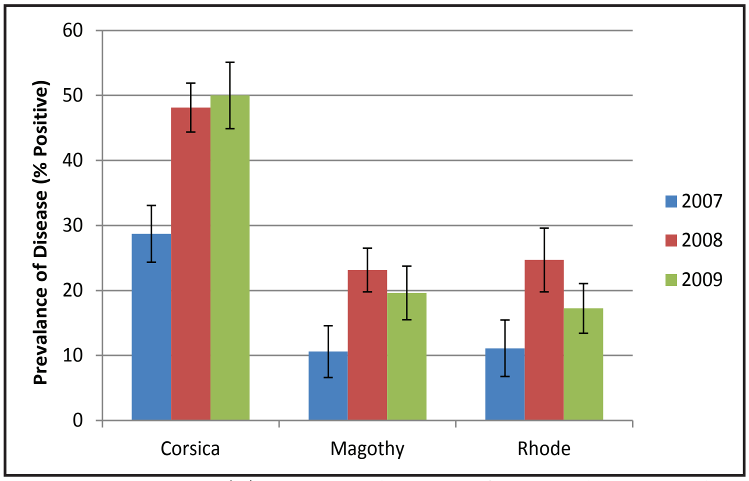
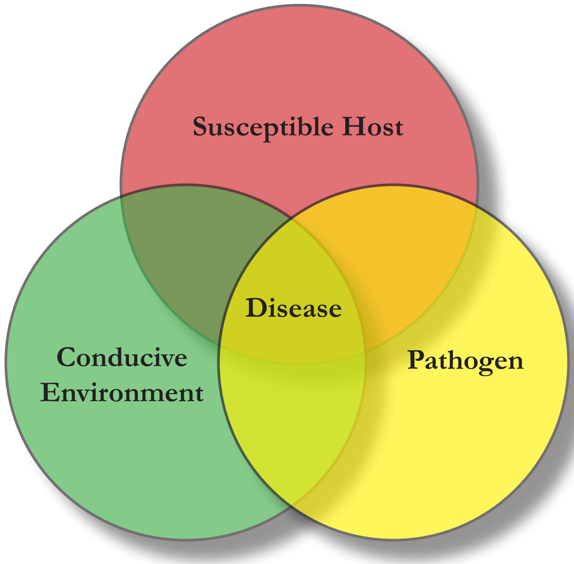
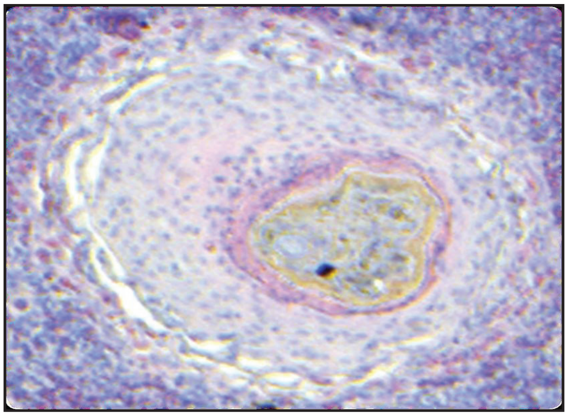


Figure LRF8. The prevalance of mycobacterial disease in white perch was consistently higher in the agricultural Corsica River watershed.



Conditions are correct for disease to occur when pathogens are present, the host organism is susceptible, and the environment is correct for the pathogen to thrive.



A typical host response is to create granulomas in an attempt to wall off the disease-causing organism.

Severity of tissue response, based on scoring the degree of observed inflammation, was much greater in the Corsica River with 36% of fish being in the most severe category (1). In contrast, 45% of fish in the Magothy and Rhode rivers were normal and healthy (5), as compared to 10% in the Corsica.

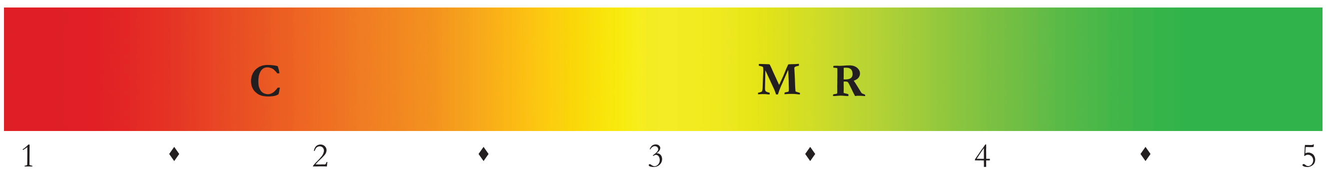
Fish Disease Summary

What we measured: White perch were necropsied with organs processed for histopathology and severity of pathological change noted.

How we assessed: We employed a severity index based on the degree of inflammatory response in the spleen. The index is scaled from 1 to 5, with 5 representing normal tissue, 3 moderate and 1 severe response.

Degree of Tissue Inflamation	Severe	Moderate	None (Normal Tissue)
Index Score	1	3	5

River Assessments:



Contaminant Exposure

A variety of chemical compounds enter our waters daily, and for many, we do not fully understand the potential impacts to living marine resources. Endocrine, or hormone, disrupting compounds have gained considerable notoriety as of late due to their ability to cause fish to change sex. In general, these are chemicals that mimic or antagonize the female estrogenic hormones (estrogen), male androgenic hormones (such as testosterone), and/or thyroid hormones [42]. Other chemicals such as pesticides and insecticides can alter the neurological system of fish leading to mortality. Because these compounds are difficult to measure in the environment, using fish as bio-indicators offers a cost effective means to determine their presence and influence.

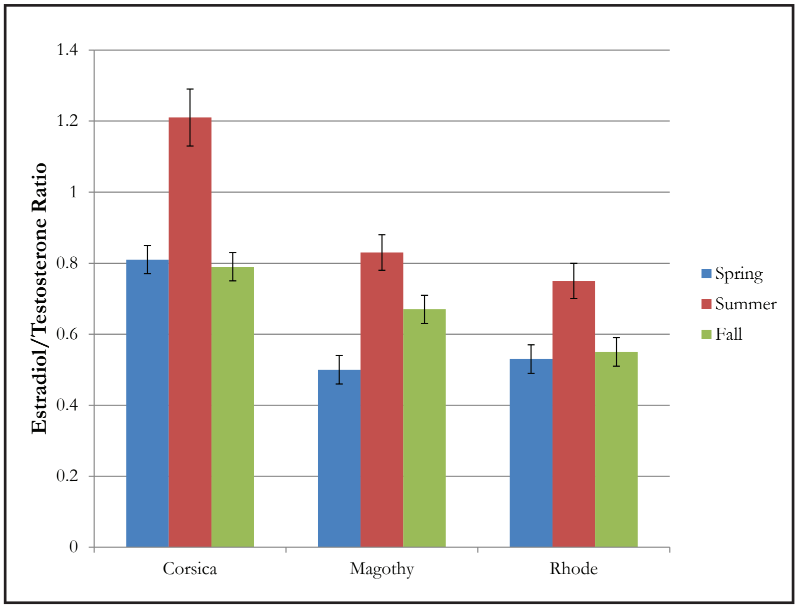


Figure LRF9. The consistently high estradiol:testosterone ratio in white perch from the Corsica River watershed is an indication of exposure to hormone disrupting compounds.

We measured estradiol and testosterone, two sex hormones, in the serum of white perch as an indicator of the presence of endocrine disrupting compounds for the first two years of the study. Both compounds fluctuate seasonally within fish due to changes in reproductive cycle, but the ratio of estradiol to testosterone can be a good indicator of contamination. A high estradiol to testosterone ratio is an indication of the presence of hormone disrupting compounds with higher ratios being an indication of greater exposure to these contaminants. Overall, white perch from the Corsica River had significantly higher estrodial to testosterone ratios than the other systems, a trend that persisted throughout the seasons.

The mummichog is an effective indicator species for measuring the effects of contaminants because of its limited home-range.

Acetylcholine is the primary neurotransmitter in fish, or the compound that allows signals to travel across nerve synapses in the body to impart movement or other responses. Acetylcholinesterase is the enzyme responsible for removing acetylcholine from the synapse when not firing. Without it, muscles would continuously twitch. Inhibition of acetylcholinesterase can occur from exposure to a variety of compounds, but most notably pesticides containing organophosphate chemicals. We use acetylcholinesterase inhibition in the mummichog as an indicator of chemical exposure.

The majority of the differences in acetylcholinesterase activity are explained by annual and seasonal changes (Figure LRF10). In particular, fish collected in 2007 demonstrated higher activity than the other years, and the spring and summer a higher degree of inhibition than other seasons. Fish from the Corsica River experienced greater inhibition in the spring while fish from the Magothy showed greater inhibition in the summer. This is likely due to changes in rainfall patterns and seasonal application of pesticides. Overall, the proportion of fish considered inhibited in this effort was greatest in the Corsica River (22%) in comparison to the others (~16%).

Percent Acetylcholinesterase Inhibition

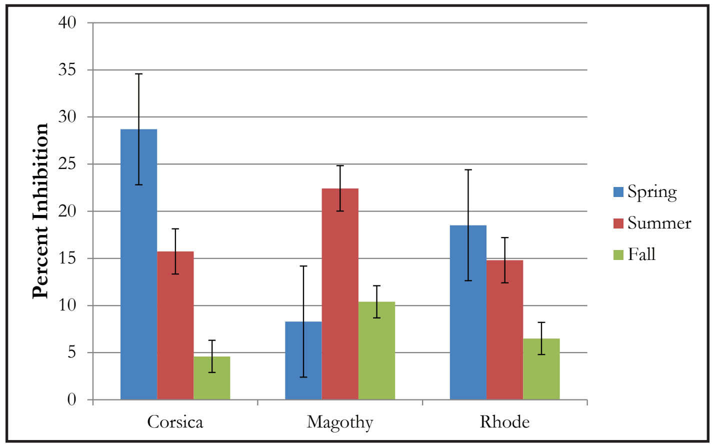


Figure LRF10. There were changes in acetylcholinesterase activity in mummichogs both seasonally and annually.

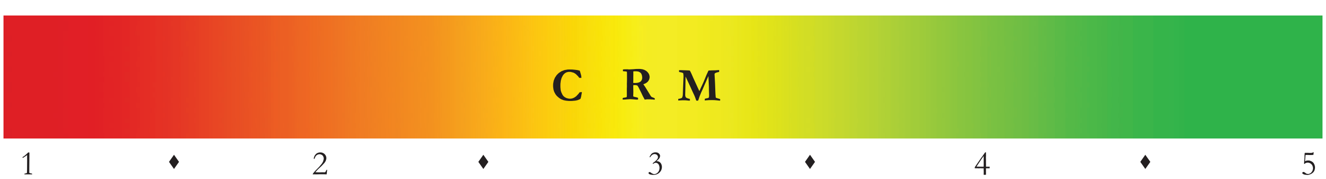
Contaminant Exposure Summary

What we measured: Acetylcholinesterase activity was determined from brain homogenates of mummichogs according to laboratory protocols, and acetylcholinesterase inhibition was used to develop an index of contaminant exposure. Estradiol and testosterone levels were not used in the index because they were not measured during all years of the study.

How we assessed: Spring and summer acetylcholinesterase activity was scaled from 0-5 as in other indices in this chapter with 1 representing greater inhibition (bottom 25% of values), and 5 the top 25% (less inhibition). Values from each river were compared to the other two to determine a relative index.

Enzyme Activity (percentiles)	< 25th (more inhibition)	50th	>75th (less inhibition)
Index Score	1	3	5

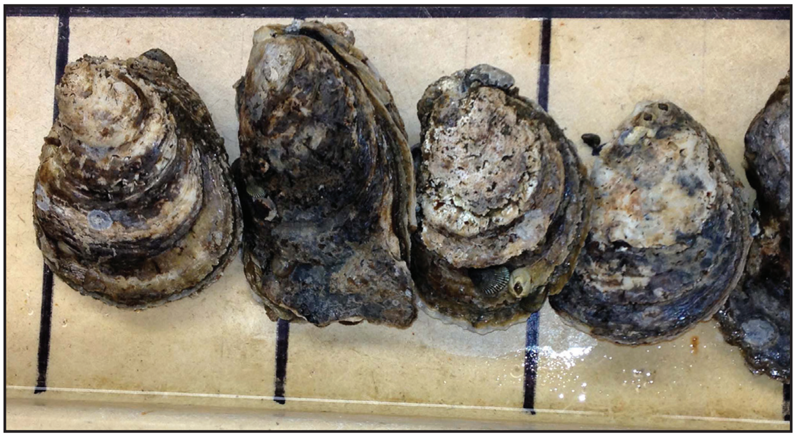
River Assessments:

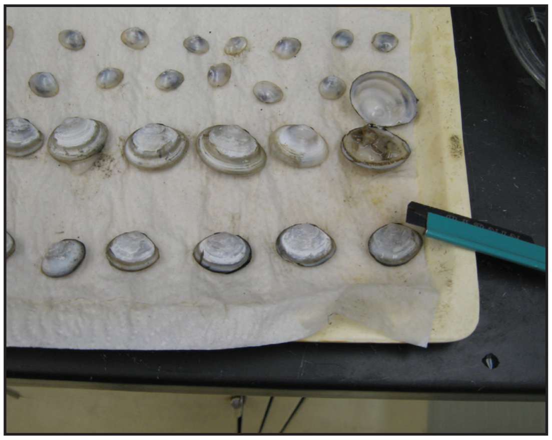


Shellfish

Shellfish, like fish, are effective indicators of environmental stress and have measurable responses to changes in land use. In Chesapeake Bay, shellfish such as the Eastern oyster, *Crassostrea virginica*, the Baltic clam, *Macoma balthica*, and the blue crab, *Callinectes sapidus,* are widely distributed, adapt easily to change and survive in a wide range of habitats. In this chapter, the utility of shellfish as bioindicators in estuarine systems is presented and the differential response from multiple levels of biological organization among watersheds noted.

Bivalve Molluscs





Oysters and clams play an important role in a balanced ecosystem by filtering water, providing habitat for fish species, and being a food source for crustaceans, fish, and birds.

Bivalve molluscs occupy an integral position in the food chain in Chesapeake Bay as key components in the diet of crustaceans, fish and birds. Molluscs are often used to monitor pathogen and pollution levels in aquatic ecosystems because they are filter-feeders and accumulate microbiological, chemical and biological contaminants from the water. Physiological responses to changes in the environment can also be measured, thereby facilitating the establishment of relationships between the concentration of chemicals in water, sediment and tissues, and associated biological effects. In this study, indices for health conditions in selected molluscs were used to examine if land use practices influence bivalve health.

Dredging for shellfish from the stern of the *R/V Laidly.*

Eastern Oyster *(Crassostrea virginica)*

Oysters, like other bivalves, are effective sentinel organisms for monitoring the status and trends of ecosystem health. Unfortunately, oyster abundance has declined significantly in Chesapeake Bay during the last 100 years, mostly due to mortality from disease, over harvesting, and habitat degradation. Harvest statistics show an average harvest of 25,413,346 pounds of oysters valued at $5.9M during the period of 1929 to 1960 [43]. This is prior to documented diseases impacts on oysters in Chesapeake Bay. These values declined to an average of 4,265,349 pounds harvested during the period 1982-2008. However, the average value is listed at $10M. The lowest harvest of record was in 2004 when only 87,233 pounds were harvested at a value of $377,128 [43]. During the last three decades, Maryland and Virginia economies have lost over $4 billion because of the decline in oyster harvesting and related industries [44].

During this study period, the few remaining oyster bars in the Rhode River were inaccessible due to reduced populations and to a lesser degree lease agreements held by commercial watermen, and the Corsica and Magothy each had only one oyster bar accessible for sampling. Therefore data was obtained from Magothy and Corsica Rivers only and were compared to one another and to the average through Maryland portions of Chesapeake Bay based on Maryland Department of Natural Resources data.

Oyster samples were collected by towing an oyster dredge on publically accessible oyster bars in the fall of 2007-2009 for this study. The overall health of oysters from the Magothy and Corsica was assessed to obtain baseline information for each river and to determine whether condition or parasite level would indicate effect of land use on health of oysters and their communities.

The Eastern oyster is an important resource in the Chesapeake, both ecologically and economically.

Oyster processing house, Rock Point, Maryland, circa 1930.

During the last three decades, Maryland and Virginia economies have lost over $4 billion because of the decline in oyster harvesting and related industries.

Condition

Condition is a reflection of general health which may be affected by changes in temperature, salinity, growth, reproductive stage and other stressors. The relative health of oysters can be estimated by opening its shell and visually ranking the physiological condition of the body on a scale of watery (poor) to fat (good) (Figure LRO1). A fat oyster has a creamy appearance and the body tissue is firm and retains its shape when lifted from the shell with a probe. On the contrary, a watery oyster is translucent and the body has no rigidity and is extremely flaccid when lifted with a probe.

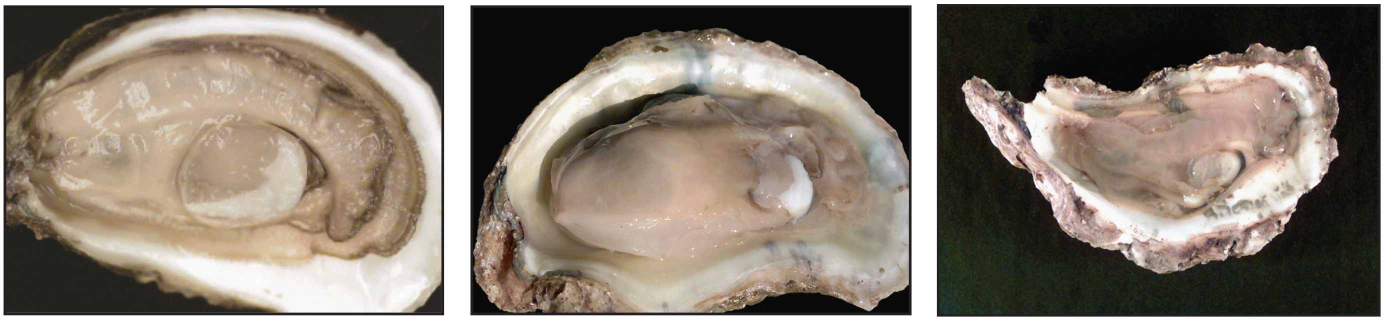


Figure LRO1. shows a fat (best condition = 9) oyster on far left, medium (=4) oyster in center, and a watery (poorest condition = 1) oyster on the right. Note the firm, creamy appearance of the fat oyster and the flaccid, translucent appearance of the watery specimen.

In this study, oysters in the Magothy had a higher condition rating than those in the Corsica, with an average condition of 6.6 between a medium and fat whereas oysters from the Corsica River were ranked as 5.1 or medium (Figure LRO2).

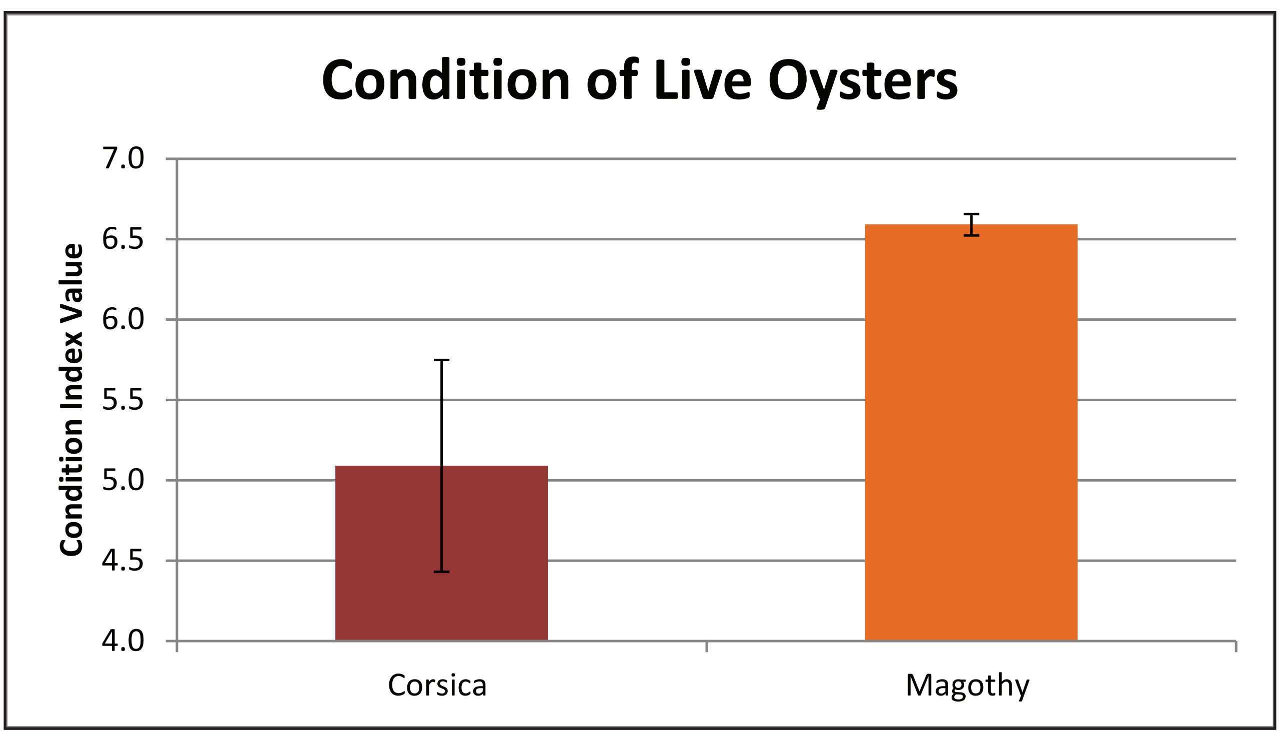


Figure LRO2. Average oyster condition by river.

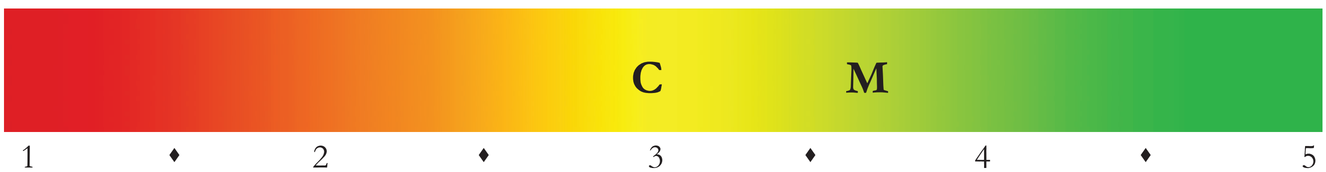
Condition Summary

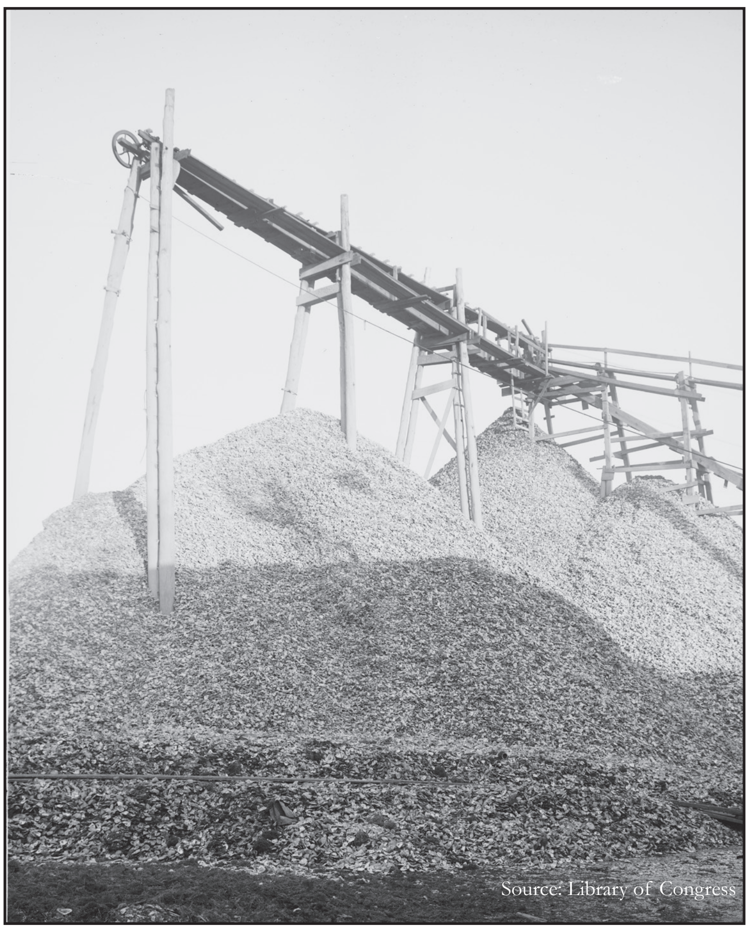
What we measured: Samples were collected by towing an oyster dredge the length of a bar. Multiple tows were often needed to collect a sample of 30 oysters from a single bar. Within 24 hours of collection, the oysters were opened by slicing through the adductor muscle with a scapel in order to view the condition of body [45].

How we assessed: Each oyster's physiological condition was visually assessed from 1 watery minus (poor) to fat plus (good). An index for condition was developed ranging from 1 (poor) to 5 (good) to correlate with the 1 to 9 or watery to fat condition assessment.

Condition Rating	1 (watery)	5 (medium)	9 (fat)
Index Score	1	3	5

River Assessments:





A mountain of oysters produced by shucking houses, circa 1910.

Parasite Prevalence- *Perkinsus* spp.

Perkinsus organisms are a group of protistan (single-celled) parasites associated with mortalities of shellfish worldwide, including bivalve molluscs. *Perkinsus marinus* is recognized as one of the most common, and devastating, parasites affecting the Eastern oyster in the Chesapeake Bay.

Although *P. marinus* survives both low temperatures and low salinities, its proliferation is high in the broad range of temperatures (15° to 35° C) and salinities (10 to 30 ppt) typical of Chesapeake Bay waters [46]. Over several years of drought during the 1980's, the range and distribution of *P. marinus* expanded into regions of the Chesapeake Bay where it had been previously rare or absent [47]. Since 1990, the parasite has been present in most Maryland oyster populations. Heavily infected oysters have clear, watery tissues instead of firm, creamy tissues of a healthy oyster and are emaciated, showing reduced growth and reproduction [48].

In this study, the *Perkinsus* spp. parasites were observed in Eastern oysters from the Corsica and Magothy watersheds. Oysters from the Magothy had a 2.2% prevalence of *Perkinsus* spp. compared to 16.7% of oysters from the Corsica. This is considerably lower than the average prevalence in oysters surveyed in Maryland portions of Chesapeake Bay between 2007-2009 which was 61% [49-51].

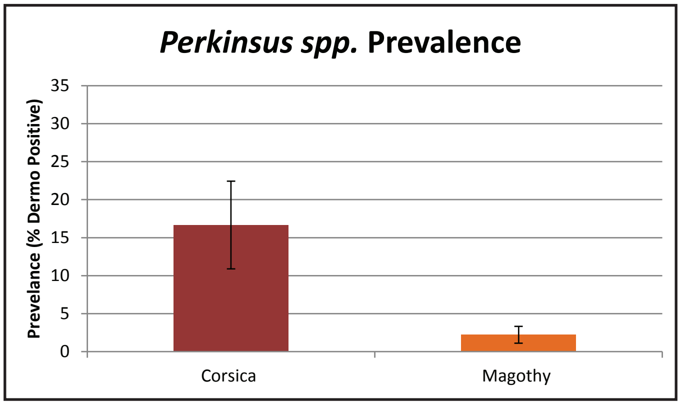


Figure LRO3. Oysters from the Magothy had a 2.2% prevalence of *Perkinsus* spp. compared to 16.7% of oysters from the Corsica.

Parasite Prevalence Summary

What we measured: The presence of *Perkinsus* spp. in oysters was determined by incubating pieces of rectal tissue in Ray's Fluid Thioglycolate Medium, following procedure described by Ray [52]. This method is effective in discerning both light and heavy infections but does not distinguish among species of *Perkinsus* which can be accomplished using molecular techniques. In this chapter, data reported refers to the parasite genus, e.g. *Perkinsus* spp. Prevalence was determined by calculating the ratio of infected oysters in a sample to the number of oysters examined.

How we assessed: A relative index for parasite prevalence was developed ranging from 1 (high) to 5 (absent) to correlate with average prevalence of the condition. Prevalence of oysters infected by the parasite in each river was compared to each other.

Parasite Prevalence (%)	51-100	41-50	31-40	21-30	0-20
Index Score	1	2	3	4	5

River Assessments:

Note that the average prevalence for *P. marinus* in Maryland Chesapeake Bay oysters for 2007-2009 is shown as "CB" on the index above [49-51].

Infection Intensity- *Perkinsus* spp.

Average infection intensity of *Perkinsus* in infected oysters from the Magothy was 0.7 on a scale from 0 to 7. This is much lower than the average intensity of infection in oysters from the Maryland portion of Chesapeake Bay during the same study period which was 2.03 [49-51]. The average infection intensity in the Corsica was 3.5 while the average in the Magothy was less than 1.0 (Figure LRO4). An intensity level of 5 or higher is considered to be lethal to an affected oyster [51]. No oysters from the Corsica were found to have an infection intensity greater than 4.

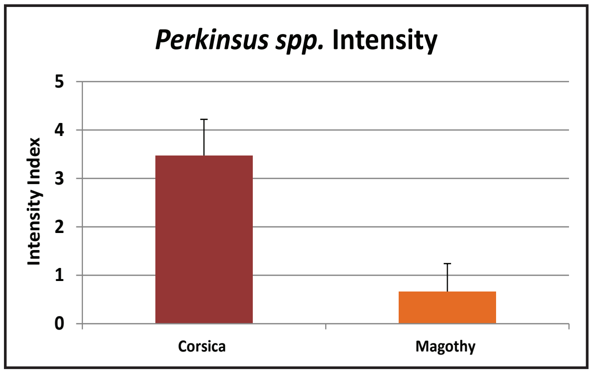
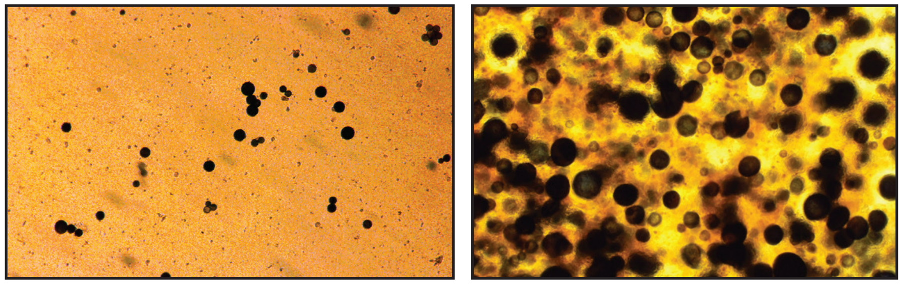


Figure LRO4. The average intensity of *Perkinsus* was greater in the Corsica River watershed than the Magothy.



Images show various intensities of *Perkinsus* infections. The left photo shows a light (stage 3) infection while the right shows a very heavy (stage 6) infection on a scale of 1-7.

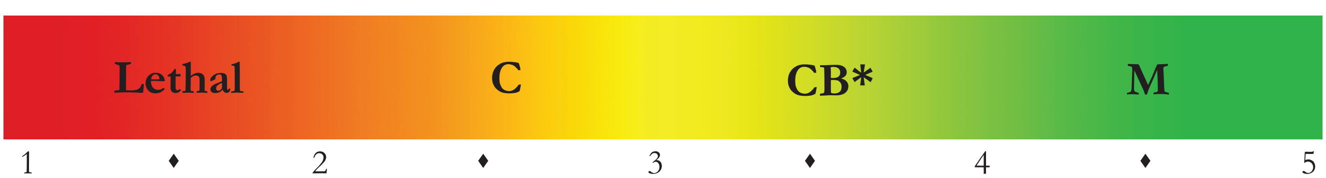
Infection Intensity Summary

What we measured: Pieces of rectal tissues were excised from oysters and incubated in Ray's Fluid Thioglycolate Medium following procedure described in [52]. Infection intensity was determined by ranking the *Perkinsus* spp. parasite burdens of individual oysters from 0 (absent) to 7 (heavy infection).

How we assessed: Mean sample infection intensity was determined by calculating the ratio of the sum of all categorical infection intensities (0-7) to the number of oysters in a sample. The infection intensity index, in contrast, for a sample was determined by calculating the ratio of the sum of individual infection intensities (1-7) to the number of infected oysters in a sample [49-51]. The infection intensity index of oysters infected with *Perkinsus* spp. was then adjusted to a scale of 1 to 5 relative to comparable rivers during the 3 years of the study.

Infection Intensity Score	7 (heavy infection)	4 (moderate infection)	1 (absent)
Index Score	1	3	5

River Assessments:



Note that the average prevalence for *Perkinsus* spp. in Maryland Chesapeake Bay oysters for 2007-2009 is shown as "CB" on the index above [49-51].

Baltic Clam *(Macoma balthica)*

The Baltic clam is a common species in these watersheds making it an effective sentinel species.

The Baltic clam (*Macoma balthica*) is a key bivalve mollusc living in soft-bottom communities of the middle and lower Chesapeake Bay. Since the Baltic clam is the predominant clam species found in the Corsica, Rhode, and Magothy rivers, this species was selected to measure abundance and health conditions in this study. Abundance, diversity, and prevalence of disease and parasites were compared with different land uses and indices of health developed.

Abundance and Diversity

A healthy ecosystem supports thriving benthic communities including clams and other bivalve molluscs. The broad distribution of Baltic clams in infaunal and intertidal regions of Chesapeake Bay indicates an ability to tolerate a range of environmental conditions. As benthic dwellers, Baltic clams may be able to acclimate to gradual changes in temperature and salinities.

The abundance of clams in three watersheds in this study was estimated using an indirect measure of abundance called Catch Per Unit Effort (CPUE). This measure is often the single most useful index for long term monitoring of a fishery and can be used as an index of stock abundance, where a relationship is assumed between that index and the stock size. In this study, bottom samples were collected at each site using a modified Smith McIntyre grab. The number of grabs required to collect 30 live Baltic clams at each site was recorded. CPUE was calculated by dividing the total catch by the number of grabs to calculate CPUE in each river. The diversity of species was estimated by recording the different species collected from each watershed during routine sampling.

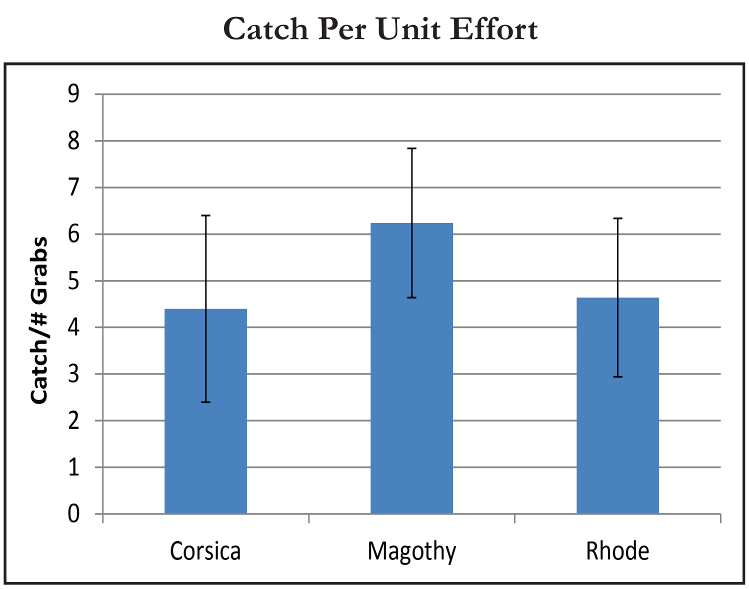


Figure LRC1. Average catch per unit effort for 2007-2009 in each river.

Total clam abundance varied among the three watersheds when data was summed for 2007-2009. Abundance of clams was highest in the Magothy (6.25 CPUE) and lower in Rhode and Corsica (4.64 and 4.4, respectively) (Figure LRC1). Abundance varied annually with highest abundances occurring in 2009 and lowest in 2008. Seasonal variation was observed with highest abundances occurring in the spring and lowest in late summer and early fall. High summer temperatures and salinities, as well as decreasing oxygen concentrations, may contribute to mortalities of molluscs in late summer and fall [53-55]. Abundances in each of the watersheds were generally lower in up-river sites than mid- and down-river sites. Abundance was lower in all three rivers than the average annual abundance of *M. balthica* in a 1979-1993 study in Rhode River [55].

Diversity of clam species in each of the three watersheds was similar with the Baltic clam most often being the dominant species and other *Macoma* species occasionally overlapping its niche. Occurrences of *Rangia cuneata* were infrequent in the Corsica and Rhode and rare in the Magothy due in part to a preference for less saline conditions. The low diversity observed in each river is characteristic of macroinvertebrate communities found in similar estuarine habitats in Chesapeake Bay [54].

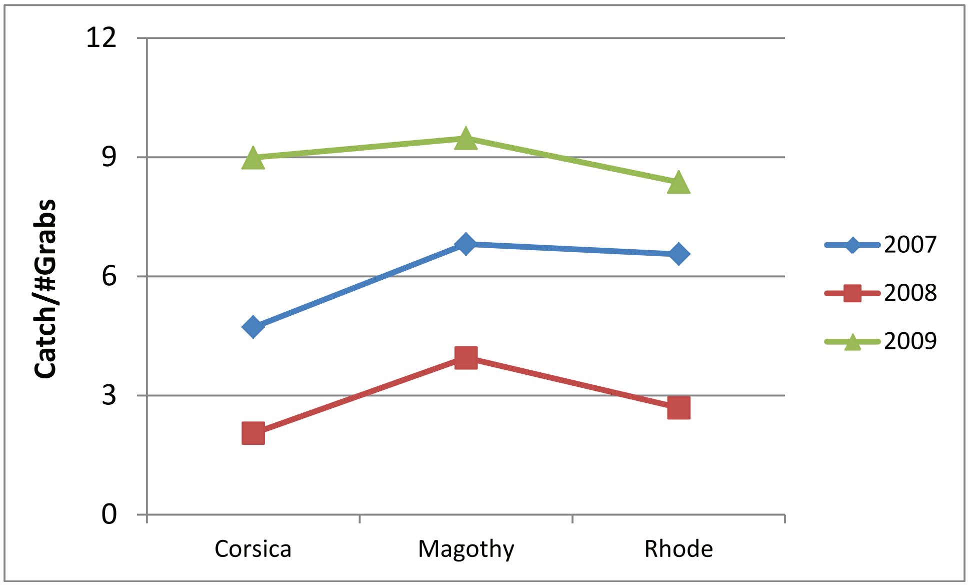


Figure LRC2. Annual catch per unit effort in each river.

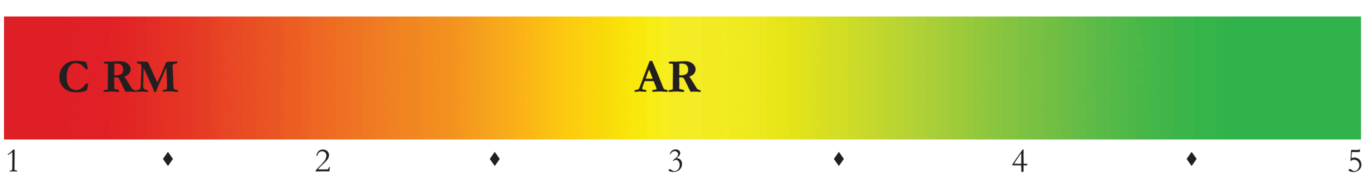
Clam Abundance and Diversity

What we measured: Relative abundance was estimated by counting the number of grabs required to catch 30 Baltic clams at each site using a modified Smith McIntyre grab. Diversity of clam species was assessed by recording the types and numbers of other clam species caught simultaneously in the grab.

How we assessed: We calculated the Catch Per Unit Effort (CPUE), the total catch divided by the total amount of effort used to harvest the catch.

CPUE (# clams)	0-74	75-149	150-224	225-299	> 300
Index Score	1	2	3	4	5

River Assessments:



AR denoted Average CPUE for clams collected in 1979-1993 in the Rhode River= 300 clams/m^2 [55]

Perkinsus Prevalence in Baltic Clams

Protozoan parasites of the genus *Perkinsus* are known to infect clams as well as oysters and other shellfish. Proliferation of *Perkinsus* spp. is often correlated with warm water temperatures during summer when pathogenicity and associated mortalities peak. High salinities in late summer and fall are associated with increased intensity and prevalence of *Perkinsus* spp. infections.

Baltic Clam

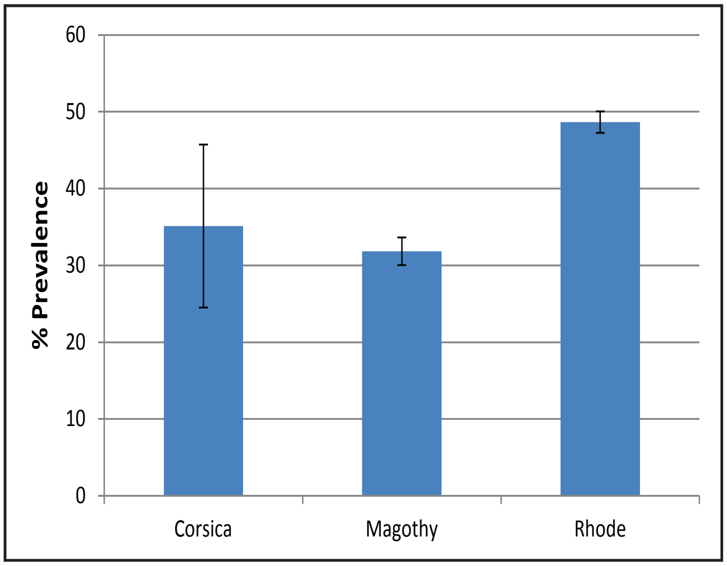
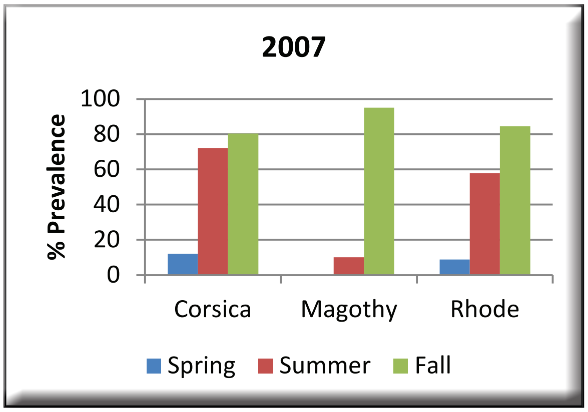
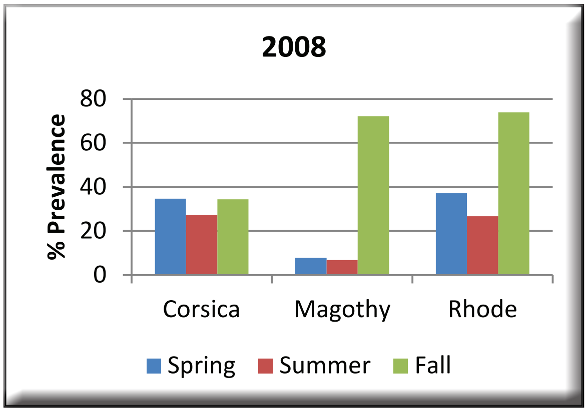


Figure LRC3. Average prevalence of *Perkinsus* spp. in Baltic clams 2007-2009 in each river.

Perkinsus spp. parasites were observed in Baltic clams from the three watersheds examined in this study. Prevalence of *Perkinsus* spp. parasites during 2007-2009 was highest in the Rhode River at 49% followed by 35 % in the Magothy and 32% in the Corsica (Figure LRC3).

Perkinsus spp. infections in Baltic clams were usually lowest in the spring, increased in prevalence during the summer, and reached peak prevalence in the fall with increasing temperatures and salinities (Figure LRC4). Highest prevalence was at the mouth of each river and lowest at the head, likely due to decreased salinity upriver.





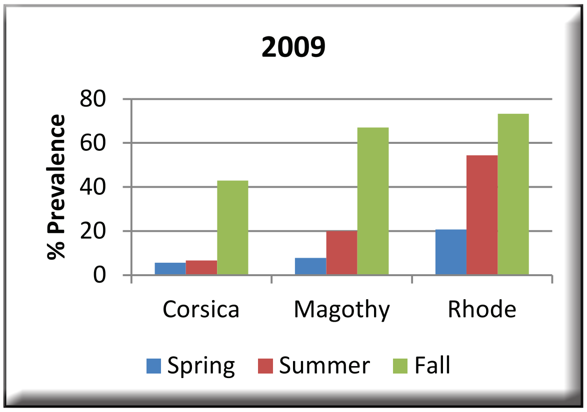


Fig. LRC4. Average seasonal prevalence of *Perkinsus* spp. in Baltic clams in each river for each year of sampling.

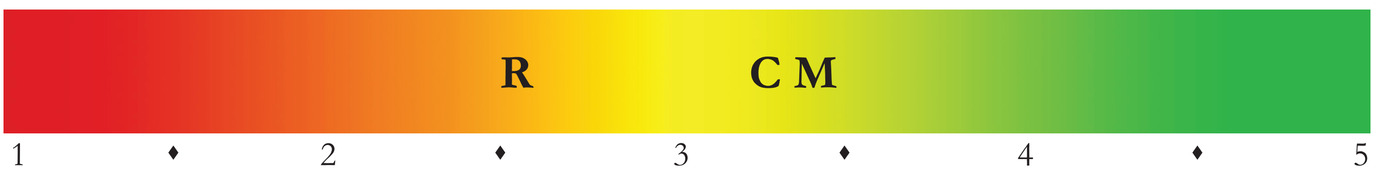
Perkinsus spp. Prevalence in Baltic Clams

What we measured: The presence of *Perkinsus* spp. in Baltic clams was determined by incubating pieces of gill and palp tissue from individual clams in Ray's Fluid Thioglycolate Medium (RFTM) following procedure described in [52]. A relative index for parasite prevalence was developed ranging from 1 (high) to 5 (absent) to correlate with average prevalence of the condition. Prevalence of clams infected by the parasite in each river was compared to each other.

How we assessed: Prevalence of *Perkinsus* spp. was determined by calculating the ratio of infected clams in a sample to the number of clams examined. Mean seasonal or annual prevalence is the ratio of the sum of sample percent prevalence to the number of samples.

Parasite Prevalence (%)	> 51	41-50	31-40	21-30	0-20
Index Score	1	2	3	4	5

River Assessments:






Infection Intensity in Baltic Clams

Average infection intensity of *Perkinsus* spp. in all live clams during 2007-2009 was highest in the Rhode River at 1.96, followed by the Corsica (1.25) and Magothy (1.09) on a scale of 0 to 7 (Figure LRC5). Infection intensities were highest in the Rhode for each year, though the Corsica had relatively high intensitites in 2007 (Figure LRC6). The mean sample infection intensity is calculated by taking the ratio of the sum of all categorical infection intensities (0-7) to the number of sample clams.

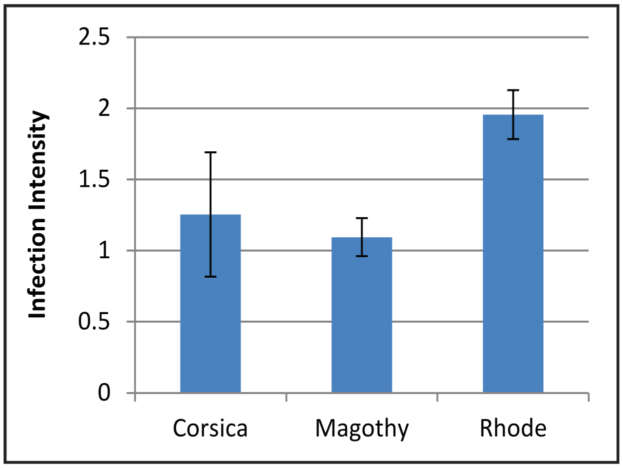


Figure LRC5. Average *Perkinsus* spp. infection intensity in Baltic clams in each river.

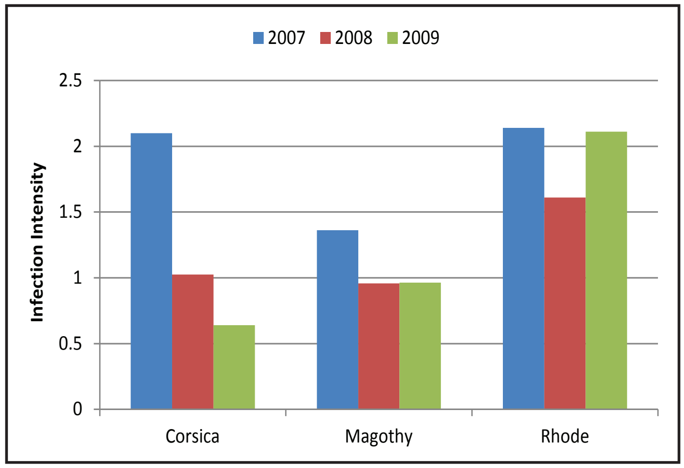
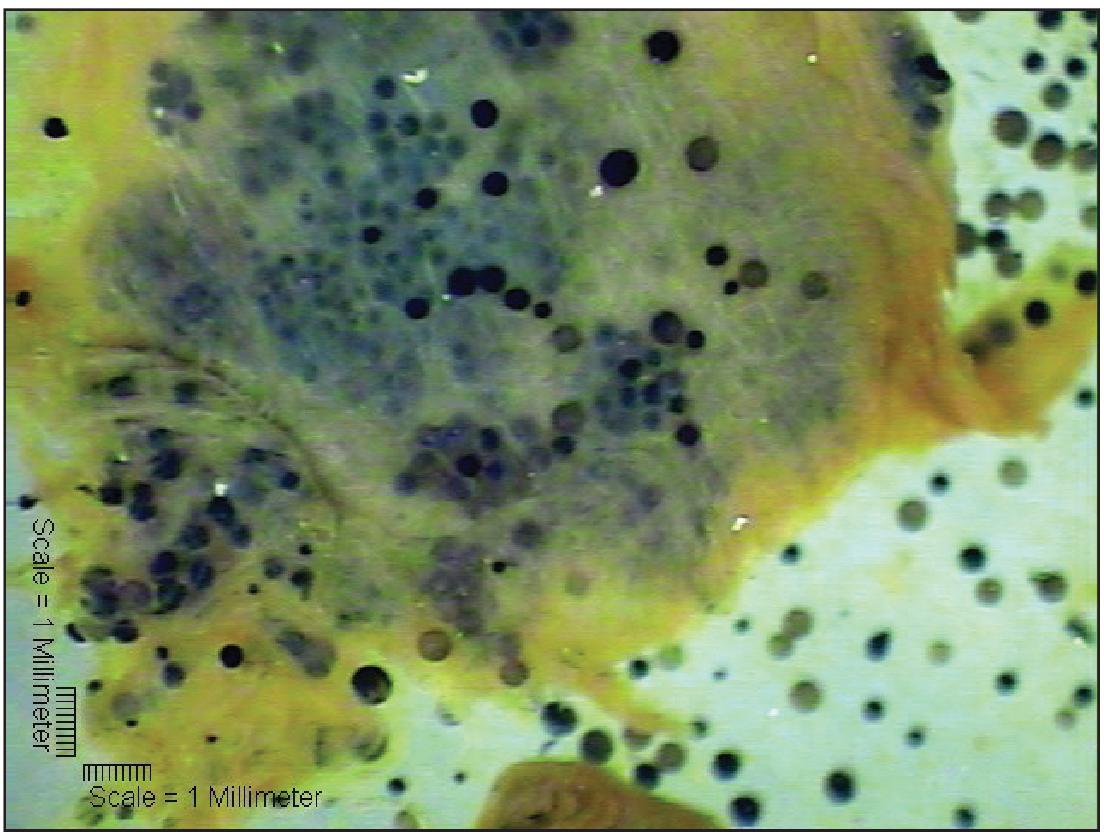


Figure LRC6. Annual *Perkinsus* spp. infection intensity in Baltic clams in each river.



***Perkinsus* spp. parasites appear as blue-black spheres when stained with Lugol's iodine after incubation in fluid thioglycolate medium.**

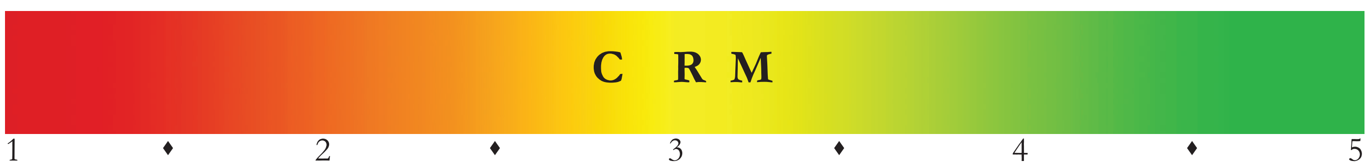
Infection Intensity Summary

What we measured: Pieces of gill and palp tissues were excised from clams and incubated in Ray's Fluid Thioglycolate Medium (RFTM) following procedure described in [52]. Infection intensity was determined by ranking the *Perkinsus* spp. parasite burdens of individual clams from 0 (absent) to 7 (heavy infection). Mean sample infection intensity was determined by calculating the ratio of the sum of all categorical infection intensities to the number of clams in the sample.

How we assessed: Mean sample infection intensity was determined by calculating the ratio of the sum of all categorical infection intensities (0-7) to the number of oysters in a sample. In contrast, the infection intensity index for a sample was determined by calculating the ratio of the sum of individual infection intensities to the number of infected clams in a sample [49-51]. The average infection intensity index of clams infected with *Perkinsus* spp. was then adjusted to a scale of 1 to 5 relative to comparable rivers during the 3 years of the study.

Infection Intensity Score	7 (heavy infection)	4 (moderate infection)	1 (absent)
Index Score	1	3	5

River Assessments:

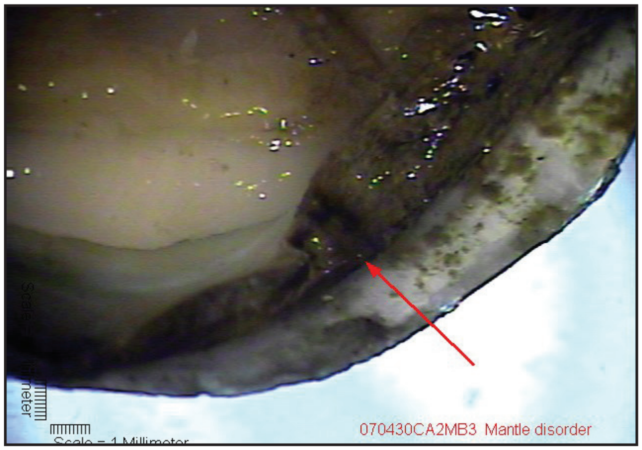





Conchiolin Deposition

Bivalve molluscs may launch a non-specific host response to pathogens, physical irritants, or other stressors by depositing brown organic material along the edge of their shell and mantle. The deposition of conchiolin has been associated with bacteria, fungi, parasites, and sediment in several bivalve molluscs [55]. Conchiolin deposits were observed in Baltic clams from three watersheds in this study.

Baltic clams from the Corsica (agriculture) watershed had the highest prevalence of conchiolin deposits, followed by the Rhode (forested), and the lowest in the Magothy (developed) (Figure LRC7). Average annual prevalence varied by year with the condition being most prevalent in 2007 with 18% of clams from Corsica and 11% of clams in Rhode affected and only rarely occurrences in Magothy clams (Figure LRC8). Prevalence reduced each subsequent year in the Corsica and Rhode rivers but increased in the Magothy in 2008. Peak prevalences for each sampling event reached 22% in the Rhode River in summer 2007, 14% in the Corsica in spring 2008, and 6% in the Magothy in spring 2008.



Conchioloin deposition is a non-specific host response to pathogens or physical irritants.

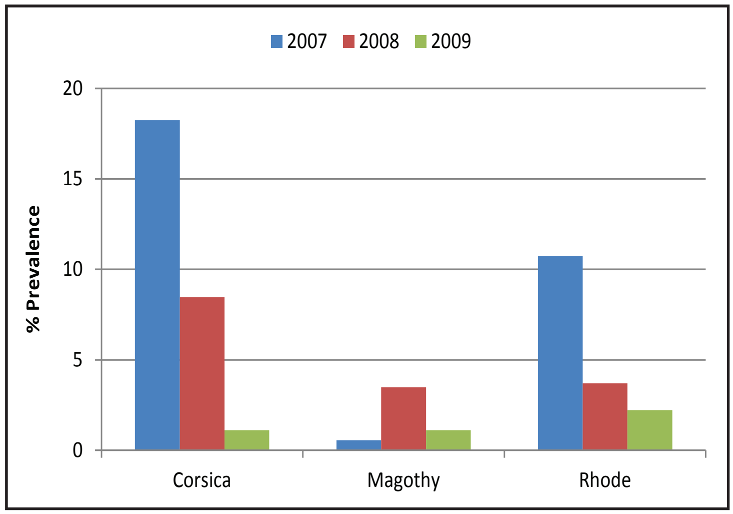


Figure LRC8. Annual prevalence of conchiolin deposits in *Macoma balthica* in each watershed.

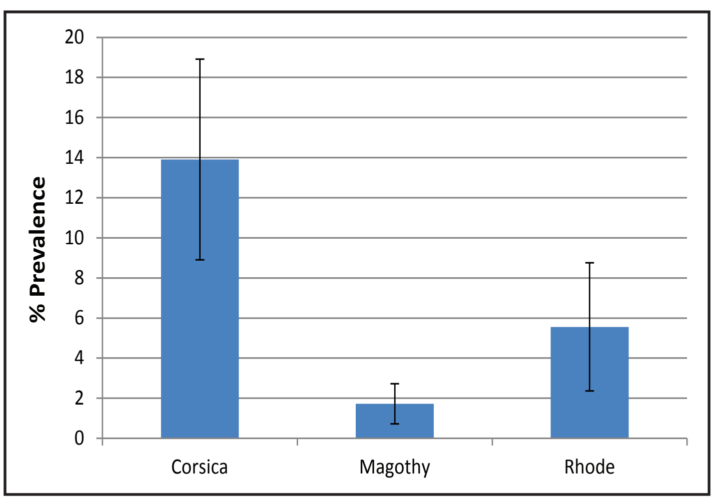


Figure LRC7. Average prevalence of conchiolion deposits in *Macoma balthica* for 2007-2009 in each watershed.

The deposition of conchiolin has been associated with bacteria, fungi, parasites, and sediment in several bivalve molluscs [59].

Conchiolin Deposition Summary

What we measured: Approximately 90 clams per river per season were visually examined for the presence of conchiolin deposits. Prevalence was calculated by dividing the number of clams affected by the number of clams in a sample.

How we assessed: A relative index for conchiolin deposition was developed ranging from 1 (absent) to 5 (present) to correlate with average prevalence of the condition. Prevalence in each river was compared to one another.

Parasite Prevalence (%)	> 51	41-50	31-40	21-30	0-20
Index Score	1	2	3	4	5

River Assessments:




Blue Crab *Callinectes sapidus*

The blue crab, *Callinectes sapidus*, is a key epibenthic component of the Chesapeake Bay food web and influences many characteristics of the Bay's ecosystem. It preys on a wide range of invertebrates and is a major food source for many fish species [56]. Blue crabs consume many bivalve species and may alter soft-bottom communities in the process. Various parameters that can be measured in blue crabs, including pathology, parasites, physiology, and shell condition can be indicators of environmental change or anthropogenic influences.

Disease such as tissue or host response, including inflammation, nodules or necrosis, can be an indication of stress in crabs. Additionally, parasites such as viruses, microsporidians, ciliates and trematodes may become more prevalent in crabs inhabiting stressed environments. The prevalence of host response and parasites in blue crabs from three rivers with distinctive land use were documented using histology. An index of host response and parasitology in the blue crab *Callinectes sapidus* was established to compare crab health based on divergent land use.

Disease or pathology is the impairment of normal functioning of an organism's body. Inflammation, nodule formation and tissue necrosis is an early host response to stress, the presence of a foreign body, or parasites. It is difficult to determine the cause of host response in many cases since the agent responsible may not be present in sufficient numbers to be observed histologically; or it may be due to a response to a stressor. In crabs, parasites often elicit a host response and if present in sufficient numbers, may be observed histologically.

Blue Crab Host Response

Host responses encountered in this study included inflammation, nodule formation and tissue necrosis. Inflammation is a relatively minor host response but prevalence far exceeded other forms of host response. Prevalence of host response was higher in crabs from the Corsica than either the Magothy or Rhode. Prevalence was higher in all three rivers than the average in 533 crabs assayed from throughout Chesapeake Bay based on data from an earlier unpublished study from 2002 and 2005-2007 [57] (Figure LRCR1).

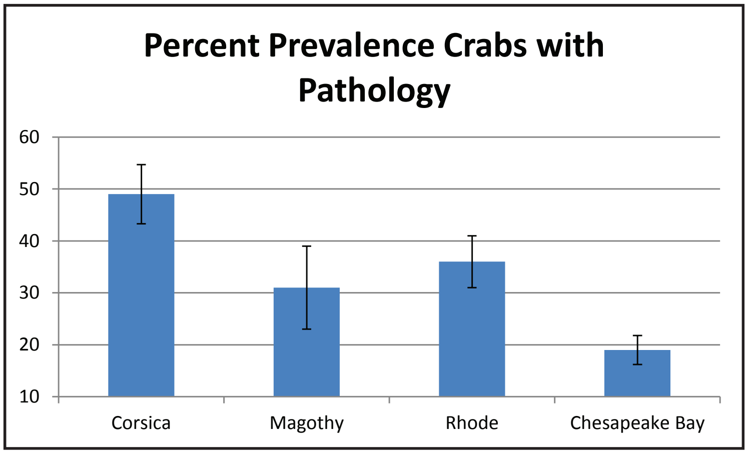


Figure LRCR1. Corsica River watershed showed higher prevalence of pathology in blue crabs.

Living Resources Crabs

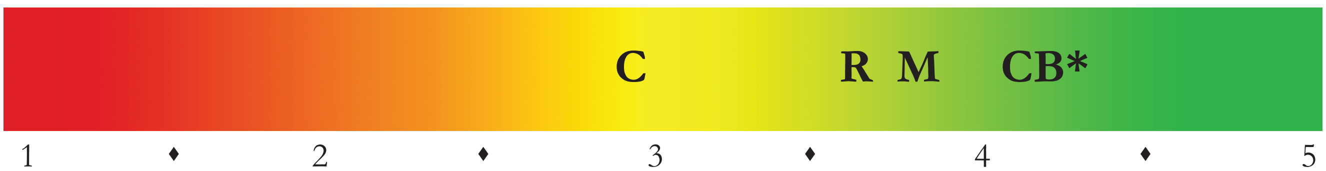
Host Response Summary

What we measured: Thirty or more crabs from each watershed were collected using a baited trot line. Crabs were chilled to reduce mobility and within a few hours, tissues were dissected and preserved for routine histopathological examination using light microscopy

How we assessed: To characterize the extent of host response, an index, based on the prevalence of crabs with any host response in tissues was developed.

River Assessments:

Prevalence of Host Response	100%	75%	50%	25%	0%
Index Score	1	2	3	4	5



Note* - Prevalence of host response in crabs collected throughout Chesapeake Bay. Crabs from Corsica ranked worse than crabs from either Magothy or Rhode.

Blue Crab Parasitology

Parasites are a normal component of ecosystems and their presence alone does not necessarily indicate degraded condition. Various parasites encountered in this study included larval worms (trematode metacercariae), microsporidans, gregarines, and viruses which infected internal tissues and symbiotic ciliates infesting gill structures. Prevalence of gill ciliates (Figure LRCR2) far outweighed other pathogens. Presence or absence on gills may be an indicator of static or current habitat quality since ciliates and other fauna are removed with "old" gill cuticle when crabs shed. Mature and terminal molt crabs no longer have this ability. Ciliates feed on bacteria and higher prevalence of ciliates on crab gills may indicate higher nutrient levels in the water, thus lower water quality. Ciliate infestation on crab gills may be detrimental if high densities inhibit the ability to respire, this along with low oxygen solubility may result in anoxia.

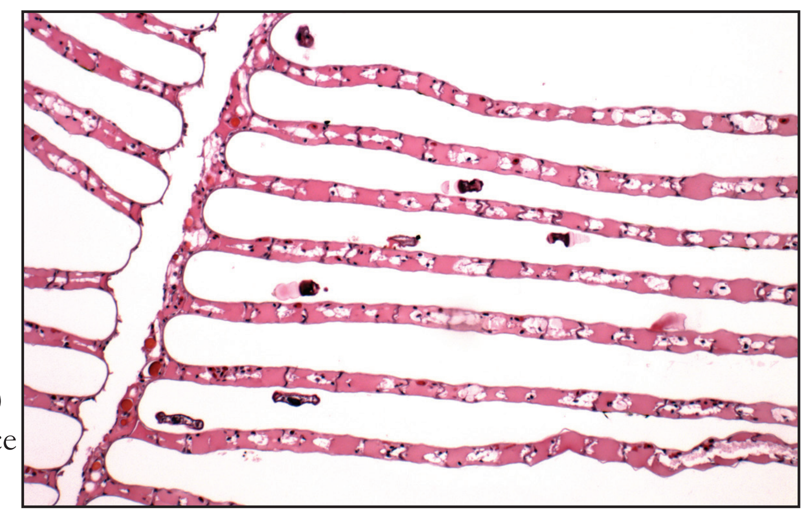


Figure LRCR2. Ciliates between gill lamellae of blue crab.

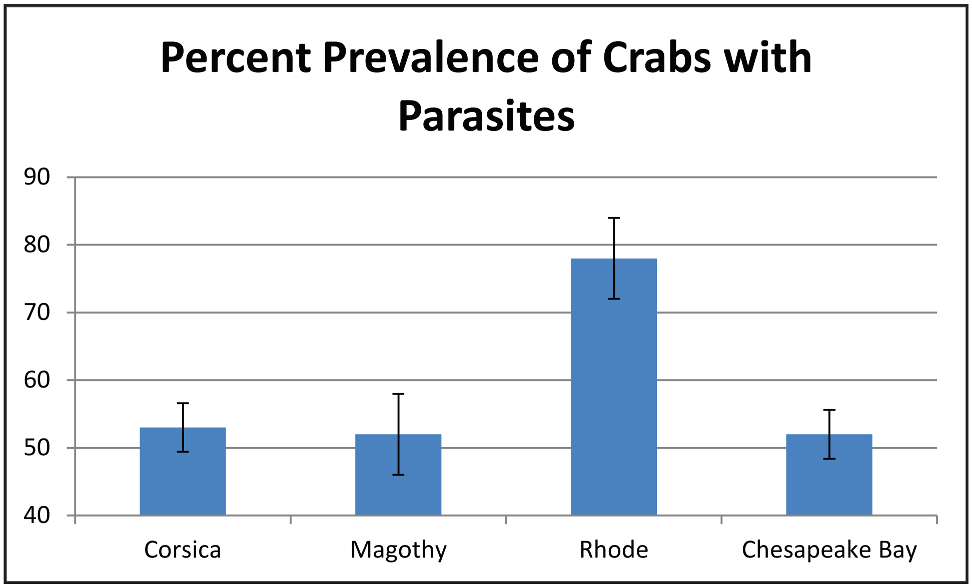


Figure LRCR3. Prevalence of all parasites in crabs was higher in the Rhode River than either the Corsica or Magothy Rivers.

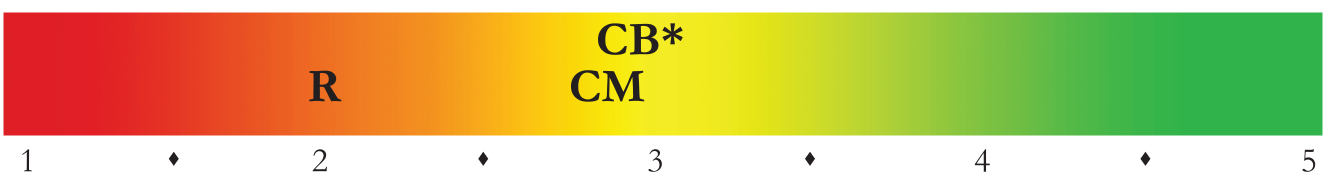
Crab Parasitology Summary

What we measured: Thirty or more crabs from each watershed were collected in 2007, 2008 and 2009 using a baited trot line. Crabs were chilled to reduce mobility and within a few hours, tissues were dissected and preserved for routine histopathological examination using light microscopy

How we assessed: To characterize the extent of parasitology, an index, based on the prevalence of parasites was developed. The index ranges from 1 to 5 with higher scores being better.

Prevalence of Parasites	100%	75%	50%	25%	0%
Index Score	1	2	3	4	5

River Assessments:



Rhode River had higher prevalence of crabs with parasites than either Corsica or Magothy Rivers or the Chesapeake Bay (CB) average (Figure LRCR3).

Note* - Prevalence of crabs with parasites in Chesapeake Bay averaged between 2 and 3 on the index based on data collected from an earlier unpublished study of 533 crabs collected throughout Chesapeake Bay from 2002 and 2005-2007; indicated on graph as CB* [57].

What factors separated the three systems?

Water quality characteristics, benthic condition and organismal response differed among the watersheds in this study (Figure Syn1). The agriculturally dominated Corsica River had the poorest water quality in terms of nutrient levels and chlorophyll, but exhibited generally good oxygen concentrations and benthic condition. While the Corsica was a eutrophic system, its shallow depth and strong tidal flushing most likely prevent it from becoming hypoxic. In the Corsica, fish, oysters, and crabs had reduced condition along with elevated disease prevalence and intensity. However, species diversity and abundance were good. This pattern is typical of eutrophic systems where abundant nutrients lead to high productivity at the cost of higher disease occurrence.

Corsica River photo courtesy of Ben Longstaff, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

Corsica, Magothy and Rhode River

Magothy River photo courtesy of Ben Longstaff, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

Water quality characteristics of the Rhode and Magothy were similar to each other with marginally better water quality than the Corsica. Oxygen concentrations were lowest in the Magothy due mainly to oxygen depletion in deeper waters of the upper reaches of the system in the peak of the summer.

This pattern of hypoxia in the Magothy River is likely a function of the depth of water and reduced flushing of this system. Benthic condition was poorest in the Magothy, scoring moderate to poor in sediment toxicity, contaminants, and benthic IBI. Metals such as zinc and mercury and PAH's were routinely found in Magothy sediment samples, which is characteristic of developed watersheds. Organismal responses were moderate to healthy in both systems with the noted exception of elevated parasite prevalence in blue crabs in the Rhode River.

Rhode River photo by NOAA staff

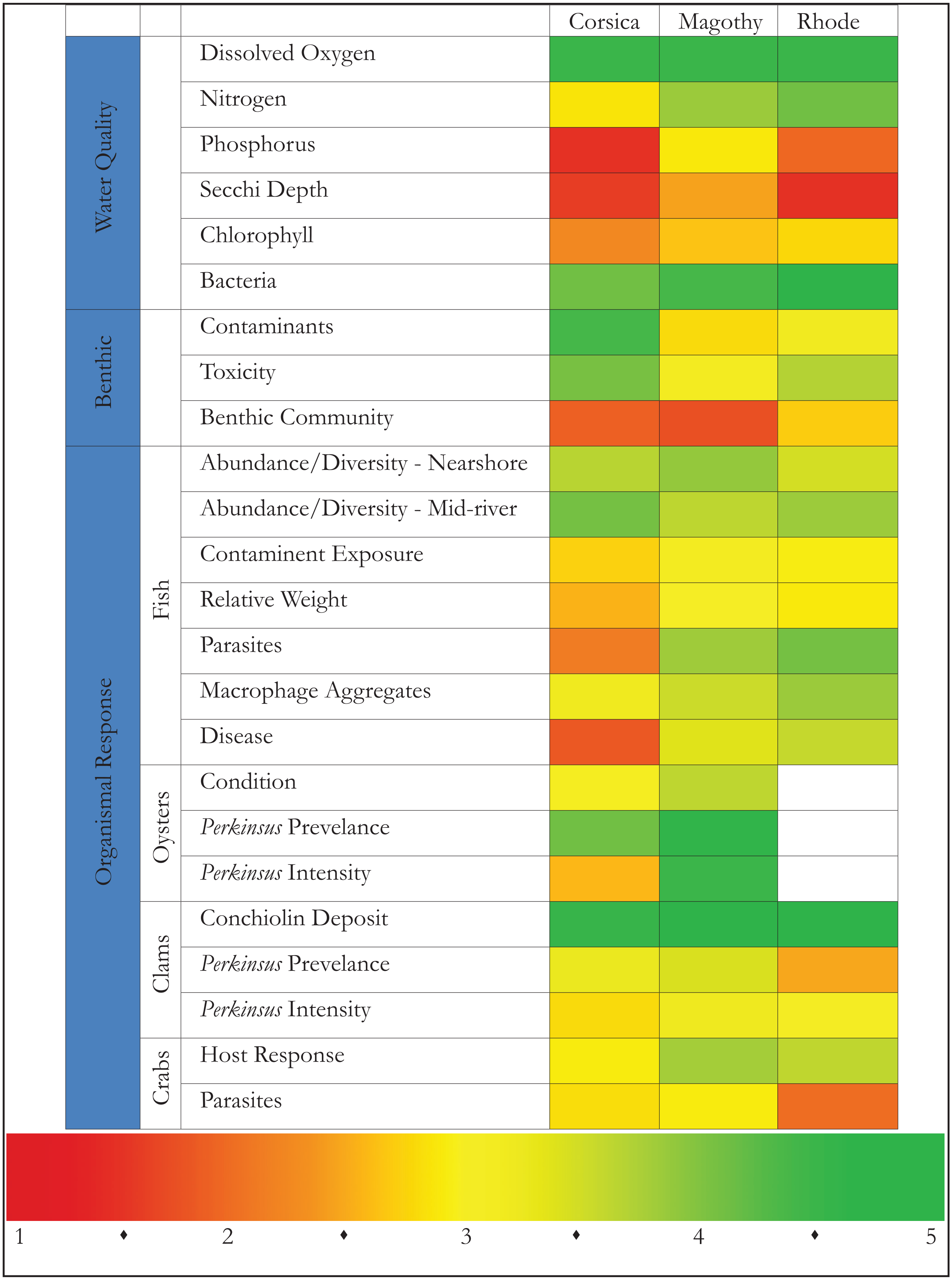


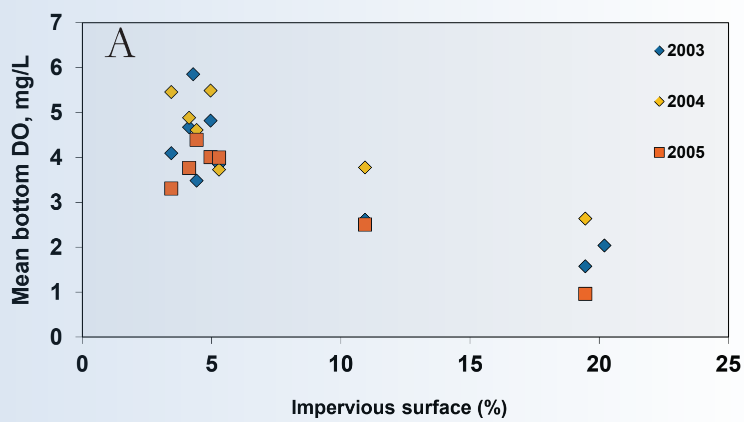
Figure Syn1. Scores for each metric assessed. Blanks indicate places where insufficient samples existed for an accurate assessment.

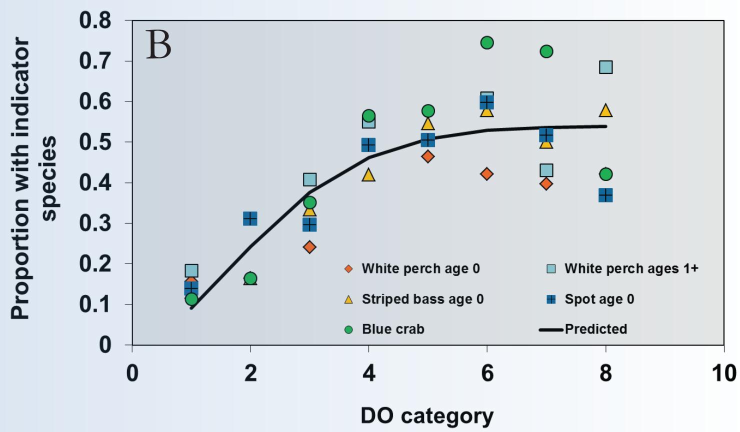
What are the Implications?

Estuaries face a complex mixture of land based influences, as a wide array of human impacts compromises their ecological integrity. These impacts will likely escalate as populations in coastal zones grow, unless there is effective management of these influences. Natural resource managers are exploring management strategies that directly address relationships between the resources and the stressors that impact them. For example, management of a single resource such as fish abundance requires information about the impact of stressors on fish growth, survival, and reproduction along with the traditional focus on fishing pressure. Similarly, management of a healthy ecosystem requires information about the complex, and often nonlinear, relationship between stressors (such as landuse activites) and natural resources, with the goal of achieving a resilient and productive environment.

Thresholds for Land Development

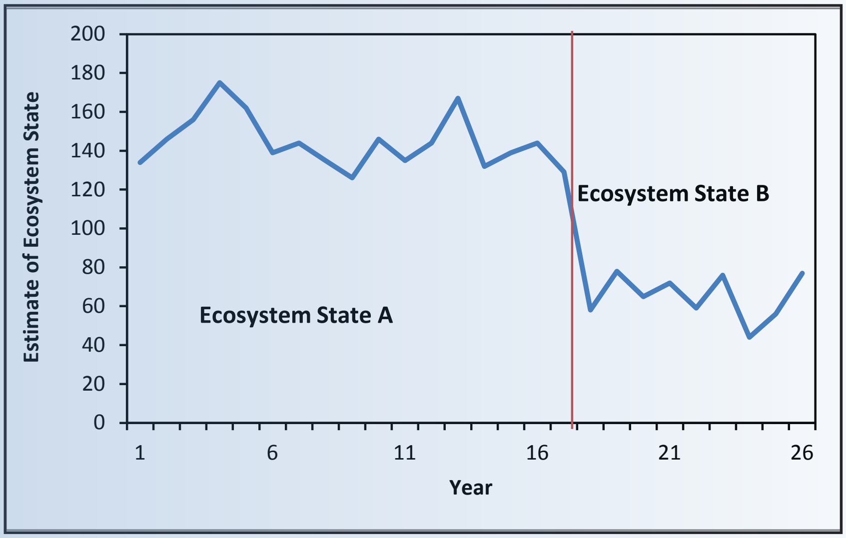
The Maryland Department of Natural Resources utilized multiyear surveys of Chesapeake Bay watersheds to determine the relationship between development and environmental health. The data demonstrate a relationship between impervious surface in the watershed (a metric for urban development), water quality, and the abundance of several fish species [58]. For example, as percent impervious surface increased to 10% and beyond, mean bottom dissolved oxygen was significantly reduced in Chesapeake tributaries sampled during the summer (A). Those waters with reduced oxygen also exhibit a reduction in the presence of white perch, striped bass, blue crab, and spot (B). These species comprise several of the most popular sport and commercial fisheries in the region. The results have led DNR scientists to propose a development threshold of 10% as a major component of successful fisheries management.





Most of the organisms in these rivers face multiple stressors and the synergistic impacts of these stressors remain largely unknown. However, the mitigation of some individual stressors may share common approaches. For example, high nutrients and some contaminants can be carried to these rivers via runoff. A potential management strategy may include reducing chemical use or preventing them from entering the waterway. The latter strategy may be partially achieved by reducing the amount of impervious surface and by improving stormwater management. Other stressors may require direct outreach to local stakeholders. For example, contamination by zinc and fuel byproducts in the Magothy likely come from boating activities. Addressing this issue will likely require direct communication with boaters and other user groups within the watershed. While it is essential to establish sound, comprehensive frameworks for coastal management policies at regional, national, and global levels, local action remains an integral long-term component in resolving anthropogenic problems [59].

Resilience Thresholds



Ecosystem resilience is the ability to withstand or recover from disturbances without disintegrating into a state that differs from what previously existed. The illustration above shows a system that is changed to a less favorable state when stresses exceed the ability of the system to recover from that stress, a time indicated by red line. A resilient ecosystem can withstand environmental stresses and repair itself to a healthy state when necessary. A system with reduced resilience is more susceptible to small disturbances that may negatively impact the abundance, distribution, and health of aquatic organisms.

Some stress in estuaries is expected. Estuaries are dynamic by nature and thus have evolved a degree of resiliency to anthropogenic and natural alterations to the environment. Many of the variables measured in this study changed seasonally and annually as fluctuations in temperature and rainfall occurred. However, other variables differed significantly between systems and likely relate to the different types of human activities in these rivers. The degradation of the environment caused by these stressors may lead to less resilient conditions.

The science challenge, going forward, is in identifying and communicating where systems fall relative to some threshold or tipping point. Many of the natural resources of the Chesapeake Bay are reduced in number or health from historic conditions. Many human activities have been involved in these changes. The current effort to restore the Bay faces many challenges, not the least of which is assessing the amount of resilience remaining in the system and whether some stresses have pushed resources to a point where restoration may be very hard, if not impossibl, to achieve. The management role is to be informed about these conditions; to understand the environmental, economic and societal implications of policy decisions; and to act on this knowledge to make regulations to manage the resources.

Promoting Ecological Resiliency

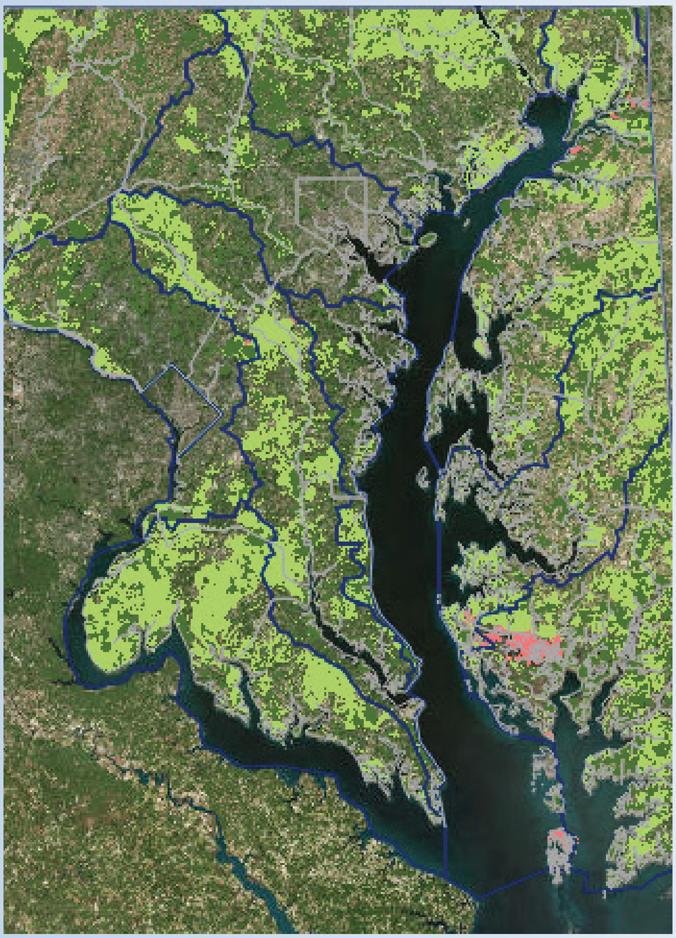


Photo courtesy of Maryland Department of Natural Resources.

It is important for us to recognize the natural resiliency inherent in the Chesapeake Bay. Wetlands, forests, and other natural scapes provide key buffering capacity against environmental perturbation. The State of Maryland has identified Targeted Ecological Areas (TEAs) around the state which are being used to protect ecologically important land that assists with the preservation of ecosystem health (http://www.greenprint.maryland.gov). The map shows areas currently protected from development (dark green) and areas targeted for protection (light green). TEA's are designated according to their ability to provide high quality habitat for both terrestrial and aquatic animal and plant species within each watershed. TEA's designated for protection are aquired through the Maryland Program Open Spaces. Maintaining portions of the Chesapeake Bay within their natural state of resiliency will assist with mitigating the impacts of development along less ecologically important or historically developed areas.

This effort largely achieved its goals in assessing the state of three watersheds with diverse land use in Chesapeake Bay through the application of a unique suite of indicators. It differs from traditional approaches in the weight placed on the response of living resources or the organisms that inhabit these watersheds impacted by varying land use. Many potential indicators have been evaluated and excluded during the course of this study in an effort to refine the approach. However, our work is only beginning in identifying consistent relationships between land use and ecosystem level responses and translating these to functional thresholds to meet management needs. Following this three year assessment, we continued sampling in these three watersheds and added three more. A second report will be published with results of the full six year survey.

EXAMPLES OF PREVIOUS STUDIES

The Atlantic Slope Consortium [60].

Goal: Identify indicators of coastal ecosystem condition that could be applied by managers.

Study Area: Entire Chesapeake Bay watershed; moderately-sized watersheds, such as the entire Choptank and entire Potomac River; small watersheds (14 digit HUC)

Findings: Relationships between several indicators were found. For example, the authors found that several fish and bird community indicators, as well as wetland condition, related to the amount of human development in the watershed and the proximity of the development to the water.

Differences to our study: Indicators were at various scales; not all targeted to particular watersheds. Data not all collected based on an a priori study design.

The Mid-Atlantic Integrated Assessment [61].

Goal: Provide condition assessment of eutrophication, sediment contamination, human impacts, and seafood contamination

Study Area: Entire Mid-Atlantic Region

Findings: Eutrophication and sediment contamination are widespread. More than half of the fish tissues contained enough contaminants to be of human health concern.

Appendix: Table of all the variables measured during this study and the years they were sampled.

Metric	2007	2008	2009
Benthic			
Benthic Contaminants	X		
Sediment Toxicity	X		
Benthic IBI	X		
Water Quality			
Physiochemical Data	X	X	X
Chlorophyll A	X	X	X
Nutrients	X	X	X
Microbial Community Composition	X	X	X
Pathogen Detection	X	X	X
Fecal Coliform Bacteria	X	X	X
Fish Bioindicators - White Perch			
Gross Pathology	X	X	X
Histopathology	X	X	X
Hemotology & Plasma Protein	X	X	X
Bacteriology	X	X	X
Transforming Growth Factor Beta	X	X	
RNA:DNA Ratio	X	X	X
Endocrine Disruption	X	X	X
Community Composition	X	X	X
Nutritional Condition	X	X	X
Fish Bioindicators - Mummichogs			
Gross Pathology	X	X	X
Acetylcholinesterase	X	X	X

Metric	2007	2008	2009
Oyster Bioindicators			
Community Assessment	X	X	X
Disease Prevalence	X	X	X
Disease Intensity	X	X	X
Clam Bioindicators			
Abundance	X	X	X
Histology/ Histocytology	X	X	X
Acetylcholinesterase	X	X	X
RNA:DNA Ratio	X	X	X
Crab Bioindicators			
Gross Pathology	X	X	X
Shell Disease	X	X	X
Histopathology	X	X	X
Gill Epibionts	X	X	X

Partners

We acknowledge partners that provided resources and support including the NOAA Chesapeake Bay Office, the Maryland Department of Natural Resources, the Maryland Department of Agriculture, the University of Maryland and the USGS Leetown Science Center.

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Dedication

We dedicate this document to the memory of Lewis M. "Skip" Collier, Captain of the COL Research Fleet. It is certain that Captain Skip's seamanship expertise, waterman's knowledge, determination and pride allowed this effort to succeed.

With fond memories of a heart and soul as expansive as the sea, we dedicate this document in deepest gratitude to Captain Skip.

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