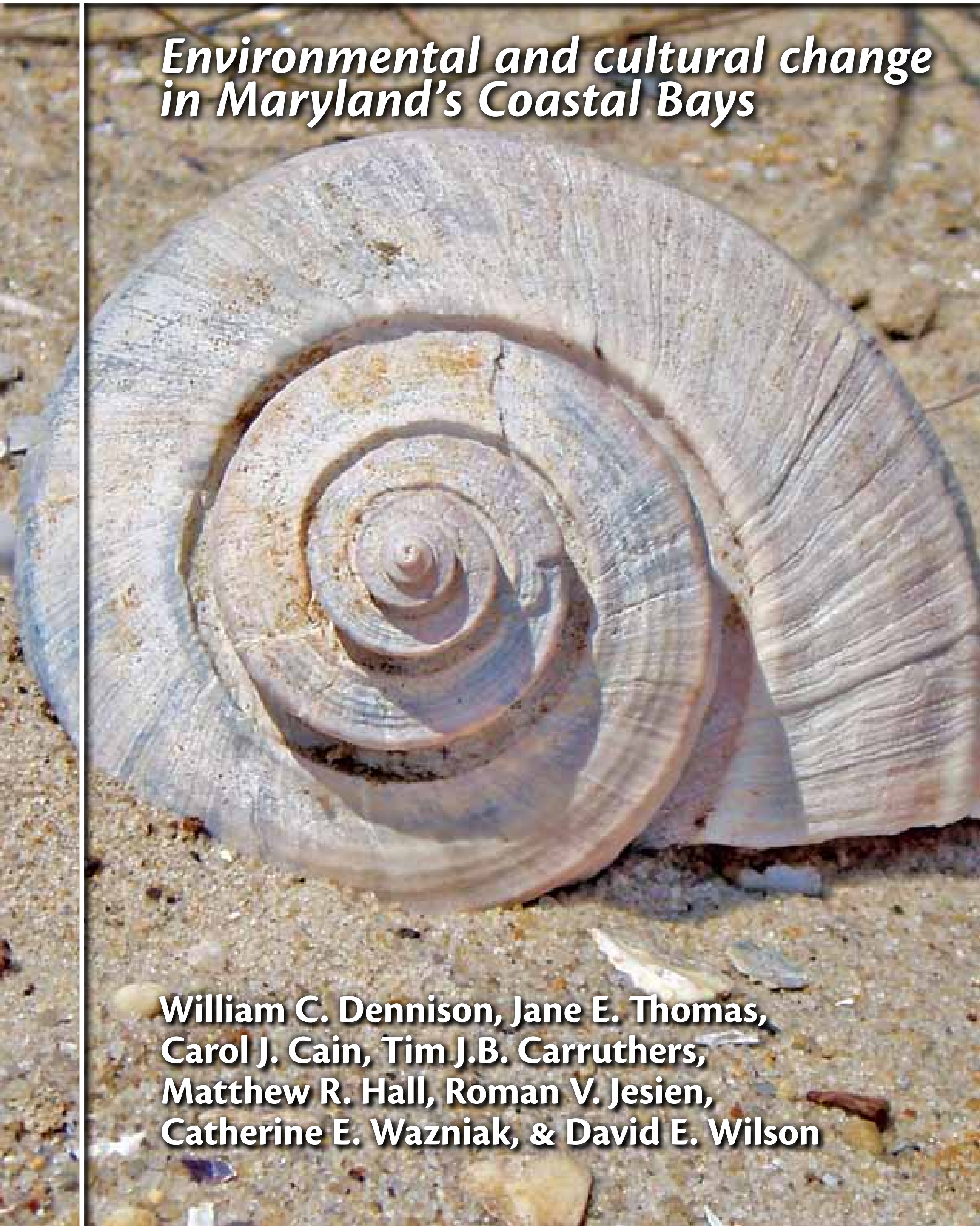
Shifting Sands

Environmental and cultural change in Maryland's Coastal Bays



William C. Dennison, Jane E. Thomas,
Carol J. Cain, Tim J.B. Carruthers,
Matthew R. Hall, Roman V. Jesien,
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The Coastal Bays locator map

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Shifting Sands: Environmental and cultural change in Maryland's Coastal Bays
W.C. Dennison, J.E. Thomas, C.J. Cain, T.J.B. Carruthers, M.R. Hall, R.V. Jesien,
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IAN
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IAN Press is committed to producing practical, user-centered communications that foster a better understanding of science and enable readers to pursue new opportunities in research, education, and environmental problem-solving. IAN Press is the publication division of the Integration and Application Network at the University of Maryland Center for Environmental Science (UMCES). Visit *www.ian.umces.edu* for information on our publications and access to downloadable PDFs of our reports, newsletters, posters, and presentations. Contact IAN Press at *ianpress@umces.edu*.

The Integration and Application Network (IAN) is a collection of scientists interested in solving, not just studying environmental problems. IAN seeks to inspire, manage, and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. IAN is an initiative of the University of Maryland Center for Environmental Science, but links with other academic institutions, resource management agencies, and non-governmental organizations.

Beginning as a small college laboratory and a state research and education agency, UMCES has developed into a multi-campus institution of Maryland's university system. UMCES continues its rich tradition of discovery, integration, application, and teaching at its three laboratories: Chesapeake Biological Laboratory (1925), Appalachian Laboratory (1962), and Horn Point Laboratory (1973), as well as Maryland Sea Grant in College Park and the Annapolis Synthesis Center in downtown Annapolis. The Integration and Application Network was established in 2002 to allow UMCES to apply the scientific knowledge of its faculty and staff to the environmental challenges we face today. The Integration and Application Network was established in 2002 to allow UMCES to apply the scientific knowledge of its faculty and staff to the environmental challenges we face today.

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Cover image: A whelk shell on Assateague Island. *Photo:* Roman Jesien.

Chapter 1—*Conclusions & Recommendations* cover image: An osprey returns to its nest in Sinepuxent Bay at sunrise. *Photo:* Jane Thomas.

Chapter 2—*Ecosystem Health Assessment* cover image: Aerial view of Ocean City and Assateague Island. *Photo:* Jane Thomas.

Chapter 3—*Management of the Coastal Bays & Watershed* cover image: Anglers fishing along the Ocean City Inlet during horseshoe crab spawning season. *Photo:* Steve Doctor, Maryland Department of Natural Resources.

Chapter 4—*Assawoman Bay* cover image: Assawoman Bay has intact salt marshes on its western shores, and heavy canal and condominium developments on Fenwick Island to the east. *Photo:* Jane Thomas.

Chapter 5—*St. Martin River* cover image: Aerial view looking from Bishopville Dam down Bishopville Prong to St. Martin River. Assateague Island is in the background. *Photo:* Jane Thomas.

Chapter 6—*Isle of Wight Bay* cover image: Aerial view of the southern end of Isle of Wight Bay, showing Skimmer Isle, the Route 50 bridge, Ocean City, and Assateague Island. *Photo:* Jane Thomas.

Chapter 7—*Sinepuxent Bay* cover image: Aerial view of Sinepuxent Bay, looking north. *Photo:* Jane Thomas.

Chapter 8—*Newport Bay* cover image: Newport Bay has many eroding marshes and ditches. *Photo:* Jane Thomas.

Chapter 9—*Chincoteague Bay* cover image: Aerial view of Mills Island in southern Chincoteague Bay, a rapidly eroding marsh island. *Photo:* Jane Thomas.

Chapter 10—*History & the Future* cover image: Young girl fishing from a boat docked in Sinepuxent Bay, circa 1930. *Image courtesy:* Ocean City Life-Saving Station Museum, Ocean City, Maryland. Collection of Mary and Hattie Bunting.

Chapter 11—*The Coastal Bays in Context* cover image: The spectacular 'blue marble' image of Earth, featuring Hurricane Linda off the Pacific coast of Mexico in 1997. *Image created by:* Reto Stockli with the help of Alan Nelson, under the leadership of Fritz Hasler, NASA Goddard Space Flight Center.

Chapter 12—*Dynamic Systems at the Land–Sea Interface* cover image: A map of the 1690 shoreline of the Coastal Bays. *Image courtesy:* NOAA Office of Coast Survey.

Chapter 13—*Water Quality Responses to Nutrients* cover image: Using Secchi disk depth, such as here in Chincoteague Bay, is a useful way to measure water clarity. *Photo:* Adrian Jones.

Chapter 14—*Diversity of Life in the Coastal Bays* cover image: During 1931, Harriett B. McCabe, the wife of Ocean City Mayor William W. McCabe, promoted surf fishing. She was an avid fisher and enjoyed showing off her catch to those strolling on the boardwalk. *Image courtesy:* Ocean City Life-Saving Station Museum, Ocean City, Maryland. Collection of Ken Jordan.

Chapter 15—*Habitats of the Coastal Bays & Watershed* cover image: The Coastal Bays support a wide variety of habitats. *Photo:* Jane Thomas.

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Preface

Paul S. Sarbanes
United States Senator from Maryland
1977–2007

Maryland's Coastal Bays—Assawoman, Isle of Wight, Sinepuxent, Chincoteague, and Newport Bays, and St. Martin River—are among our state's most precious resources. For centuries, their waters, forests, marshes, and fertile soils have sustained growing populations. They have supported jobs in the agricultural, fishing, recreation, and tourism industries. They have provided important habitat for numerous species of fish and wildlife. They are a vital part of Worcester County's and the lower Eastern Shore's economy and quality of life. But, by their very nature, the Coastal Bays are especially vulnerable to environmental and human pressures.

In 1990, I had the opportunity to participate in a conference on Maryland's Coastal Bays. Entitled the 'Forgotten Bays,' the conference was organized by the Committee to Preserve Assateague Island (now the Assateague Coastal Trust) and the Worcester Environmental Trust, among others, to draw attention to the growing threats to the Coastal Bays and to the need for a coordinated strategy to protect them. The conference sparked a series of actions at the federal, state, and local levels to begin addressing those threats and I am proud to have been associated with this effort. Working with Senator Mikulski, we enacted a Resolution and provided federal funding for the U.S. Army Corps of Engineers to undertake a multi-year water resources study—the first comprehensive assessment of the Maryland Coastal Bays, the Atlantic coast of Maryland, and the changing coastal environment of the barrier islands. That study was completed in 1998 and recommended restoration of the northern end of Assateague Island National Seashore, navigation improvements to the Ocean City harbor and inlet, and restoring habitat for fish and wildlife in the Coastal Bays.

Working with our state and local partners, we brought the Maryland Coastal Bays Program into U.S. EPA's National Estuary Program, which provided federal assistance to develop a comprehensive conservation management plan for the Coastal Bays. We secured funding and the necessary legislation to implement the recommendations of these studies and plans and to improve the water quality and wildlife habitat in the region.

The good news is that today the health of the Maryland Coastal

Bays ecosystem is still in fair condition, according to the assessment completed by the authors of this book. This study is the result of a remarkable effort by a team of 80 authors from 24 different organizations and agencies, including scientists from the University of Maryland Center for Environmental Science (UMCES) and other experts from the Maryland Coastal Bays Program, the Maryland Department of Natural Resources, the National Park Service, NOAA, and the Assateague Coastal Trust. This team took stock of the condition of the Coastal Bays ecosystem, reviewed the history of human settlement in the area, and the action plans and management strategies now in place, as well as emerging issues.

The bad news is that the water quality and biodiversity of the Coastal Bays, as a whole, are declining and the ecosystem remains extremely vulnerable to both natural and human-induced impacts which threaten to overwhelm the progress made to date. Projections cited in the study indicate that the population of the Coastal Bays will continue to steadily expand over the next decade with associated development likely to have new or increased impacts on the region. Sea level rise, storm surges, and continued changes in land use patterns will compound current stresses on the ecosystem.

Thanks to this book and the efforts that have been undertaken over the past two decades, today we know a lot more about the Coastal Bays ecosystem. We know that problems such as loss of wetlands, algal blooms, and declines in fisheries persist in the Coastal Bays. We know that we can develop and promote ecologically sound solutions to many of these problems. We know that the continued economic prosperity and the quality of life that the citizens of Worcester County, and indeed, citizens throughout the region, enjoy will depend in large part on our ability to manage the Coastal Bays in a sustainable manner. The authors make a series of important recommendations for doing just that and improving the management, research, and monitoring of each of the six Coastal Bays and of the entire ecosystem. I highly commend this book to all the citizens and decision-makers in Maryland and throughout the region.

Foreword

David P. Blazer
Executive Director
Maryland Coastal Bays Program
1999–2007

The Coastal Bays along Maryland's seaside have long been recognized as a very special place, one corner in the land of pleasant living known as Delmarva. The diverse ecology, fertile soils, abundant timber, and easy access to water has supported untold generations in hunting, fishing, trapping, and agriculture. The temperate climate supports more species of wildlife than any other place in Maryland. Together, these qualities have served as a platform for more than 150 years of tourism and leisure which has further helped the region prosper.

As popularity of the area increased, Worcester County locals began to recognize the changes to the watershed, but we were slow to monitor or address those changes. Prior to the early 1990s, the Coastal Bays did not receive much attention along the ecological front. We became the 'forgotten bays' as other local watersheds and estuaries received much more attention with monitoring, data collection, research, and management actions.

Because of their economic, aesthetic, and recreational value, estuaries like the Coastal Bays are increasingly attractive to both people and commerce. Activities like boating, fishing, swimming, and nature observation draw millions of visitors here each year that support hundreds of local businesses.

Like other coastal areas around the country, the Coastal Bays community continues to experience rapid population growth and increased development. Human populations and built environments in America's coastal watersheds are growing rapidly, with 55% of the U.S. population already living within 50 miles of the coast. The environmental impacts of development directly affect the ability of communities to balance natural resource protection with sustainable economic growth in their decision-making.

Our area's population is expected to continue to grow during the next 10 years, accompanied by increasing environmental impacts likely to threaten the bays' health. Already the bays are experiencing early warning signs of stress. In the northern bays, where human influences are greatest, populations of seagrasses, hard clams, and fishes are degraded. Warning signs are now also being witnessed in the formerly 'pristine' southern bays.

Recognizing the potential for additional stress on the fragile ecosystem of the Coastal Bays and the importance of a healthy ecosystem to our economy and quality of life, a number of federal, state, and local government agencies have joined with private individuals, civic organizations, scientists, and business and industry to work together to prevent further degradation of the Coastal Bays' water quality and to stem the continuing loss of natural habitat.

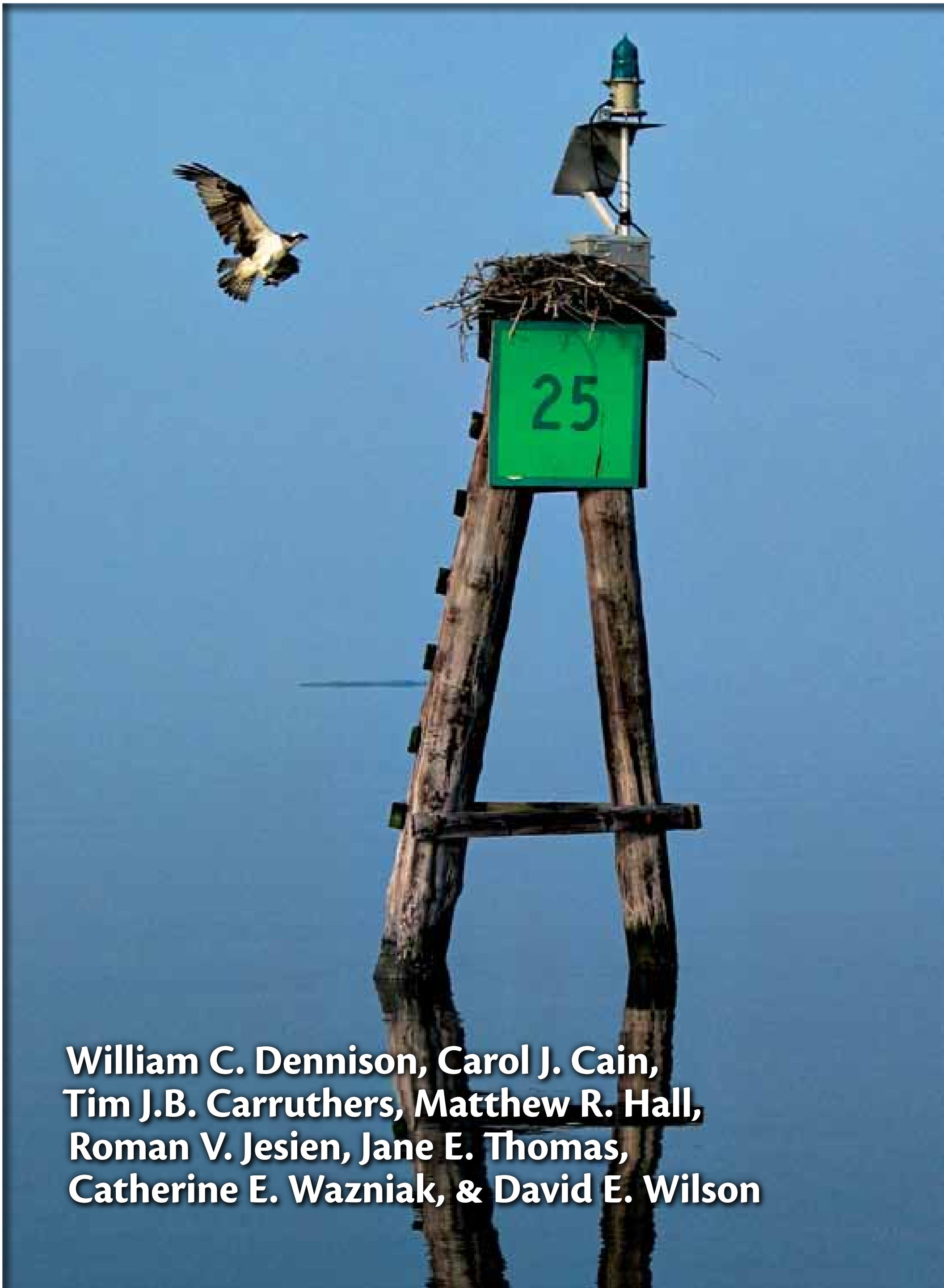
Around the United States, there are approximately 144 bays and estuaries. Of those 144, 28 are in the National Estuary Program (NEP) and are declared 'estuaries of national significance' because of the value of their natural resources. The Maryland Coastal Bays Program is one of those 28 nationally significant estuaries. This is a prestigious, high-profile program that receives national attention. The NEP is a broad-based program, taking a comprehensive approach to addressing the wide range of problems facing the nation's estuaries—preventing habitat degradation and loss of recreational and commercial fisheries, protecting and improving water quality, pioneering watershed management techniques, controlling sewage outfalls and septic system impacts, mitigating impacts from increasing land development, and developing strategies to deal with invasive species and harmful algal blooms. The list goes on and reflects the inter-related nature of these problems and the community-based nature of the NEP approach.

As an NEP, the Maryland Coastal Bays Program is a public–private partnership designed to build consensus on corrective actions to restore and protect our local natural resources. By engaging and involving state and local governments, watershed groups, and citizens, many additional resources are brought into play in addressing estuary problems. The NEP has a history of valuing community involvement and building support for initiatives.

This book characterizes the physical, chemical, and biological resources of the Coastal Bays and serves as an additional step in providing sound management for the future. It identifies our most pressing problems and sets the stage for community problem-solving and corrective action. Information contained in this report reflects what is believed to be the updated current status and offers recommendations for the future of our Coastal Bays.

Today the Coastal Bays are finally receiving the attention they deserve. We must continue to focus our attention on the watershed and pursue corrective activities in order to maintain that which makes our coastal community so special.

1. Conclusions & Recommendations



William C. Dennison, Carol J. Cain,
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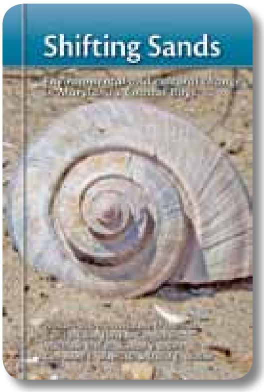
INTRODUCTION



Shifting Sands: Environmental & cultural change in Maryland's Coastal Bays

This book was conceived from a successful and dynamic collaboration between the University of Maryland Center for Environmental Science, Maryland Department of Natural Resources, and the Maryland Coastal Bays Program. This collaboration resulted in the well-received public report, *State of the Maryland Coastal Bays 2004*, and the accompanying technical document, *Maryland's Coastal Bays Ecosystem Health Assessment 2004*.

This book is presented a little differently, in that the first chapter focuses on the overall conclusions and recommendations, along with one-page summaries of each of the other chapters. The following chapters will guide the reader through the various facets of the Coastal Bays system, highlighting management issues, topics relevant to the six subwatersheds, the history of the region, the Coastal Bays in a national and international context, the geologic and hydrologic setting of the area, and finally, water quality, living resources, and habitats of the Coastal Bays.

An initial series of workshops was used to scope out the content of each chapter, with chapter authors identifying key conclusions and the data, images, and diagrams to support those conclusions. Working with the science communicator, authors produced a draft of each section and these were assembled into a draft chapter by the chapter editors. The editors, authors, and science communicator worked together to integrate the various chapter components, fill in missing pieces, and edit the content for continuity. The editors and science communicator then produced summaries, conclusions, and recommendations which were edited by the entire authorship team.

The production of *Shifting Sands* used an intensely collaborative process, involving multiple authors, multiple editors, and multiple reviewers. The one constant throughout the prolonged process of producing this book was the science communicator, Jane Thomas. She served as workshop organizer, logistics coordinator, photographer, editor, author, graphic designer, and her most time-consuming and difficult role was chasing authors and editors for their input, which she did with unflappable good cheer. This book became much more than the original scoping, based on the enthusiastic inputs by authors, and Jane took this expanded scope, additional chapters, and multiple edits in stride.

The expanded scope of the book resulted in a long volume that took longer than originally intended. The Maryland Coastal Bays evoked strong emotions by the scientists studying and managing this region and they argued persuasively to include more content. The value of this extended and intensely collaborative process was that a multitude of new insights occurred during the book production and several unique syntheses were generated. The final product is much more comprehensive and synthetic as a result of these insights and syntheses. Thus, the process of producing the book was as important as the final product. So to the authors, editors, reviewers, and the all-important science communicator, *thank you* for your fine efforts.

—William C. Dennison
Cambridge, MD

CONCLUSIONS & RECOMMENDATIONS

1. Conclusions & Recommendations

Overall conclusion

Maryland's Coastal Bays are dynamic, diverse, and vulnerable to natural and human-induced impacts.

Recommendations

Management: **SUSTAIN** a long-term commitment to improving the management of the Coastal Bays, with a renewed focus on achieving nutrient reductions.

Research: **IDENTIFY** and **PRIORITIZE** causal factors for the ongoing ecological transitions occurring in the Coastal Bays.

Monitoring: **LINK** terrestrial and aquatic monitoring efforts and **PROVIDE** regular and accessible reporting to a broad group of stakeholders.

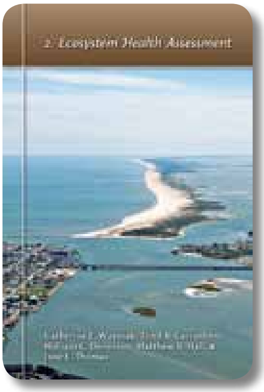
Shifting Sands—the title of this book—refers not only to the dynamic nature of the barrier island, lagoon, and watershed complex, but also to the sands of time, both the geologic and recent history of this region. The title also refers to the shifting baselines of human perception of Maryland's Coastal Bays, with perceptions changing over time and differing among individuals and groups. The subtitle, *Environmental and Cultural Change in Maryland's Coastal Bays,* refers to the ongoing ecological transitions and the human rediscovery of these formerly 'forgotten bays.'

This book provides an overview of the management strategies in place to deal with existing issues as well as highlighting approaches being developed for emerging problems. The subwatersheds and estuaries of the Coastal Bays are all impacted—some more so than others, resulting from geographical differences in oceanic exchange and human impacts.

The rich history of this region is explored, with future projections of development and continued agricultural impacts likely to place new and increased pressures on the region. In context with other coastal lagoons regionally, nationally, and internationally, the Coastal Bays are especially vulnerable to human impacts. The geologic setting of the barrier islands and coastal lagoons is a product of both modern processes and historical geological and oceanographic processes. Water quality in Maryland's Coastal Bays exhibits symptoms of nutrient over-enrichment, but the specific causes and sources of the recent degradation remain elusive. Terrestrial and aquatic biodiversity and habitats react to natural and human change and there are indications that biodiversity and habitats are being compromised by human impacts.

Environmental and cultural change is the one constant in the Coastal Bays due to their position at the land and sea interface and also as a result of changes occurring throughout the world. This book provides the context for interpreting these changes and the basis for better managing the resources of this magnificent place.

ECOSYSTEM HEALTH ASSESSMENT



Overall conclusion

Combining estuarine and watershed health indicators gave a broad picture of ecosystem health in the Coastal Bays.

The Ecosystem Health Index simply combined the nine estuarine health indicators with the five watershed health indicators. The 2004–2006 Ecosystem Health Index ranked the subwatersheds in the following order from best to worst: Sinepuxent Bay (0.58), Chincoteague Bay (0.57), Newport Bay (0.52), Isle of Wight Bay (0.42), Assawoman Bay (0.41), and St. Martin River (0.39). The overall range from best to worst was relatively small (0.39–0.58) compared with the range of both the Estuarine Health Index (0.35–0.60) and the Watershed Health Index (0.27–0.59). This is partially a result of combining multiple indicators but it also results from compensating factors so that a low score for estuarine health can be mitigated by a high watershed score, and vice versa.

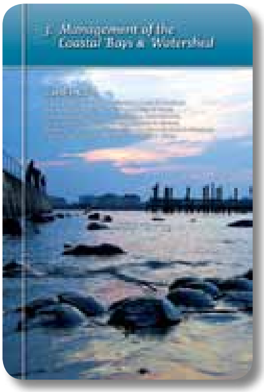
Several parameters were in good shape across the board—the bay benthic index, sediment toxicity, tidal wetlands, and natural shoreline were mostly healthy in the Coastal Bays. However, this was balanced by a number of parameters that returned degraded results—brown tide, hard clams, and stream benthic index were generally degraded throughout the Coastal Bays. Tidal wetlands and natural shorelines were correlated, which is not surprising given that they measure different attributes of the same habitat. The remaining parameters were variable throughout the bays, with water quality, seagrass, and impervious surface having the largest ranges.

Ecosystem Health Index 2004–2006

- 🟩 **Healthy**
- 🟨 **Impacted**
- 🟥 **Degraded**

			Sinepuxent Bay	**Chincoteague Bay**	**Newport Bay**	**Isle of Wight Bay**	**Assawoman Bay**	**St. Martin River**
ESTUARINE	***Water quality***	Water quality	0.65	0.43	0.21	0.47	0.42	0.14
		Brown tides	>200	>200	>200	>200	>200	nd
		Macroalgae	nd	nd	nd	nd	nd	nd
	Living resources	Bay benthos	3.4	3.7	3.7	3.5	4.0	2.0
		Hard clams	0.31	0.20	0.13	0.30	0.15	0.04
		Sediment toxicity	0.08	0.10	0.12	0.11	0.11	0.21
	Habitat	Seagrass area	70	51	17	21	30	3.0
		Tidal wetlands	(87)	(95)	(97)	(58)	(72)	(90)
		Natural shoreline	86	97	100	49	69	50
WATERSHED	***Stream water quality***	Stream benthos	1.38	1.79	2.21	1.70	1.29	1.70
		Stream nitrate	0.89	2.30	2.00	3.58	nd	2.63
		Impervious surface	6	1	4	10	18	7
	Land use	Forest cover	36	48	42	41	28	17
		Non-tidal wetlands	33	47	43	41	21	26
2004–2006 Ecosystem Health Index			**0.58**	**0.57**	**0.52**	**0.42**	**0.41**	**0.39**

MANAGEMENT OF THE COASTAL BAYS & WATERSHED



Overall conclusion

As existing problems are being addressed, new issues are emerging.

Recommendations

Management: **INCREASE** the effectiveness of management activities through a combination of regulatory and voluntary initiatives.

Research: **IMPROVE** our understanding of how to reverse water quality degradation in the Coastal Bays.

Monitoring: **EXPAND** existing monitoring activities and **DEVELOP** an integrated watershed and bay monitoring approach.

Healthy watersheds result in healthy coastal waterways and communities. Maintaining good air and water quality, combined with beneficial land management and an engaged public, will result in healthy coastal communities that maintain their seaside town and rural character. These communities will benefit from 'swimmable' and 'fishable' waters, an abundant food and fiber supply, and will support tourism as well as commercial and recreational activities for residents. Integrated air, water, and land management actions are needed to reduce nutrient inputs into the Coastal Bays.

Implementing 'green design' and sustainable planning principles, reducing runoff from impervious surfaces (e.g., roofs and roads), treatment of wastewater, sustainable agriculture practices (e.g., cover crops and buffer strips), and protection of groundwater, wetlands, forests, and natural shorelines will benefit the Coastal Bays. Water quality management through the Clean Water Act, fisheries management through state and federal regulations, and special protection for critical habitats are key elements of Coastal Bays' management. Utilization of oceanic resources (e.g., aquaculture, offshore fisheries, and wind farms) will need to comply with state and federal regulations. Regulatory functions, both permit issuance and enforcement, are critical elements in the management of the Coastal Bays and should be adequately supported by the respective jurisdictions.

A major challenge in managing a dynamic and diverse ecosystem like the Coastal Bays is the 'shifting baseline,' as environmental conditions are changing due to natural and human-induced influences. Management goals need to reflect these shifting conditions. Global environmental change is forecast to drive accelerated sea level rise and increase storm intensity—these factors would introduce additional management challenges for the region. Regional and local changes in land use, in particular the conversion of forested or agricultural lands to housing developments, will also keep affecting the Coastal Bays. Shifts in agricultural practices which are affected by global economic factors as well as local and regional regulations and business models will continue to influence the watershed and bays. Management of the Coastal Bays needs to be adaptive to cope with a changing human footprint.

THE SUBWATERSHEDS

Overall conclusion

There was a spectrum of ecosystem health in the subwatersheds of the Coastal Bays.

Recommendations

Management: **PROTECT** healthy areas and **RESTORE** degraded areas in the face of increasing pressures.

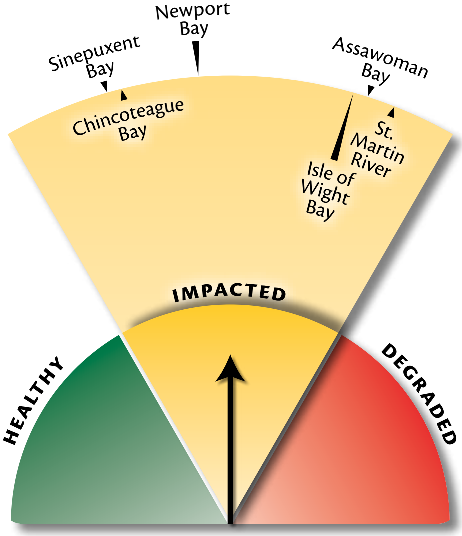
Research: **ACHIEVE** maximum benefit by identifying and targeting specific locations for protection or restoration.

Monitoring: **MEASURE** effectiveness of management at the subwatershed scale.

The subwatersheds of the Coastal Bays varied in terms of their ecosystem health, but they are all impacted (see Chapter 2—*Ecosystem Health Assessment*). Sinepuxent and Chincoteague Bays rated the highest due to good water quality and seagrass coverage, with relatively intact shorelines. Newport Bay had extensive salt marshes and relatively intact shorelines, but somewhat degraded water quality, reducing its position compared with the adjacent Sinepuxent and Chincoteague Bays. The other subwatersheds scored less favorably, with Isle of Wight and Assawoman Bays having reduced rankings in spite of relatively good water quality from oceanic exchange at the Ocean City Inlet. These bays had degraded shorelines, marsh loss, and limited seagrasses. St. Martin River had the lowest position due to degraded water quality, shorelines, marshes, and seagrasses.

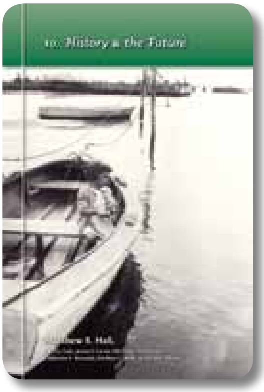
While the subwatersheds shared the same major issues—shoreline development, water quality degradation, and habitat loss—the relative importance of these issues varied across the subwatersheds. For instance, a challenge for management of St. Martin River and Assawoman and southern Chincoteague Bays is the multi-state coordination needed with Delaware and Virginia, respectively. Also, several of the subwatersheds have established Total Maximum Daily Loads (TMDLs), and the management challenge will be in the implementation of the TMDL strategies currently being developed. These examples demonstrate the need for subwatershed-specific management, research, and monitoring activities.

Subwatershed ecosystem health



All six subwatersheds of the Coastal Bays rank as having impacted ecosystem health.

HISTORY & THE FUTURE



Overall conclusion

The 'forgotten bays' have been rediscovered.

Recommendations

Management: **ACHIEVE** existing management goals and **ENHANCE** management activities to keep pace with the expanding population.

Research: **ADDRESS** the sustainability of expanding human populations.

Monitoring: **EVALUATE** the impacts of increased human pressures in the watershed.

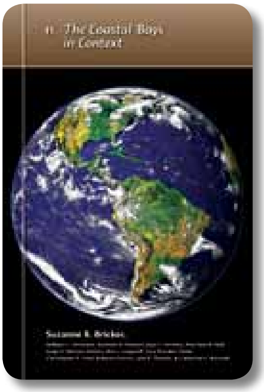
With the passage of time, the only constant in the Maryland Coastal Bays is change. A study of natural history reveals a dynamic beginning as geological and climatic forces created barrier islands and the Coastal Bays themselves. Slowly, natural forces shaped living habitats on land and in water. Periodic storms force the ecosystem and its inhabitants to adapt to an environment that could change rapidly. Inlets open and close, changing salinity and altering the assemblage of creatures comprising the aquatic ecosystem.

Human populations, from early Native Americans through European settlement, changed the land. During this time, storms continued to wrack the coast, including one in 1933 that opened the existing Ocean City Inlet and established the present estuarine lagoon ecosystem. Through the 20th century, these lagoons saw the rise of the Ocean City resort as improvements in transportation increased access to the seaside, the heyday of the Chincoteague oyster reduced to relict populations, and seagrasses nearly disappear, only to rebound to record high abundances. The establishment of Assateague Island National Seashore in 1965 was a high point in the conservation and management of the Coastal Bays ecosystem.

Later in the century, with the establishment of federal and state environmental legislation, inhabitants of the Coastal Bays watershed began to come together with government regulators to monitor, protect, and restore this important resource. This movement culminated in the founding of the Maryland Coastal Bays Program, focused on restoring and conserving the Coastal Bays through a Comprehensive Conservation and Management Plan.

However, challenges still abound, such as water quality degradation, historic habitat losses, rapid population rise, and the looming effects of climate change. The march of time will undoubtedly yield more alterations, testing the resilience of this ecosystem and the human population it supports.

THE COASTAL BAYS IN CONTEXT



Overall conclusion

The Coastal Bays share many characteristics with coastal lagoons worldwide that make them especially vulnerable.

Recommendations

Management: **IMPLEMENT** strategies that are appropriate for these vulnerable ecosystems.

Research: **COMPARE** and **CONTRAST** the effects of management strategies on coastal lagoons from different regions.

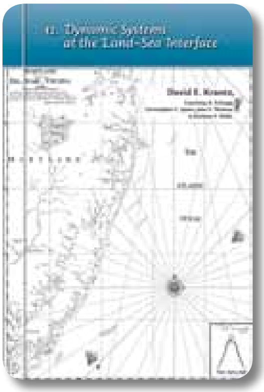
Monitoring: **DEVELOP** and **USE** appropriate indicators to assess impacts of stressors.

Coastal lagoons are typified by shallow waters behind long, narrow barrier islands with restricted oceanic exchange. The Mid-Atlantic region has a set of similar coastal lagoons, with Great South Bay in New York and Barnegat Bay–Little Egg Harbor Estuary in New Jersey sharing many characteristics with the Delaware Inland Bays and Maryland Coastal Bays. Coastal lagoons differ from drowned river valleys such as Chesapeake Bay, and historically have not received as much research, monitoring, or management attention.

A key threat to coastal lagoons is excess anthropogenic nutrients leading to eutrophication. Eutrophication has been manifested not just in Maryland's Coastal Bays, but in coastal lagoons at regional, national, and international scales. Eutrophication of U.S. coastal waters was recently assessed by the National Estuarine Eutrophication Assessment program, and eutrophication symptoms were evident in all the lagoons evaluated.

A suite of case studies illustrates features of coastal lagoons that have relevance to Maryland's Coastal Bays. In Upper Laguna Madre, Texas, an ecosystem transition was documented when these coastal lagoons were affected by chronic brown tide algal blooms, analogous to what has happened recently in Chincoteague Bay. In Ria Formosa, Portugal, eutrophication led to excessive macroalgal blooms, an emerging problem in Maryland's Coastal Bays. In the Lagoon of Venice, Italy, sewage treatment plant upgrades and a phosphorus ban have decreased eutrophication symptoms, providing incentive for resource managers in Maryland's Coastal Bays to take similar actions. In the Yucatán peninsula of Mexico, coastal lagoons are becoming eutrophic with no stream or river inputs—the sole source of nutrient inputs is through groundwater, providing a cautionary tale for Maryland's Coastal Bays.

DYNAMIC SYSTEMS AT THE LAND–SEA INTERFACE



Overall conclusion

The Coastal Bays are products of modern processes and past geologic history.

Recommendations

Management: **RECOGNIZE** the dynamic nature of the Coastal Bays and adapt management to changing conditions.

Research: **DEVELOP** tools to project future scenarios of potential changes.

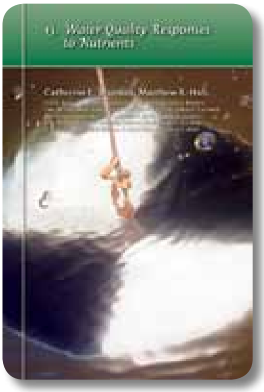
Monitoring: **MEASURE** climatic, geologic, and meteorological changes over time, and their effect on habitat and living resources.

The physical setting and dynamic processes of the Coastal Bays provide the foundation for a complex, productive, and ever-changing ecosystem. Sand moves along the coast, barrier islands migrate landward, storms create inlets which naturally open and close, and groundwater flows into and under the Coastal Bays. Against the background of daily to seasonal weather cycles, a few major storms in a 50- to 100-year period can exert a powerful influence by reshaping and restructuring the islands and bays, altering their function for the following decades.

One example of such a storm is the hurricane of 1933, which opened the current Ocean City Inlet. The opening and subsequent stabilization of the inlet changed the nature of the Coastal Bays by increasing salinity and altering sediment transport along the coast, resulting in the accelerated migration of Assateague Island landward. The Coastal Bays inherit much of their character from their geologic legacy of sea level highs and lows over the last two million years, and have continued to evolve over the past 5,000 years as sea level has risen slowly but continuously.

The seaside appeal of the Coastal Bays and Ocean City is resulting in increasing human population and development in the coastal zone, presenting management challenges that must be addressed at timescales much shorter than those over which most natural processes operate. Climate change and resulting accelerated sea level rise will continue to compound these challenges now and into the future.

WATER QUALITY RESPONSES TO NUTRIENTS



Overall conclusion

Symptoms of nutrient over-enrichment are becoming more evident.

Recommendations

Management: **REDUCE** nutrients (nitrogen and phosphorus) from all sources. **PROTECT** groundwater recharge areas.

Research: **IDENTIFY** contributions from specific sources and **UNDERSTAND** key nutrient transformations and pathways, including those for phosphorus.

Monitoring: **MEASURE** sources and impacts of nutrients in the Coastal Bays.

Overall, water quality is degraded in the bays, worse in the streams, and best near the Ocean City Inlet (Isle of Wight and Sinepuxent Bays). Increased nitrogen loading into the Coastal Bays could induce a change from seagrass to macroalgae (seaweed) to phytoplankton (microscopic algae). Increasing signs of eutrophication indicate that the southern bays are close to, or have passed, a tipping point beyond which recovery will be difficult and lengthy. Long-term trends in the southern bays indicate that improvements were made in water quality during the late 1980s/early 1990s. However, these trends reversed in the late 1990s, and currently water quality is degrading.

Harmful algae blooms (especially brown tide), loss of seagrass, and reduced oxygen are problematic and anticipated to worsen if water quality trends do not change for the better. Nutrient budgets indicate that groundwater (septic, shallow groundwater seepage, ditching), the atmosphere (including regional Mid-Atlantic sources), and surface runoff (agriculture) are significant sources of nitrogen to the Coastal Bays. Nitrogen in streams is related to the amount of agriculture in the watershed and streams may be the first areas to show improvement. It may take 15 or more years to see improvements due to the time lag of groundwater inputs. Phosphorus improvements may take longer if bay sediments are a significant source. Reduction of all nutrient sources will improve water quality.

DIVERSITY OF LIFE IN THE COASTAL BAYS

Overall conclusion

The biodiversity of the Coastal Bays is reacting to natural and human-induced ecosystem changes.

Recommendations

Management: **MAINTAIN** biodiversity through habitat protection, pollution reduction, and harvesting strategies.

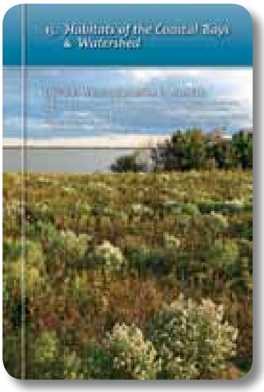
Research: **UNDERSTAND** community dynamics and habitat interactions.

Monitoring: **EXPAND** terrestrial monitoring programs while maintaining adaptive aquatic monitoring.

The Coastal Bays and their watershed exhibit the highest diversity of habitats and living creatures in Maryland, as a consequence of being the only portion of the state possessing an ocean coast, while also possessing estuarine, non-tidal aquatic, and mainland habitats. Some of these creatures depend on specific habitats within the watershed, such as amphibians that spawn in wetlands, while others use a wide range of habitats, like white-tailed deer browsing in forests and open fields. Similarly, some use the Coastal Bays for brief periods, such as migrating shorebirds or visiting dolphins and sea turtles, and others remain in the Coastal Bays for their entire lives, like schools of silversides residing in the shallows.

The creatures of the Coastal Bays, along with their habitats, make up ecosystems and are thus interdependent. As one species rises in abundance, another may decline. These dynamic relationships are responsive to various natural factors and anthropogenic stressors. Storms may disrupt the nesting habitat of neotropical songbirds, forcing them to adapt and find new nesting sites. Blue crabs react to both the condition of the water in which they live as well as fishing pressure, causing unpredictable variations in abundances. With human population growth, biodiversity tends to decrease as species that are tolerant to altered habitats (white-tailed deer, for example) or those species that humans introduce (such as the Assateague horses) increase their numbers. As change is inevitable in the Coastal Bays, researchers and resource managers will continue to keep track of and preserve this crucial biodiversity.

HABITATS OF THE COASTAL BAYS & WATERSHED



Overall conclusion

The diverse mosaic of habitats in the Coastal Bays is threatened.

Recommendations

Management: **PROTECT** and **RESTORE** habitats to maintain the health of the ecosystem.

Research: **DETERMINE** critical habitat requirements to maintain ecosystem services and living resources.

Monitoring: **EXPAND** habitat monitoring to develop measures of status and trends of key habitats, especially in terrestrial environments.

The diverse mosaic of habitats (forests, wetlands, grasslands, and aquatic habitat) in the Coastal Bays watershed are threatened. Forests, largely a mixture of pine and hardwood, are a dominant land type, with planning and growth projections predicting significant losses in the next 20 years. Another important habitat is wetlands. An estimated 41% of historic wetlands have been lost to development, erosion, ditching, farming, and logging activities. Despite current regulations to protect wetlands, sea level rise will exacerbate future losses.

Conservation of grassland habitat has been successful in providing wildlife habitat and reducing nutrient runoff. Assuming 95% of the watershed was historically forested, only 42% of Maryland's watershed remains forested. Although croplands pale in comparison to forests or wetlands for habitat value, agricultural lands can be important to many species and need to be preserved from development. Terrestrial habitat in the northern bays is more degraded due to development, while the southern bays have more undeveloped and protected lands.

Storms are a primary natural force shaping coastal habitat, driving landscape-level changes essential to the health of the ecosystem. The continued existence of bay islands as habitat is critical for certain waterbirds. The shifting sands of Assateague and Fenwick Islands epitomize the interactions between land and sea.

Aquatic habitats are stressed. Streams that connect the land to the bays are in poor condition as a result of ditching and excessive nitrate levels. Sea level rise and erosion are additional factors altering aquatic habitat and changing bottom type. Historically, seagrass acreage has been dynamic. Seagrass coverage expanded to the greatest levels ever recorded in the Coastal Bays in 2000, but then suffered significant declines in 2005. In 2004–2006, only 48% of the seagrass goal was being met. Variations in goal attainment were related to differences in water quality. Loss of seagrass will have a cascading effect on ecosystem health by reducing aquatic species (e.g., scallops), water quality, and other living resources (e.g., Atlantic brant).

ACKNOWLEDGEMENTS

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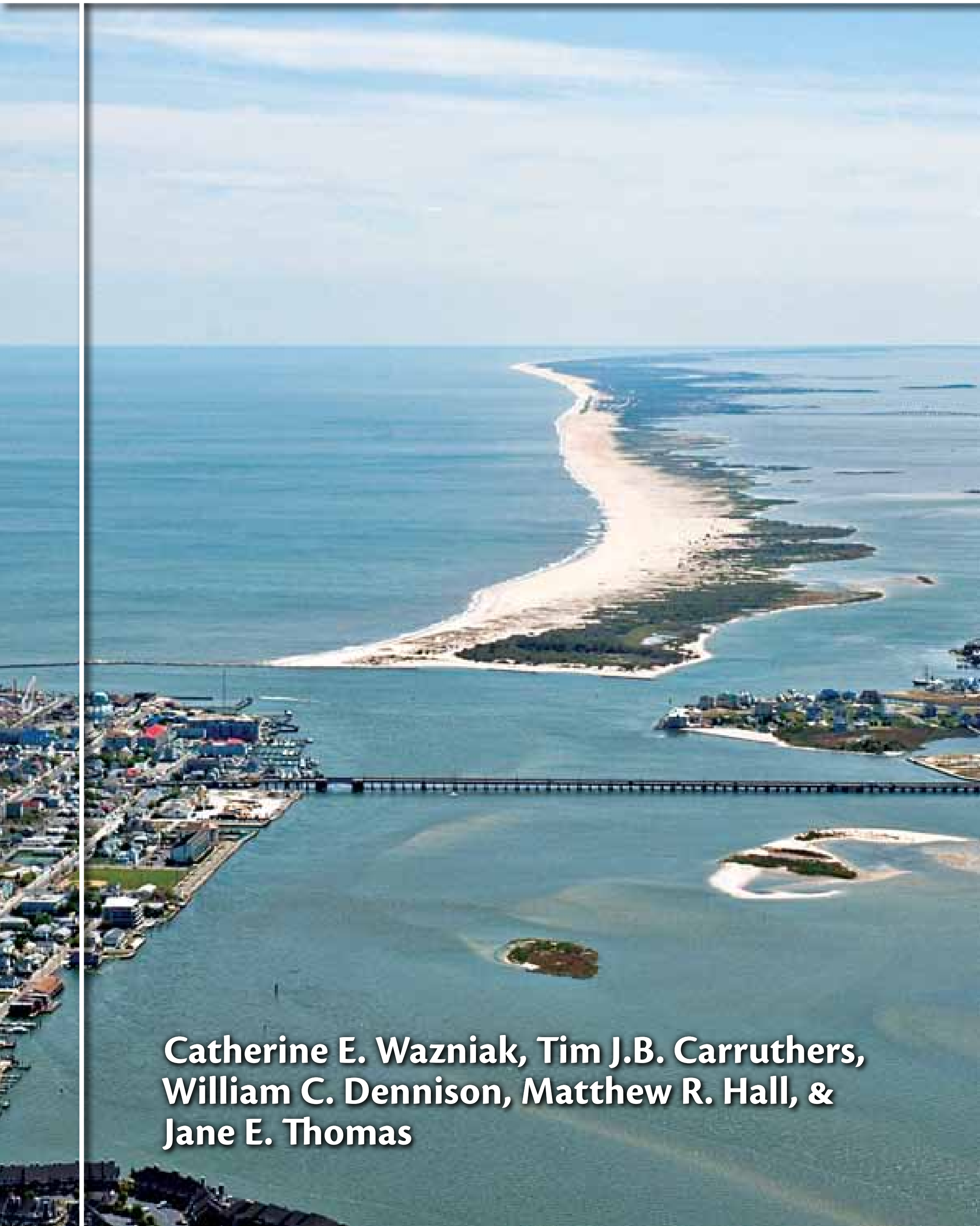
2. Ecosystem Health Assessment



Catherine E. Wazniak, Tim J.B. Carruthers, William C. Dennison, Matthew R. Hall, & Jane E. Thomas

ESTUARINE INTEGRATED ASSESSMENT, 2001–2003

In 2001–2003, the Coastal Bays were in good to fair condition

So, how are the Coastal Bays doing? This simple question provided the impetus to develop an Estuarine Health Index to compare the different subwatersheds of the Coastal Bays. An integrated assessment approach was developed based on a suite of estuarine indicators. The assessment was calculated over two successive three-year time periods: 2001–2003 and 2004–2006.[4] In addition, watershed indicators were developed for 2004–2006.

The Estuarine Health Index was calculated by summing three water quality indicators (composite water quality index, brown tides, and macroalgae), three living resources indicators (bay benthic index, hard clams, and sediment toxicity), and three habitat indicators (seagrass, tidal wetlands, and natural shoreline). The 2001–2003 Estuarine Health Index ranked the subwatersheds in the following order

Estuarine Health Index 2001–2003

🟩 **Healthy**
🟨 **Impacted**
🟥 **Degraded**

		Sinepuxent Bay	**Chincoteague Bay**	**Assawoman Bay**	**Newport Bay**	**Isle of Wight Bay**	**St. Martin River**
Water quality	Water quality[1]	0.85	0.74	0.33	0.35	0.53	0.33
	Brown tides[2]	35–200	>200	35–200	>200	35–200	35–200
	Macroalgae[3]	47	316	102	10	251	393
Living resources	Bay benthos[4]	3.5	3.6	3.4	3.4	3.1	2.2
	Hard clams[5]	0.32	0.27	0.16	0.14	0.28	0.04
	Sediment toxicity[6]	0.10	0.08	0.12	0.07	0.11	0.19
Habitat	Seagrass[7]	68	70	28	32	19	3.3
	Tidal wetlands[8]	(100)	(100)	(98)	(90)	(100)	(79)
	Natural shoreline[9]	81	98	72	96	35	52
2001–2003 Estuarine Health Index[10]		**0.75**	**0.66**	**0.56**	**0.54**	**0.52**	**0.35**

1. Water quality index (total nitrogen, total phosphorus, chlorophyll *a*, and dissolved oxygen) based on 2001–2003 period. Potential range is 0 (poor) to 1 (good). Data are for Maryland and Virginia.
2. Highest average brown tide peak concentration ($\times$ 1,000 cells µL^{-1}) measured within a subwatershed between 2001–2003 (a total of 15 stations monitored). Potential range is 0–>200. Data are for Maryland and Virginia.
3. Macroalgae data are maximum biomass (g L^{-1}) from surveys of 388 sites throughout the Coastal Bays in 2001 and 2003. Potential range is 0–600. Data are for Maryland only.
4. Bay benthic index results are for the period 2000–2001. Potential range is 1 (poor) to 5 (good). Data are for Maryland and Virginia.
5. Hard clam data was average clams m^{-2} for 1994–2000. Potential range is 0–1.34. Data are for Maryland only.
6. Sediment toxicity data based on 1991–1996 data from >900 sites using the Apparent Effects Thresholds. Potential range is 0 (good) to 0.5 (poor). Data are for Maryland and Virginia.
7. Seagrass area based on percent goal achieved for the period 2001–2003. Potential range is 0–100%. Data are for Maryland only.
8. Tidal wetland data based on 1988/1989 tidal wetlands as a percentage of estimated historical wetland acreage (hydric soils).[1,2] Potential range is 0–100%. Note that these data cannot be compared directly to the 2004–2006 results as different methodologies were used. Data are for Maryland only.
9. Natural shoreline based on an aerial photographic survey carried out in 1989 and is expressed as a percentage of total shoreline. Potential range is 0–100%. Data are for Maryland only.
10. For each of the nine indicators listed above, average values over each of the Coastal Bays segments were calculated (reported in table). Each of these raw indicator values were then converted to scaled values relative to the potential minimum/maximum scores listed in the footnotes above. Individual parameters were scored on a 0–1 index value and were then averaged over all segment parameters to obtain the Estuarine Health Index value.

from best to worst: Sinepuxent Bay (0.75), Chincoteague Bay (0.66), Assawoman Bay (0.56), Newport Bay (0.54), Isle of Wight Bay (0.52), and St. Martin River (0.35). A previous report used the same indicators but with different thresholds.[4] Therefore, slightly different results were obtained.

ESTUARINE INTEGRATED ASSESSMENT, 2004–2006

In 2004–2006, Estuarine Health Index values of the Coastal Bays declined

The 2004–2006 Estuarine Health Index ranked the subwatersheds in the following order from best to worst: Sinepuxent Bay (0.60), Chincoteague Bay (0.56), Newport Bay (0.50), Assawoman Bay (0.48), Isle of Wight Bay (0.42), and St. Martin River (0.35).

Estuarine Health Index 2004–2006

🟩 **Healthy**
🟨 **Impacted**
🟥 **Degraded**

		Sinepuxent Bay	**Chincoteague Bay**	**Newport Bay**	**Assawoman Bay**	**Isle of Wight Bay**	**St. Martin River**
Water quality	Water quality[1]	0.65	0.43	0.21	0.42	0.47	0.14
	Brown tides[2]	>200	>200	>200	>200	>200	nd
	Macroalgae[3]	nd	nd	nd	nd	nd	nd
Living resources	Bay benthos[4]	3.4	3.7	3.7	4.0	3.5	2.0
	Hard clams[5]	0.31	0.20	0.13	0.15	0.30	0.04
	Sediment toxicity[6]	0.08	0.10	0.12	0.11	0.11	0.21
Habitat	Seagrass[7]	70	51	17	30	21	3.0
	Tidal wetlands[8]	(87)	(95)	(97)	(72)	(58)	(90)
	Natural shoreline[9]	86	97	100	69	49	50
2004–2006 Estuarine Health Index[10]		**0.60**	**0.56**	**0.50**	**0.48**	**0.42**	**0.35**

1. Water quality index (total nitrogen, total phosphorus, chlorophyll *a*, and dissolved oxygen) based on 2004–2006 period. Potential range is 0 (poor) to 1 (good). Data are for Maryland and Virginia.
2. Highest average brown tide peak concentration (× 1,000 cells μL^{-1}) measured within a subwatershed between 2004–2006 (a total of 15 stations monitored). Potential range is 0–>200. Data are for Maryland and Virginia.
3. No macroalgae data collected during this time period.
4. Bay benthic index results are an average of individual station indices within each bay. Data are from 55 stations collected as part of the 2004 National Coastal Assessment Survey. Potential range is 1 (poor) to 5 (good). Data are for Maryland and Virginia.
5. Hard clam data was average clams m^{-2} for 2004–2007. Potential range is 0–1.34. Data are for Maryland only.
6. Sediment toxicity data based on 2004 using the Apparent Effects Thresholds. Higher values indicate higher levels of toxins present. Potential range is 0–0.5. Data are for Maryland and Virginia.
7. Seagrass area based on percent goal achieved for the period 2004–2006 (note: no 2005 data). Potential range is 0–100%. Data are for Maryland only.
8. Tidal wetland area based on 1998 update of 1989 National Wetlands Inventory tidal wetlands as a percentage of estimated historical wetland acreage (hydric soils).[2,3] Potential range is 0–100%. Note that these data cannot be compared directly to the 2001–2003 results as different methodologies were used. Data are for Maryland only.
9. Natural shoreline data was collected by Virginia Institute of Marine Science for Maryland's Coastal Program in 2004 and is expressed as a percentage of total shoreline. Potential range is 0–100%. The survey was conducted only along areas of shoreline that were developed—the rest was assumed to be natural shoreline. Data are for Maryland only.
10. For each of the nine indicators listed above, average values over each of the Coastal Bays segments were calculated (reported in table). Each of these raw indicator values were then converted to scaled values relative to the potential minimum/maximum scores listed in the footnotes above. Individual parameters were scored on a 0–1 index value and were then averaged over all segment parameters to obtain the Estuarine Health Index value.

* nd = no data available for the index period.

Using the same indicators and thresholds, none of the 2004–2006 Estuarine Health Index values were higher than the 2001–2003 values. Only one subwatershed score was the same in both time periods—St. Martin River, with the lowest value (0.35) in both time periods. Sinepuxent and Chincoteague Bays were the highest ranked in both time periods, but the relative rankings of Newport, Assawoman, and Isle of Wight Bays were variable between the two time periods. There was an overall reduction in Estuarine Health Index values between the two time periods. The decline in the Estuarine Health Index was largely due to water quality degradation along with changes in seagrass, tidal wetlands, and natural shoreline. The water quality, seagrass, wetlands, and shoreline indices were the most variable among embayments and thus were most influential in the rankings.

WATERSHED INTEGRATED ASSESSMENT, 2004–2006

A new assessment was developed to measure watershed health

The Watershed Health Index used three stream water quality indicators (stream benthic index, stream nitrate, impervious surface) and two land use indicators (forest cover, non-tidal wetlands). The 2004–2006 Watershed Health Index ranked the subwatersheds in the following order from best to worst: Chincoteague Bay (0.59), Newport Bay (0.57), Sinepuxent Bay (0.54), St. Martin River (0.43), Isle of Wight Bay (0.42), and Assawoman Bay (0.27).

The new watershed integrated assessment ranks the subwatersheds according to stream and watershed ecosystem health indicators. With the lowest impervious surface and highest cover of forests and

Watershed Health Index 2004–2006

🟩 **Healthy**
🟨 **Impacted**
🟥 **Degraded**

		Chincoteague Bay	**Newport Bay**	**Sinepuxent Bay**	**St. Martin River**	**Isle of Wight Bay**	**Assawoman Bay**
Stream water quality	Stream benthos[1]	1.79	2.21	1.38	1.70	1.70	1.29
	Stream nitrate[2]	2.30	2.00	0.89	2.63	3.58	nd
	Impervious surface[3]	1	4	6	7	10	18
Land use	Forest cover[4]	48	42	36	17	41	28
	Non-tidal wetlands[5]	47	43	33	26	41	21
2004–2006 Watershed Health Index[6]		**0.59**	**0.57**	**0.54**	**0.43**	**0.42**	**0.27**

1. Stream benthic index based on Maryland Biological Stream Survey type data collected by Maryland Department of Natural Resources and Maryland Coastal Bays Program/Worcester County in 2005 and 2006. Potential range is from 1 (poor) to 5 (good). Data are for Maryland only.
2. Stream nitrate (mg L^{-1}) data is the maximum value recorded between 1999–2003. Potential range is 0.025–6.0 mg L^{-1}. Data are for Maryland, Delaware, and Virginia.
3. Impervious surface estimates (percentage of watershed) were from preliminary 2004 information provided by Worcester County Department of Comprehensive Planning. Range is 1–25%. Data are for Maryland only.
4. Forest goal based on historic forest information from Maryland Department of Natural Resources, based on Maryland Department of Planning estimates, and percent reference is based on wetland data.[3] Potential range is 0–100%. Data are for Maryland only.
5. Non-tidal wetlands area was based on current non-tidal wetlands as a percentage of historical acreage based on Soil Survey Geographic Database hydric soils layer. Potential range is 0–100%. Data are for Maryland only.
6. For each of the five indicators listed above, average values over each of the Coastal Bays segments were calculated (reported in table). Each of these raw indicator values were then converted to scaled values relative to the potential minimum/maximum scores listed in the footnotes above. Individual parameters were scored on a 0–1 index value and were then averaged over all segment parameters to obtain the Watershed Health Index value.

* nd = no data available for the index period.

non-tidal wetlands, Chincoteague Bay ranked first among the Coastal Bays; however, it still ranked as impacted. Assawoman Bay ranked last of the Coastal Bays, and was the only subwatershed to receive a degraded ranking. This was a result of the poorest values for stream benthic animals, impervious surface, and non-tidal wetland cover—evidence of the extensive development in this subwatershed.

~

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3. *Management of the Coastal Bays & Watershed*

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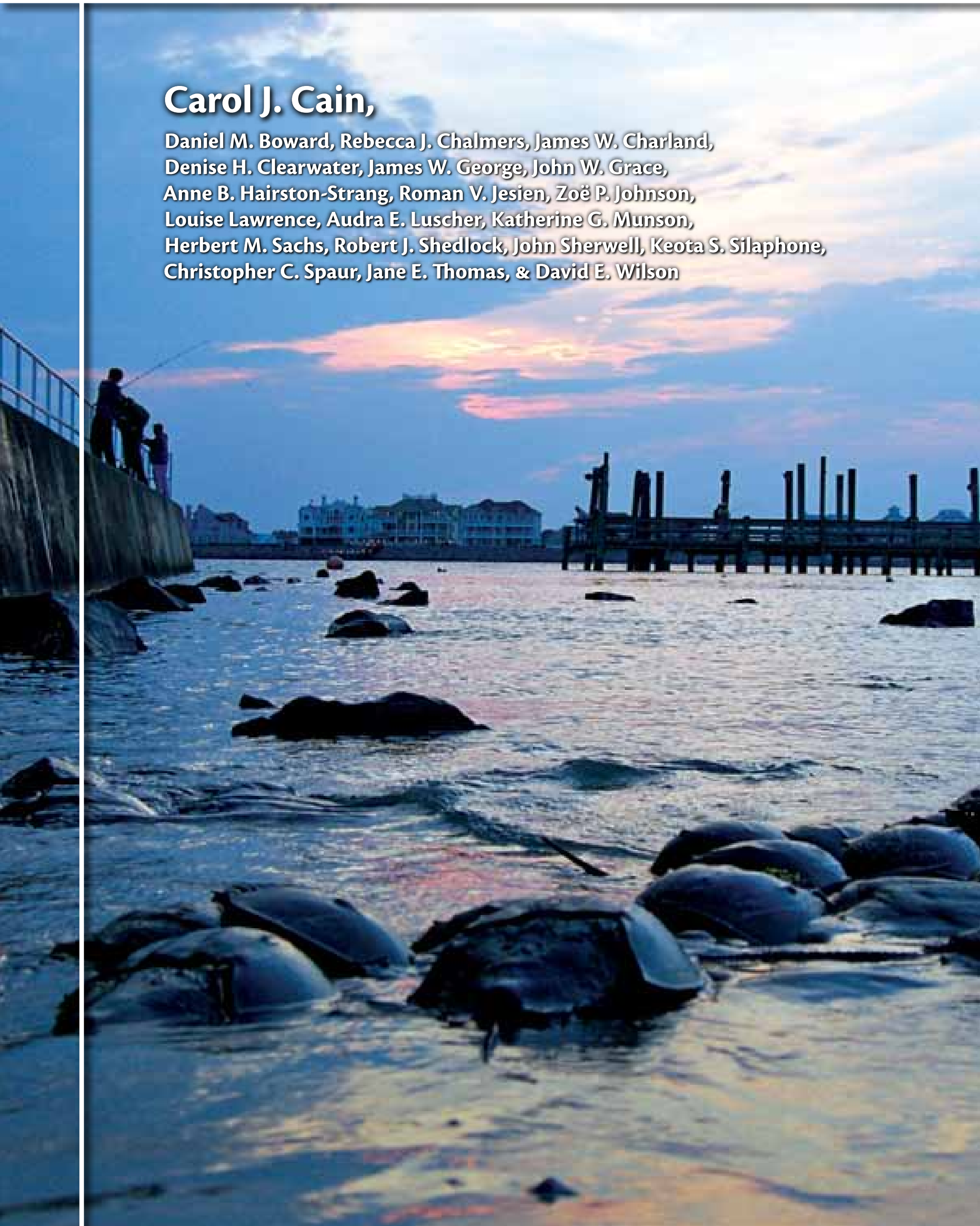


HEALTHY WATERSHEDS = HIGHER QUALITY OF LIFE

Communities are only as healthy as their air, land, & water

Community and individual health is intrinsically linked to the air, water, and land that support us. Protect your quality of life by protecting your environment.

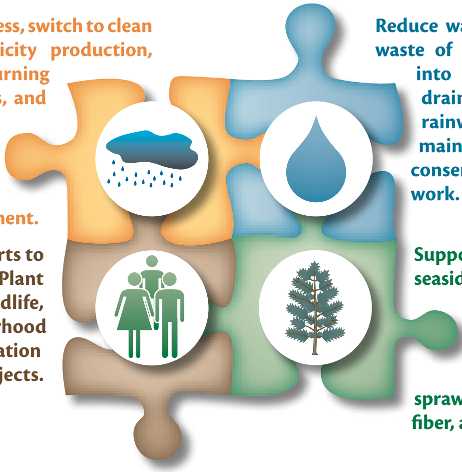
Our community has enjoyed centuries of benefits from our precious natural resources. We have also subjected our area to over-fishing, water and air pollution, and inadvertent neglect. The problems in our watershed did not occur overnight and will not be remedied quickly. It is our responsibility to preserve and restore our natural resources in order to protect our health and to improve the community that has provided us with so much.

Engaged communities are essential for achieving healthy watersheds & waterways

The Coastal Bays of Maryland were once referred to as the "forgotten bays." Over the last 10 years, a great deal of time and research has been expended to verify the health and status of the bays, measure economic and ecological pressures, and suggest management efforts that will support our collective goals to protect and preserve our quality of life. This chapter provides brief summaries of topics of local interest and management recommendations that have been devised by local community members and federal, state, and local decision-makers. Some of these recommendations have been formally approved by the Maryland Coastal Bays Program, while others have been collected from ad-hoc groups and state initiatives. Regardless of the level of formality, these topics and recommendations serve as a bridge for further discussion on the protection and conservation of the Coastal Bays watershed.

With the knowledge that everything on land can impact everything in the water, it is a natural transition for the Maryland Coastal Bays Program and our community to begin to focus more closely on what is happening within the watershed and, further, what is occurring regionally.

The challenge before us is best summarized as 'overarching themes' to further investigate in the coming years:



Reduce air pollution—drive less, switch to clean energy vehicles and electricity production, decrease energy usage by turning off or unplugging appliances, and choose home products, such as building materials, carpets, and cleaning solutions, that are better for your family and the environment.

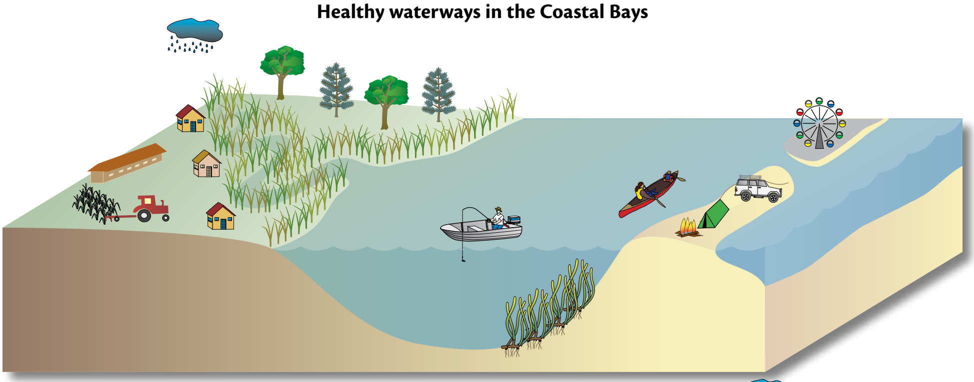
Reduce water pollution—never dump waste of any kind onto the ground, into a waterbody, or down the drain, pick up after pets, collect rainwater for your garden, maintain your septic system, and conserve water at home and at work.

Support community efforts to restore our environment. Plant trees, recycle, protect wildlife, and participate in neighborhood clean-ups and restoration projects.

Support local agriculture and our seaside rural heritage by buying local produce and decreasing fertilizer and pesticide applications, which will reduce the potential for sprawl, provide healthy food and fiber, and preserve wildlife habitat.

Air, water, land, and community are essential elements for healthy Coastal Bays.

Healthy waterways in the Coastal Bays



Achieving healthy watersheds and waterways in the Coastal Bays will require good air quality, healthy water, well-planned land use, and engaged and active communities.

Landscape & terrestrial matters

1. A watershed-wide Nutrient Reduction Action Strategy is being developed using the most recently acquired scientific data and community input from the individual Watershed Action Strategies. This strategy is intended to identify the resources and specific areas for on-the-ground improvements and promote sound policies to reduce nutrient loading. By extension, the improvements will help watershed residents reach the ultimate goals of improving their quality of life by improving habitat and water quality, and removing local waterbodies from the federal list of impaired waters. Some of the tools available to assist in this effort include:
   - Implementing Worcester County's Comprehensive Plan, including the new provisos related to water resources, water quality, coastal hazards, and large lot zoning. Zoning and other ordinances should be revised to be consistent with the comprehensive plan.
   - Strengthening enforcement and compliance of existing laws that relate to wetlands preservation, shoreline changes, seagrass protection, stormwater management, and sediment and erosion control.
   - Developing a GIS-based water quality hydrologic model to assist with predictive methods for pollution loads based on land-use changes.
   - Promoting and stabilizing local economies and practices of agriculture, aquaculture, and forestry to assist in maintaining the rural character of the watershed.
   - Using indicators to assess natural resource-based economics, quality of life, and terrestrial wildlife and habitat quality and abundance.
   - Improving communication between local, state, and federal agencies to identify restoration and policy opportunities. For example, modify the 'flush fee' policy to allow septic tanks to be hooked up to area wastewater treatment facilities, and coordinate efforts to best serve the community as industrial wastewater treatment plants are converted for public use.
   - Improving community involvement by targeting outreach and educational efforts to determine solutions to environmental problems that are

important to minority, business, and other niche groups.

- Pressing forward with habitat protection and restoration plans at a subwatershed scale to realize environmental improvements. Some potential projects include buffer plantings, ditch improvements, fish passages, wetland and forest restoration, and soft shorelines.
- Monitoring groundwater to determine changes in nutrient concentrations and flow.

Regional collaboration

2. Delmarva Atlantic Watershed Network—the Maryland Coastal Bays Program has been leading an effort to bring the four coastal counties in Delaware, Maryland, and Virginia (Delmarva) together to discuss key issues for protecting and preserving Delmarva's seaside. Rapid development and changes in land use are occurring in each jurisdiction and are being addressed with varied planning practices. These states are interconnected by coastal streams, bays, roads, tourism, groundwater, air quality, agriculture, development, habitat corridors, and pollution inputs. This collaboration provides an unprecedented opportunity for the four counties to share data and other resources.
3. Ocean protection and management as related to the recommendations from the U.S. Ocean Action Plan and Ocean Commission reports. To date, most efforts have focused on gathering basic information related to ocean governance, management, monitoring, resources, and human impacts.
4. Discuss and develop a process to evaluate support for the Assateague Island National Seashore's interest in designating park waters and Chincoteague Bay as Outstanding National Resource Waters as defined by the Clean Water Act. This designation will protect the ecological and recreational value of these high-quality waters by preventing new point source loadings from being permitted.

AIR QUALITY

Atmospheric sources contribute about one-third of the nitrogen pollution

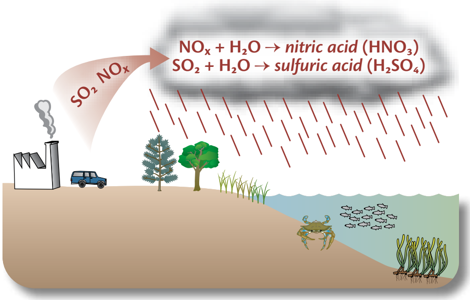
Modeling studies for atmospheric deposition indicate that many sources contribute nitrogen pollution to the Coastal Bays. These sources include electrical generation at power plants, on-road vehicles, local area sources (small industrial sites, domestic heating, off-road vehicles/combustion engines, poultry house ammonia, etc.), and tall stack industry. For more information, see Chapter 13—*Water Quality Responses to Nutrients.*

Reductions of deposition from these sources will be achieved primarily through the implementation of the federal Clean Air Act and also through emission reduction actions by individual states.

Emission reductions will be achieved through regional & local initiatives

The 2006 Maryland Healthy Air Act is a ground-breaking four-pollutant law that significantly reduces both ozone and fine particle-related emissions from

Causes of acid rain

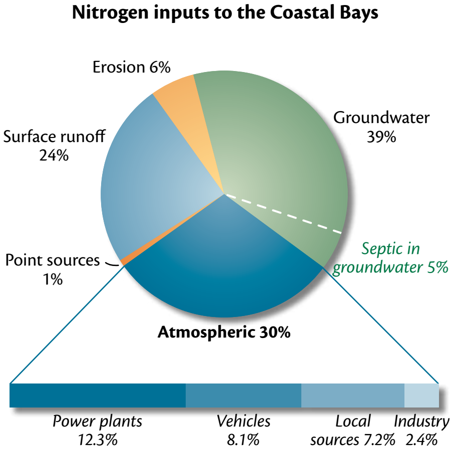


Acid rain is the product of nitrogen oxide (NO_x) and sulfur dioxide (SO_2) emissions from industry and vehicles interacting with sunlight in the atmosphere.

Sources of atmospheric nitrogen pollution

- Power plant emissions.
- Motor vehicle exhausts.
- Two-stroke engine exhausts, including boats and jet skis.
- Volatilization of ammonia from poultry litter.

For more information on atmospheric nitrogen in the Coastal Bays, see Chapter 13—*Water Quality Responses to Nutrients.*



MARYLAND DEPARTMENT OF NATURAL RESOURCES

Atmospheric deposition makes up almost one-third of the nitrogen inputs to the Coastal Bays. Data are for the Maryland portion of the Coastal Bays.[25]

Maryland's seven largest coal-fired power plants. These seven plants account for approximately 95% of the state's power plant emissions. This law is the most stringent power plant law on the East Coast. Not only will these reductions result in less ground-level ozone and fine particulates, but the effects of these stressors, such as increased asthma, throat and eye irritation, heart attacks, and other respiratory problems, should decrease as well. For more information, see *www.mde.state.md.us/Air/MD_HAA.asp*.[17]

Recommendations[10]

- Develop educational materials on home and workplace energy conservation practices, and automobile exhausts or combustion contributions to atmospheric pollution. These would include such practices as turning the thermostat down in winter and up in summer to reduce heating and cooling energy use, and walking or biking to work.
- Advance the use of alternative energy sources, such as clean-burning fuels, geothermal, solar, wind, etc.
- Support the use of non-motorized and solar-powered lawn mowers and four-stroke boat engines.
- Examine the benefits of adopting a model energy code for residential and commercial buildings.
- Worcester County should promote mass transit in the Coastal Bays watershed to decrease the amount of nitrogen in the atmosphere.

Pollutant	2009	2010	2012	2013
Nitrogen oxides —contribute to ground-level ozone 'smog'	70%		75%	
Sulfur dioxides —contribute to fine particulate pollution and acid rain		80%		85%
Mercury —a toxin that can build up in the food chain		80%		90%
Carbon dioxide —contributes to global warming	To be determined through the Regional Greenhouse Gas Initiative			

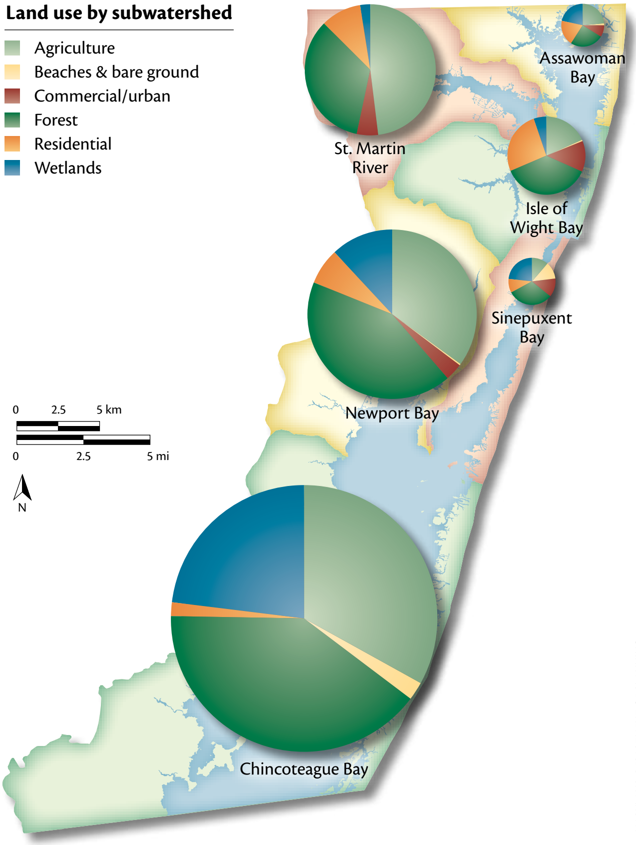
The Maryland Healthy Air Act calls for specific reductions of four pollutants, beginning in 2009. Air pollution occurs when fossil fuels are burned by stationary (power plants) and mobile (automobile) sources.

- The county should also provide alternative transportation modes that will reduce our dependency on fuel. Efforts should be focused on planning for pedestrian-friendly communities and developing an extensive network of bicycle lanes that will connect communities and commercial centers.
- When feasible, individuals can carpool to work or work at home once a week to decrease the amount of driving time.

LAND MANAGEMENT

The seaside & rural qualities are key to the Coastal Bays' character

Maryland's Eastern Shore consists of many compact, mixed-use towns along with associated neighborhoods that work to harmonize man-made infrastructure and natural environments. Due to development pressures and expansion, close attention must be paid to maintaining this balance into the future. In addition to the merits of compact development, many types of environmental design and low-impact development techniques ensure awareness and protection of our natural resources and their sustainability over time. Such techniques also respect how to incorporate ecologically sound and culturally appropriate applications so the character of the local community is maintained in the face of new growth and development.



Land use in the Maryland portion of the Coastal Bays subwatersheds. The size of the chart indicates the relative size of the subwatershed. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

MARYLAND DEPARTMENT OF PLANNING

Compact, cluster, or open space development is defined as a development pattern where buildings are concentrated in Priority Funding Areas to minimize infrastructure and development costs while still having the same number of buildings. Concentration of roads and other infrastructure, and reduced total lengths of these, will also reduce future maintenance costs. This approach allows for the preservation of natural open space, environmentally sensitive features, and valuable natural resources, such as agricultural lands (see prime farmland map later in this chapter). Currently, in the Coastal Bays watershed, land near Berlin and Showell are targeted areas for future growth, while Ocean City, West

Ocean City, and Ocean Pines can expect infill of existing lots or conversion of existing structures.

Environmental design strategies use careful site design and resource conservation techniques to reduce the environmental impact of new growth and improve the performance of buildings, neighborhoods, and communities while preserving local natural resources. Some examples include the use of permeable pavement, rain gardens and bioretention swales, native landscaping, water and energy conservation, recycling and reuse of building materials, and alternative energy production.

Sustainable land management uses environmentally sensitive practices

Buildings consume nearly a third of America's energy—much of it wasted—while land-use decisions influence another third by limiting choices for transportation. Development, therefore, can offer abundant opportunities for saving resources, reducing waste, and restoring damaged land. Future generations will be affected by today's choices.[44]

Existing regulations to protect wetlands, forests, shorelines, and other natural features are prescriptive and mainly negative ('thou shalt nots'), directing what should not be done. This established an unintentional path of least resistance leading to urban sprawl, traffic congestion, unnecessary environmental damage, and disjointed, disconnected communities. To create well-designed, sustainable, and diverse neighborhoods, a revised approach using simple, long-held principles of urban design is needed. Examples of these principles include the tradition of shop owners living above their businesses in urban areas, or walkable neighborhoods where children can safely reach schools away from traffic corridors.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The seaside qualities of the Coastal Bays attract people, necessitating consideration of sustainable development principles.

Conservation development and low-impact site design will minimize land consumption, preserve open space, and improve community interaction to protect existing features as well as provide opportunities to restore damaged sites. Natural processes can be used to manage stormwater, energy consumption, and pollutant reduction. Architectural designs can reduce energy and non-renewable material consumption, while promoting a sense of place and cohesiveness.

Low-impact development & conservation development

Low-impact development is the practice of using techniques in building and construction that minimize stormwater runoff and the effect that development will have on the quality of the surrounding environment.

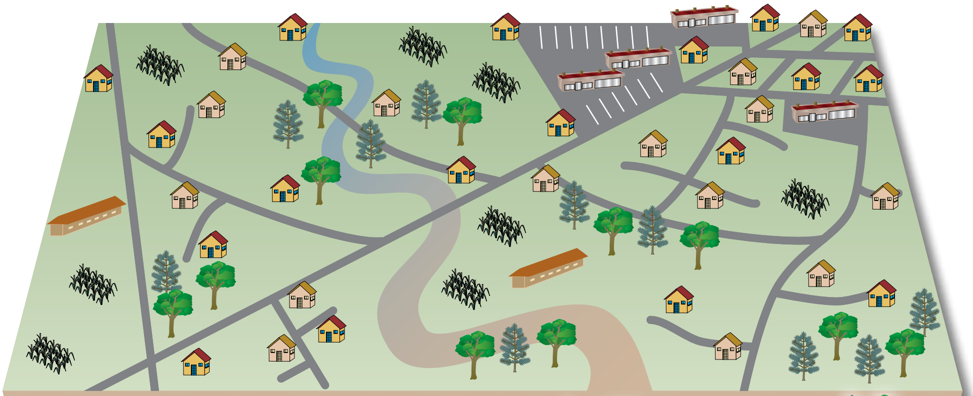
Conservation development, also known as conservation design, promotes sustainable development while protecting the area's natural environmental features in perpetuity, including preserving open space and viewsheds, protecting farmland or natural habitats for wildlife, and maintaining the character of rural communities. A conservation development is usually defined as a project that dedicates a minimum of 50% of the total development parcel as open space. The management and ownership of the land are often formed as a partnership between private landowners, land conservation organizations, and local government. It is a growing trend in many parts of the country.

Development does not inherently damage the environment. However, its form and pattern must be designed to protect natural resources and processes. Today's technology joined with improved scientific understanding and commitment to environmental protection can create more compatible and livable neighborhoods and communities. Using these basic principles and working with natural features, rather than considering them obstacles, can produce development that enhances the quality of life and our built environment.

Recommended model development principles for Worcester County[2]

The Worcester County Local Site Planning Roundtable, made up of a diverse cross-section of local government, civic, non-profit, environmental, homebuilding, development, and other community

Unsustainable communities



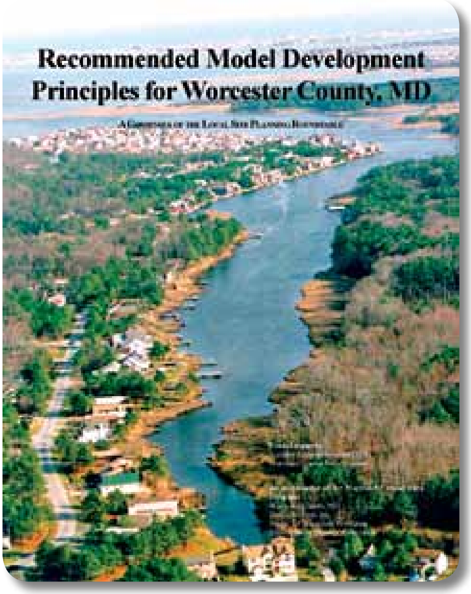
Poorly planned communities result in unmanaged urban sprawl , fragmenting forested and agricultural lands .

Sustainable communities

Well-planned communities ensure that new development uses a whole-systems approach to environmental planning, preserves hubs of high-quality habitat connected by natural corridors for wildlife movement, strives to restore and enhance reduced or lost environmental functions, clusters development , uses integrated pest management to reduce the need for pesticide application, and uses other low-impact development techniques to minimize runoff and habitat loss. Worcester County can lead the way to sustainable development by ensuring that county buildings are energy- and water-efficient, use environmentally conscious building materials and practices, have improved indoor air quality, and are planned from the beginning to have all of these characteristics.

professionals, participated in a nine-month-long consensus process in order to recommend development principles for Worcester County. The consensus process reviewed existing development codes and identified regulatory barriers to environmentally sensitive residential and commercial development at the site level. Members adapted the National Model Development Principles to specific local conditions resulting in general and specific code and ordinance revisions that would increase flexibility for site design standards and promote the use of open space and flexible design development in Worcester County. The National Model Development Principles refined by the Worcester County Local Site Planning Roundtable meet the following objectives:

- Reduce overall site impervious cover.
- Preserve and enhance existing natural areas.
- Integrate stormwater management.
- Retain a marketable product.



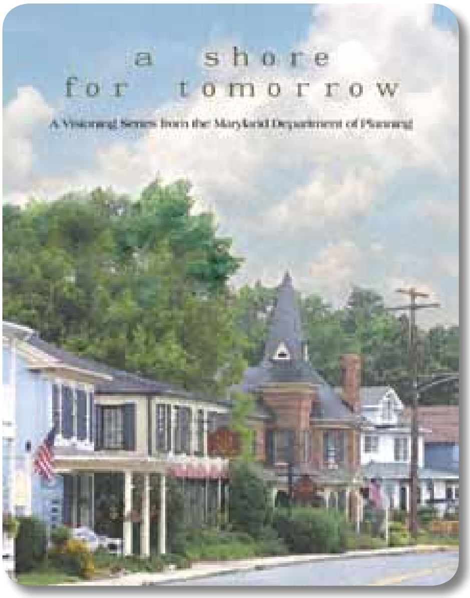
Recommended Model Development Principles for Worcester County, MD

Copies of Recommended Model Development Principles for Worcester County, MD are available from the Center for Watershed Protection at *www.cwp.org*, the Maryland Coastal Bays Program at *www.mdcoastalbays.org*, or Worcester County Department of Comprehensive Planning at *www.co.worcester.md.us/compplan.htm*.

A Shore for Tomorrow

Worcester County has been at the forefront of wise planning in Maryland and is actively promoting smart growth policies and regulations. A recent report by the Maryland Department of Planning—A Shore for Tomorrow—encourages Eastern Shore counties to maintain their traditional landscape and resource-based economies through proper planning and land management.[30]

In addition to illustrating growth trends over the last three decades, this report presents two future growth scenarios: "Current Policies" and "Smart Growth." The purpose of these scenarios is to illustrate future growth alternatives resulting from different land management policies. The Shore is expected to add nearly 160,000 additional people over the next 25 years. This population will be more diverse than in the past, creating many challenges and opportunities for planning in the future. Eastern Shore citizens can evaluate which of the alternatives can better create the Eastern Shore they envision for the future.



a shore for tomorrow

Copies of A Shore for Tomorrow are available from the Maryland Department of Planning at *www.mdp.state.md.us/pdf/Shore_for_Tomorrow.pdf*.

Build-out scenarios: What would Delmarva look like if it were completely developed according to current zoning regulations?

Due to the close geographic nature of Delmarva—which encompasses parts of Delaware, Maryland, and Virginia—it is nearly impossible for the actions of one state or county to not affect neighboring areas. With rapid population increases in coastal communities, steps taken to promote sustainable planning practices are of utmost importance to successfully and simultaneously balance natural resources with future land use to ensure Delmarva's long-term viability.

Coastal development, emergency preparedness, infrastructure planning, tourism, groundwater, agriculture, and wildlife habitat corridors are just some of the shared issues that cross state boundaries. Each state has different means for tackling these quality-of-life issues and there is a need for larger-scale planning as well as opportunities for sharing technology and ideas. Responding to this need, in January 2005 the Maryland Coastal Bays Program gathered planners and elected officials from Sussex (DE), Worcester (MD), Accomack (VA), and Northampton (VA) Counties to convene the Delmarva Coastal Communities Planning Conference. There, the group shared both tools and needs and began brainstorming for what is now called the Delmarva Atlantic Watershed Network (DAWN)—a tri-state effort to create a technology network and promote regional collaboration among decision-makers on issues related to coastal conservation.

In 2007, DAWN gathered planning staff and more than 150 citizens from Sussex, Worcester, Accomack, and Northampton Counties and the Delaware, Maryland, and Virginia Coastal Zone Management Programs to determine what the region would look like at build-out if development continued under current zoning regulations. Maps were developed to visualize existing versus potential development density. Changes in nutrient inputs, land consumption, population, and even school enrollment were measured

Sustainable planning recommendations

- Integrate open space requirements for new development with the green infrastructure plan to provide maximum wildlife connections.
- Require low-impact development techniques for new and re-development.
- Produce and adopt an illustrated development guidelines document.
- Require new development to meet ecological function and restoration goals.
- Include integrated pest management and xeriscaping into new development covenants and design guidelines. (Xeriscaping uses plants adapted to local conditions and other methods to minimize irrigation needs.)
- Ensure that all new county buildings are environmentally friendly by designating staff to facilitate the county's adoption and implementation of a green building program.
- Foster the use of green building techniques in the private sector.
- Seek grants to help offset initial costs associated with environmentally friendly design and building.

Maryland Department of Planning's 10 principles of smart growth

1. Mix land uses.
2. Take advantage of compact building design.
3. Create housing opportunities and choices.
4. Create walkable communities.
5. Foster distinctive, attractive communities with a strong sense of place.
6. Preserve open space, farmland, natural beauty, and critical environmental areas.
7. Strengthen and direct development toward existing communities.
8. Provide a variety of transportation choices.
9. Make development decisions predictable, fair, and cost-effective.
10. Encourage community and stakeholder collaboration in development decisions.

and shown graphically. These illustrations also provided a glimpse of what Delmarva could lose—prime agricultural soils, green infrastructure, and rare and endangered species' habitats. Additional pollution inputs would further exacerbate water quality problems and losses of seagrasses and other living resources.

What came out of the efforts was the sobering fact that in just a few decades, with current laws, not much would be left of the Eastern Shore as we know it.

With strong agricultural zoning and a comprehensive plan that keeps most new growth adjacent to existing infrastructure and out of forests, wetlands, and floodplains, Worcester County serves as the model to which to aspire. At build-out, Worcester County should have less than 100,000 full-time residents—about twice the current population. In stark contrast, Sussex County's 223,000 ha (550,000 acres) have no agricultural zoning. At the permitted two lots per acre and after extracting wetlands, built lands, and protected lands, the county is facing a build-out of around 2 million residents sprawled across the county. This is more than 10 times its current population of 184,000 people. At its current pace, the county will lose close to 80% of its forests, 80% of its agricultural land, and is looking at a four-fold increase in nutrients over much of the western and northern parts of the county.

On the Eastern Shore of Virginia, things are changing for the better. While not perfect, the newly proposed comprehensive plan in Accomack County and the proposed zoning changes in Northampton County represent new steps to direct residents around existing infrastructure and away from sensitive areas. At build-out, both counties combined are projected to have around 100,000 people, up from 44,000 today.

As a result of these workshops, Sussex County citizens undertook a massive campaign to educate the public about the county's shortcomings. The Sussex Heart and Soul campaign asked county residents to send photos of the things that make Sussex County the place they want to live. This work culminated in an early 2008 summer workshop to both show how the changes in landscape would affect its residents' desires and to contemplate alternatives.

The work has taken on more than a water quality component with the data from DAWN work raising the interest and concern of residents who think the Shore's legacy should be more than strip malls and subdivisions. For more information, see *www.thedelmarvanetwork.org*.

Green building design minimizes environmental impacts

At its core, 'green building' is the intent to consider the entire life cycle of structures, i.e., plan, design, construct, maintain, and then dismantle or refurbish buildings to create neighborhoods that are healthy and comfortable, conserve energy and resources, and minimize impacts to the local and global environment.

A new home, built by Chestnut Creek, Inc., and the neighborhood in which it stands, are examples of 'green building' in the Coastal Bays watershed. Only a three-to-10 minute walk to all major town amenities, Walnut Hill is an 'infill' neighborhood in Berlin. The neighborhood is compact, with narrow, tree-lined streets and sidewalks, a


KATHERINE MUNSON

The 'green' house in Walnut Hill, Berlin.

common open space, and clustered mail delivery. All homes are required to meet the U.S. EPA's Energy Star standards for energy efficiency. In addition, these homes meet the U.S. Department of Energy's "Building America" energy efficiency standards, and incorporate all the core features of green building:

Health & comfort

- No/low volatile organic compound glues and paints.
- Soy-based spray foam insulation.
- Oriented to accept winter sun and summer breezes.
- Groundwater source heat pump with Heat Recovery Ventilator system.

Energy & resource conservation

- Pre-cast basement walls (using 70% less concrete than equivalent poured concrete walls).
- Steel roof of 95% recycled content.
- Energy- and water-saving appliances.
- Plumbed for gray water recovery, storage, and use.

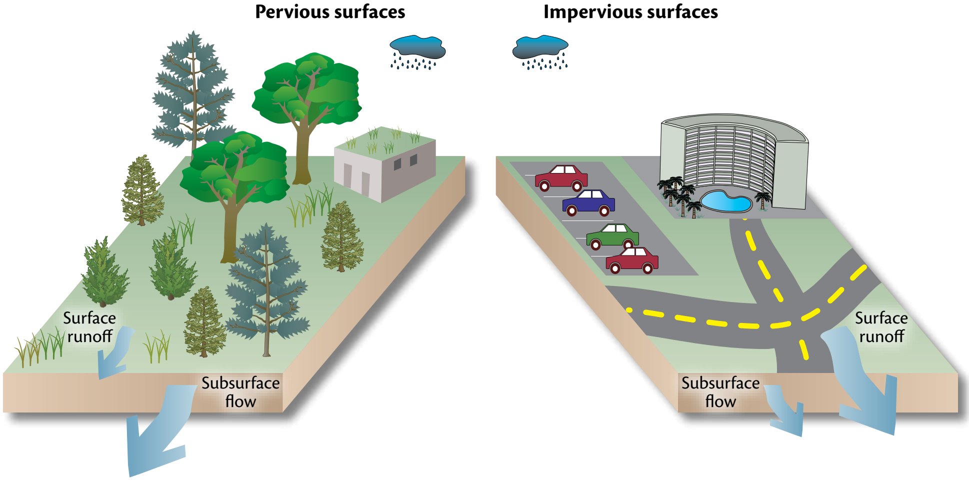
Minimized environmental impacts

- Modestly sized, at 185 m^2 (2,000 ft^2).
- Framing of locally sourced pine.
- Cabinetry frames made from agricultural waste sheet goods.
- Passive solar water heater.
- Cork and limestone tile floors.

Utility expenses (gas and electric) at the 'green' house in Walnut Hill average about $0.30 per square foot of living space (basement excluded) per month. A range of $0.25–$0.30 is usually considered extraordinary. The electric charges are approximately $2.30 per day, and natural gas charges approximately $1.00 per day, totalling approximately $100 per month (2007 rates).

Impervious surfaces impact environmental quality

Impervious surfaces are any areas that prevent water from penetrating the ground, such as pavement, rooftops, decks, compacted soils, etc. Water runoff volume increases as natural areas are replaced with these hardened surfaces. In a natural system, soil, forests, and wetlands act like sponges, soaking up the rain. Most of the water infiltrates into the soil and is slowly released into streams, rivers, and bays through groundwater. The steady absorption and release of water to streams



Pervious surfaces such as grass, soils, and 'green roofs' allow water to infiltrate the ground, slowing and reducing runoff and recharging groundwater. Impervious surfaces such as cement, asphalt, and roofing prevent infiltration, increasing the volume and velocity of surface runoff which carries nutrients and sediments with it.[33]

minimizes flooding, erosion, and drought, as well as thermal, nutrient, and chemical pollution.[3]

The construction of roads, buildings, and other watertight surfaces disrupts this natural hydrology, changing land from a filter to a funnel for stormwater runoff. This change alters stream hydrology, transports pollution downstream, and increases both the volume and velocity of stormwater runoff.

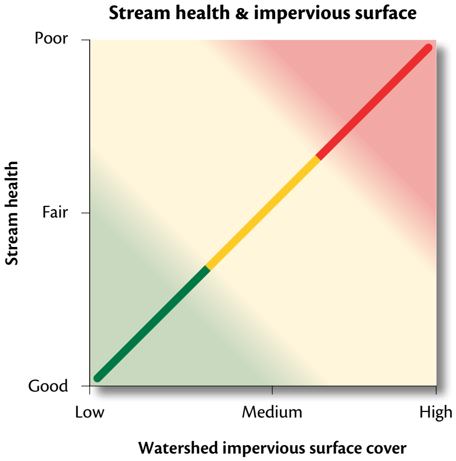
Even relatively small amounts of impervious surface can impact waterbodies. Research, from streams to estuaries, finds significant biological degradation whenever impervious cover in a watershed exceeds 10%. Impervious surface area can add up quickly. In an average subdivision, more than 20% of the total land area is impervious. In a typical shopping center, 95% of the land area is impervious.

How runoff affects natural streams

The rural lowland of Delmarva is characterized by slow-moving streams, well-drained soils, and low topography. Many natural streams have been modified and ditches have been cut into the landscape to manipulate the water table and provide a means for moving water off agricultural fields and away from roads and residential areas. These changes have provided the region with better living and economic conditions but have also contributed excess nutrients, pesticides, and sediments to local waterways. We must be careful to balance ecological manipulation with human expectations.

Impervious surfaces

Precipitation can either nourish a well-designed landscape or cause detrimental effects by transporting soil, nutrients, bacteria, and heavy metals to nearby waterways. Maryland has progressive stormwater management practices that require post-development hydrology to equal pre-development hydrology for many new developments. Current guidelines and requirements are in the 2000 *Maryland Stormwater Design Manual, volumes I & II*, via Maryland Department of the Environment: *www.mde.state.md.us*.



This graph demonstrates the relationship between stream health and the amount of impervious surface in the watershed.[34]

The relationship between stream health and the amount of impervious surface in the watershed is described below.[35]

Stable—Vegetated streambanks, large forests, fields, and wetlands protect streams by filtering out pollutants and soaking up stormwater. Stream water flows clear and contains low levels of nutrients. Stable streams support diverse and abundant fish and wildlife populations.

Impacted—Increased runoff volume from impervious surfaces erodes and widens streambanks and transports an increasing amount of pollution to streams. Overall water quality deteriorates as nutrients create algae blooms and sediments cloud the water. Populations of fish and aquatic insects that are sensitive to pollution decline sharply. At this stage, proper stormwater management can help mitigate stream degradation.

Highly degraded—Stream water runs brown with sediments and pollutants from developed areas. Streams in

Subwatershed	%
Assawoman Bay	18%
Isle of Wight Bay	10%
St. Martin River	7%
Sinepuxent Bay	6%
Newport Bay	4%
Chincoteague Bay	1%

WORCESTER COUNTY DEPARTMENT OF COMPREHENSIVE PLANNING

Estimated impervious area by watershed, from the preliminary assessment of imperviousness by watershed (2004 land use data).

watersheds with more than 25% impervious cover can only support a few fish species that are able to tolerate high levels of pollution. This level of development is a point of no return—even the best stormwater management practices cannot mitigate all the impacts of overwhelming runoff.

Recommendations[10]

- Use pervious pavers, rain barrels, swales, and rain gardens to prevent neighborhood flooding, slow down runoff, and allow the water to penetrate into the soil.
- Consider impervious surfaces effects on aquatic systems in the planning process and avoid exceeding the 10% threshold in a watershed by a 'safe' margin (2–3% at least).
- Initiate research projects to define successful measures for preventing or restoring degraded coastal plain streams.
- Determine the feasibility of starting a stormwater utility in each bay watershed to raise funds for drainage improvements to handle water volume and water treatment.
- Consider stormwater infrastructure retrofits, such as catch basin inserts which collect trash and debris and prevent downstream pollution.
- Increase the use of advanced methods for stormwater management, including those that reduce the 'developed' footprint.

CAROL CAIN

Impervious surfaces increase the rate of runoff into streams, resulting in increased pollution reaching waterways.

Human waste treatment is an essential part of land management

Few issues in land use planning cause more vexation than the treatment of wastewater. A town of 10,000 people will produce, on average, over one million gallons of wastewater every day. That water must be treated to remove harmful bacteria and chemicals before it can be released back into the environment. Other contaminants of concern include pharmaceuticals, heavy metals, and household chemicals such as cleaning solvents and flame retardants. How that treatment is to be accomplished—and more importantly, who will pay for it—has become a central issue in the current and future management of the Coastal Bays. Three basic options exist: central sewer systems, small, neighborhood treatment plants, or septic tanks.

Central sewer systems achieve the highest level of water treatment and are closely monitored and maintained by licensed operators. They are expensive to build and operate, but the cost can be spread over many customers and many years. But central sewer systems can attract dense development, bringing additional air and water pollutants and more impervious surfaces to an area.

Septic tanks have the advantages of low cost and simple operation. Cleaned

Septic systems by watershed (Maryland only)

Assawoman Bay	454
Isle of Wight Bay	1,680
Sinepuxent Bay	1,031
Newport Bay	328
Chincoteague Bay	674
Total	*4,167*

Of this total, 1,300 septics are within the Critical Area (within 1,000 ft of tidal waters or adjacent tidal wetlands). At 16 kg (36 lb) of nitrogen per year per septic, the potential loading equals 21,228 kg (46,800 lb) of nitrogen per year, or 1.2 million liters (325,000 gal) per day. This is equivalent to the load produced by 4.5 Ocean Pines wastewater treatment plants. These numbers do not include the Town of Chincoteague in Virginia, which has around 2,000 households and relies entirely on septic systems.

out every two to three years, a septic tank can function for decades. In a properly functioning septic system, soil and soil microbes process the nutrients before they reach the groundwater. Their chief downside is that, when not maintained properly, they discharge nutrients like nitrogen and phosphorus to surface and ground waters. *One household on septic can discharge as much pollution as 60 houses on central sewer.*

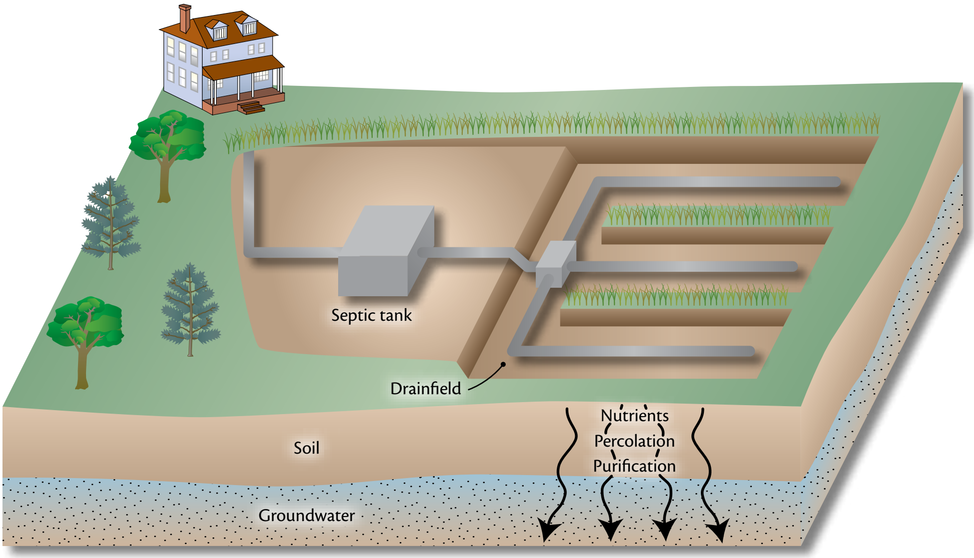
Small treatment plants, often called package plants, offer something of a balance. Their expense is distributed over numerous users and their treatment quality is high. Yet they require regular maintenance to ensure proper operation, and the problems of maintaining dozens of small treatment plants appear overwhelming.

There are no easy answers to wastewater treatment. Interactions between the type of system an area needs and how a selected system changes that area's character can provide communities with a difficult decision between the choices of poor water quality or unchecked growth. Generally speaking, however, centralized sewer that is designed to meet designated growth targets is the most cost-effective and environmentally friendly option.

Area of Special State Concern

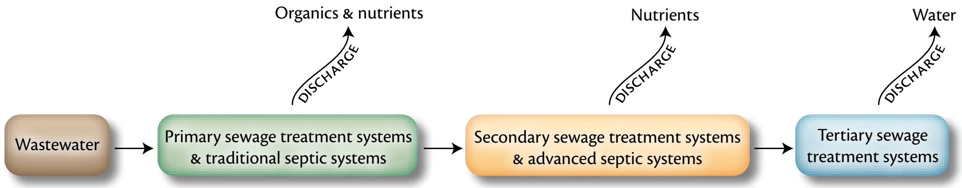
Worcester County has requested that the state of Maryland declare the Coastal

A typical septic system



A typical residential septic system.[41]

Wastewater treatment & septic system options



Different levels of wastewater treatment and septic systems discharge different quality effluent.

Bays watershed as an Area of Special State Concern, which would warrant a careful examination of septic system nutrient inputs to the Coastal Bays. The Area of Special State Concern Plan was prepared in 2002 and presented to the Worcester County Commissioners. Formal adoption and implementation of the plan has been hampered by lack of sufficient personnel for enforcement and public resistance to the high cost of advanced treatment systems.

New considerations

Projections of more than 10,000 new homes in northern Worcester County will add to existing nitrogen loading. There is a movement toward greater regulatory requirements for septics due to their groundwater nutrient loading potential. The recently established Bay Restoration Fund will generate an estimated $5.5 million per year available state-wide for septic pre-treatment upgrades with a priority on those in the Critical Area. Block grants can be applied for to upgrade individual and shared systems.

Recommendations[10]

- Nutrient-reducing septic systems should be required, at the very least throughout the Critical Area, for all new or repaired non-residential, multi-family systems and as a replacement for existing failing systems.
- Provisions for monitoring, inspection, pump-out frequency, and tracking of these systems should be made to promote and quantify nutrient reduction activities.
- Consider setting larger fees for establishing septic systems outside of Priority Funding Areas and Designated Growth Areas as an incentive to direct growth to appropriate areas.
- Identify areas within the watershed with appropriate soils and groundwater tables that have the capacity for wastewater re-use and sludge application. Determine the loading rate for nutrient runoff for forest and agricultural land accepting biosolids.

Forests are essential in healthy watersheds

Maintaining a healthy core of rural lands is critical to sustain a balance between economic growth and quality of life. Forest and wetlands in particular provide clean water and moderated water flows by buffering against flood or drought. Without conservation of our green infrastructure, re-establishing healthy streams and clean water becomes difficult and costly. Conserving and augmenting forests and wetlands, however, are cost-effective ways to protect watershed health. Some current programs to do this include:

- *Buffers along streams or wetlands.* Planting trees along waterways provides multiple benefits for water quality and wildlife in crucial locations, and can be cost-shared through Conservation Reserve Enhancement Program (CREP), Environmental Quality Incentive

Program (EQIP), or Wildlife Habitat Incentives Program (WHIP).

- *Tree planting*. Planting trees in targeted areas like wellhead protection areas or groundwater recharge areas can be cost-shared through EQIP or the Woodland Incentive Program, done in concert with a forest management plan.
- *Wetland restoration*. Restoring hydrology to previously-existing wetlands or enhancing functions of degraded wetlands can be cost-shared through the Wetlands Reserve Program or CREP.
- *Easements*. Donating or selling development rights helps keep natural cover and rural character, usually through programs like Rural Legacy (Chincoteague Bay watershed), Maryland Environmental Trust, or local land trusts.
- *Tax abatement*. Signing up for a Forest Conservation Management Agreement and following an approved forest management plan qualifies landowners for lower property tax rates, essentially a term easement that precludes development for a 15-year cycle.
- *Urban tree planting*. Planting trees in developed areas to contribute to clean air and water and offset the heat island effect.
- *Mitigation banks*. Combining fee-in-lieu funds to plant trees or restore wetlands in a larger block than would be possible on a project-by-project basis.

For more information on the benefits of intact forests, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Recommendations[9]

- Promote reforestation and wetland restoration in sensitive

WORCESTER COUNTY. 2004 AERIAL IMAGERY PROVIDED BY MARYLAND DEPARTMENT OF NATURAL RESOURCES

Headwater forests and wetlands, such as the Holly Grove Swamp area which protects the headwaters of Herring and Ayers Creeks, should be conserved.

areas such as those which are wet, riparian (streamside), or provide essential habitat. Require the use of native vegetation in all planting requirements for buffering, screening, and mitigation. When possible, permanently preserve stream headwaters for habitat and water quality benefits.

- Create a mitigation bank and planting site in each subwatershed to re-establish lost trees. Look for opportunities to plant near new or existing forests, CREP buffers, Forest Legacy and Rural Legacy areas. Review public lands to determine areas that may benefit through the restoration of trees.
- Protect critical root zones of trees during development.
- Educate homeowners' associations on forest easement management and the ecological functions of forests and streams as well as the need to protect diversity.

Sustainable agriculture supports ecological, economic, & cultural features

Worcester County's agricultural zoning is one of the best in the state. In 1967, it was at the behest of the community that major subdivisions be kept out of agricultural zones. This has had the positive effect of concentrating growth, benefiting wildlife populations, and keeping Worcester's property taxes the lowest in Maryland. This zoning has protected farming, allowed for significant land conservation, and left parcel sizes large enough to help agriculture stay viable. The agricultural economy has kept pace with tourism as the county's biggest sources of income.

Despite the value of agriculture to the area, local farmers are facing increasing pressure that threatens the viability of local agriculture. Fragmentation and high land prices, international competition, difficulty gaining access to markets, and efforts to reduce nutrient runoff all impact an already small profit margin. Currently, there is much higher demand for corn and soybeans; however, the rising costs

Prime agricultural land in the Coastal Bays watershed. Prime farmland has the soil quality, growing season, and moisture supply needed to produce economically sustained high yields of crops when treated and managed according to acceptable farming methods, including water management (irrigation and maintaining drainage).[39] Map prepared by the Worcester County Comprehesive Planning Department.

DATA OBTAINED FROM THE SOIL SURVEY GEOGRAPHIC DATABASE PROVIDED BY THE NATURAL RESOURCES CONSERVATION SERVICE of fuel adds to market volatility. But as fuel prices remain elevated, demand for locally/regionally grown and processed foods is likely to increase—creating new markets and opportunities for Delmarva agriculture.

Protecting the rural character and farmland of the Coastal Bays will require implementation of strategies to retain farmers and their ability to maintain profitable businesses. Protecting the Coastal Bays will require assisting all interested landowners with options for land preservation and implementing nutrient reduction strategies at every opportunity.

Throughout 2005, the American Farmland Trust, the Maryland Agricultural Commission, and the Maryland Department of Agriculture sponsored numerous listening sessions throughout the state in order to develop a state-wide plan for agricultural policy and resource management. The responses from the public revealed three overarching issue areas: enhance profitability, ensure an adequate base of well-managed agricultural land, and advance research, education, and the advocacy of agriculture. The result of this collaborative process was a compilation of 30 policy recommendations to ensure the future viability of agriculture in Maryland. Listed here are 13 of those key recommendations of particular importance in the Coastal Bays watershed.


DAVE WILSON

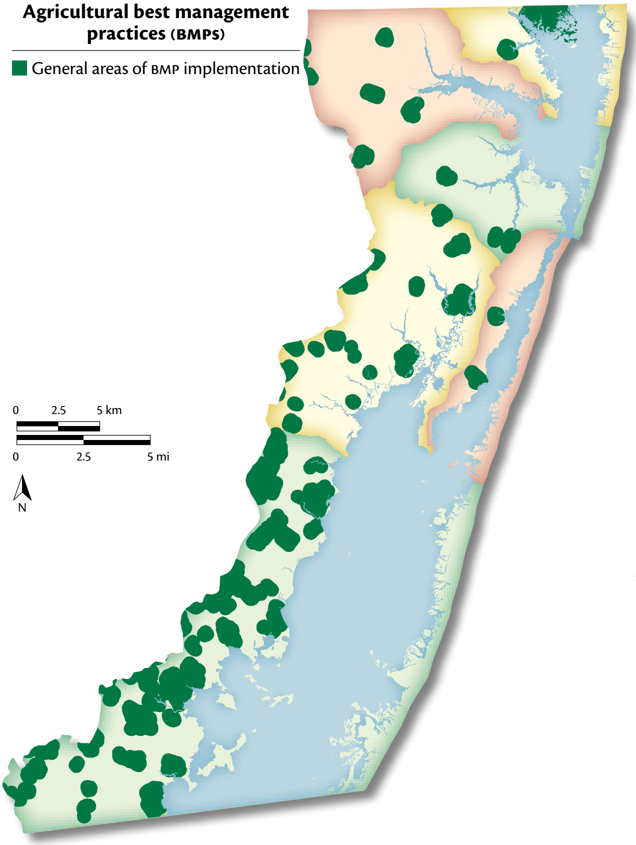
Sustainable agricultural practices and strong zoning can reduce the potential for sprawl development.


DAVE WILSON

Agriculture is a large part of the character of the Coastal Bays region.

Recommendations[7]

- Pay up to the fair market value for land easements as many farmers tend to have most of their wealth tied up in their land equity.
- Provide a range of choices for landowners seeking to preserve their land.
- Maintain state and local agricultural preservation programs.
- Implement transfer and purchase of development rights programs that complement each other.
- Provide tax incentives for donations or discounted land sales.
- Consider installed purchase agreements for easements.
- Offer the use of easement programs to help contract purchasers finance farmland acquisition (for new farmers or expansion of existing farms).
- Provide support for the development of agricultural industries, including improved marketing efforts and educating the non-farming community.
- Provide consistent and dedicated funding levels and support to public programs for land preservation and installation of best management practices (BMPs).
- Educate policy makers and the public about the fact that preserved farmland stays on local tax rolls, costs less in public services expenses, and requires an implemented soil conservation and water quality plan.
- Determine the feasibility of adding an Agricultural Economic Development staff person as well as a Soil Conservation District (SCD) staff person within county government. Several counties now utilize these positions effectively to achieve many of the goals listed above.
- Coastal Zone Management currently supports one SCD staff person who targets technical assistance to farmers in the Coastal Bays watershed. Support continued funding for SCD staffing and state and federal incentive programs that assist farmers with the installation of BMPs.
- Consider using the USDA's Conservation Security Program



Best Management Practices implementation in the Coastal Bays watershed.

CONSERVATION RESERVE ENHANCEMENT PROGRAM & WETLANDS RESERVE PROGRAM, U.S. DEPARTMENT OF AGRICULTURE

BMP type	Assawoman Bay	Isle of Wight Bay	Newport Bay	Sinepuxent Bay	Chincoteague Bay
Conservation cover	0	0	5	0	0
Existing filter strip/ grass buffer	0	0	6	0	0
Existing trees	0	0	0.3	0	0
Filter strip/grass buffer	4	70	65	3	0
Food plot	0	0	2	0.4	0
Pond	0	0.5	0	0.4	0
Tree buffer	1,297	141	425	96	596
Wetland	1,064	0	71	44	15
Total	**2,365**	**211.5**	**574.3**	**143.8**	**611**

Approximate acreage of best management practices implemented within the Coastal Bays watershed.

CONSERVATION RESERVE ENHANCEMENT PROGRAM AND WETLANDS RESTORATION PROGRAM FUNDING BETWEEN 1998–2005, NATURAL RESOURCES CONSERVATION SERVICE, SNOW HILL, MARYLAND

(CSP) as a model to develop local programs based on incentives that reward ongoing stewardship of natural resources. The CSP provides tiered annual payments to farmers according to the level and extent of conservation management on their land. They are also eligible to receive funds for installing additional BMPs.

The 2002 Census of Agriculture showed the value of products sold by Worcester County's 403 farms was $123.5 million. The same area accounts for 20% or 10.3 million of the state's broiler and other meat-type chickens sold and now ranks second in the state in corn production and fifth in soybean production.

The Maryland Agricultural Land Preservation Foundation (MALPF) has preserved more than 1,600 ha (4,000 acres) in Worcester County since 1996. For more information, visit *www.malpf.info*. A significant amount of funding for MALPF in the past has come from the U.S. Department of Agriculture Natural Resources Conservation Service Farm and Ranch Lands Protection Program (FRPP). Maryland typically receives some of the greatest FRPP allocations nationwide ($3–$5 million per year). More information is at *www.nrcs.usda.gov/programs/frpp/*.

Wetlands & streams have been channelized for agriculture & stormwater control

The flat landscape of the Eastern Shore, coupled with high water tables and nearness to sea level, fosters slow drainage of water off the land. To promote faster drainage, ditches were often used by farmers and landowners to drain low-lying fertile lands that are subject to flooding. Public Drainage Associations are authorized legal entities with taxing authority who coordinate the construction, management, and maintenance of these conveyance systems.

ROMAN JESIEN

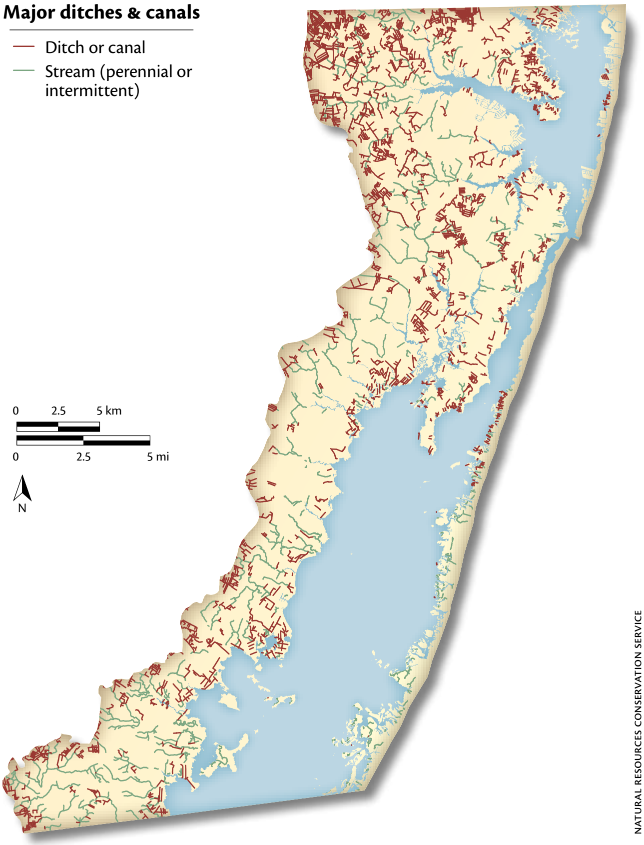
With no best management practices in place around this agricultural ditch, runoff from the newly plowed field on the right will not be slowed or filtered before it reaches the waterway.

Historically, proper drainage of frequently saturated soils has helped create more productive farmland, reduced localized flooding on individual parcels, and improved transportation infrastructure in addition to supporting local economies and public health. The unintended consequence of removing wetlands and channelizing streams has resulted in accelerated delivery of nutrients to nearby waterways, disruption of groundwater flow paths, loss of wildlife habitat, and exacerbated erosion and sediment loss through pulsed stormwater loads.

The Coastal Bays watershed has eight established Public Drainage Associations which manage a total of 90 km (56 mi) of ditches. Funding for maintenance is provided by taxing landowners (usually farmers) who benefit from the drainage system. Often the funds available are enough to address routine needs such as right-of-way mowing and removing blockages, but not enough to install and maintain additional improvements. As development has replaced farmland over the past century, drainage for roads, housing, businesses, and schools has added an additional burden to carry away stormwater and prevent flooding without additional compensation for upkeep and maintenance.

Drainage ditches are an integral component of many agro-ecosystems and it may not be economically feasible to restore these areas to former natural conditions. There are, however, a number of innovative BMPs that can allow for continued drainage while improving water quality and enhancing habitat and also serving the needs of farmers and other landowners.

To help Public Drainage Associations achieve their water quality goals and maintain the integrity of local drainage systems, the Maryland Department of Agriculture and the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) provide cost-share grants for the installation of several eligible BMPs for drainage ditches. The funding is available in part through a U.S. Environmental Protection Agency Section 319 grant. Eligible BMPs include water control structures that slow the transport of water from a drained watershed and allow natural processes to take effect, pocket wetland systems used to curb runoff and create wildlife habitat,



Major ditches and canals in the Maryland Coastal Bays watershed.

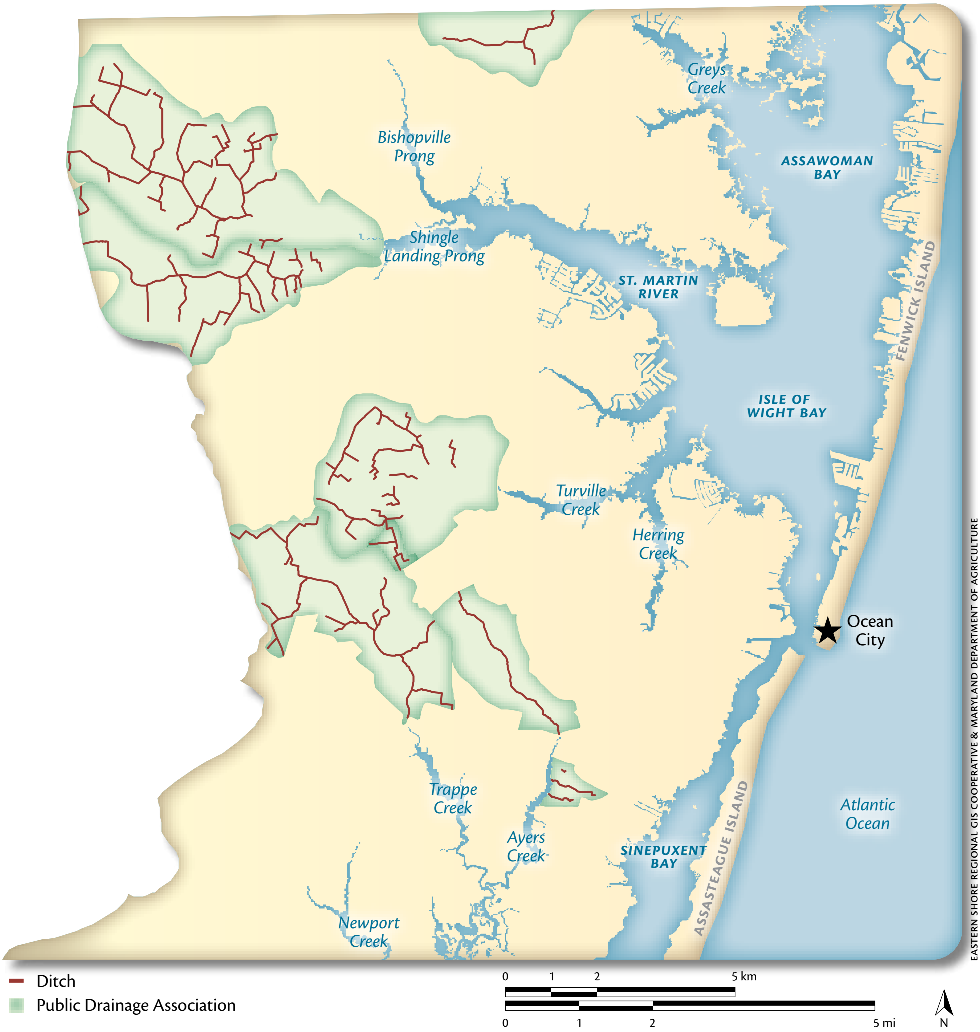
NATURAL RESOURCES CONSERVATION SERVICE

water course enhancements designed to create more naturally functioning streams, the expansion of vegetative buffers to help intercept contaminants from surface and groundwater, and a range of repairs and outlet modifications aimed at reducing sediment losses and improving water quality.

Recommendations[10]

- While adoption of BMPs can reduce nutrient and sediment loads delivered by land drainage, reduction should be maximized by installing BMPs that keep nutrients and sediments from entering ditches in the first place.
- Municipal and residential properties benefit from established Public Drainage Associations. Explore taxing those beneficiaries using alternative metrics such as the amount of impervious surface, which relates to the amount of runoff that is contributed by their

Ditches & Public Drainage Associations



EASTERN SHORE REGIONAL GIS COOPERATIVE & MARYLAND DEPARTMENT OF AGRICULTURE

Ditches within Public Drainage Associations in the Maryland portion of the Coastal Bays watershed.

property. Homeowners could receive credits/rebates based upon the use of stormwater BMPs they employ to reduce runoff.

- Right-of-way infringement issues should be addressed when development activity occurs, to ensure it does not impact maintenance.

Stream buffers control sediments & nutrients & provide habitat

Opportunities for improving streams in the Coastal Bays watershed include restoring physical and chemical integrity. Biological quality of streams will improve as a result, as well as through management for native species.

Conservation planning and zoning at the county or watershed level should include species diversity and rare species habitat management planning. Native species management should be a priority. Obstructions to fish passage should be removed and culverts should be built with fish and wildlife passage capability. Individuals can help protect native animals in their watershed by never releasing pets, bait, or wild animals to new locations because those non-native and invasive species can reduce diversity, alter ecosystems, and spread disease.

Physical improvement of Coastal Bays streams should include restoring historic wetlands and forested riparian zones. Nutrient and sediment transport downstream may be reduced by modifying ditches and implementing multi-objective maintenance practices (e.g., one-sided mowing, two-stage reconstruction design that allows for re-connecting or re-creating floodplains). Individuals can refrain from mowing to the edge of streams, permit trees to grow in the riparian zone, and utilize gravel and other permeable surfaces to minimize imperviousness.

Chemical integrity of streams will be improved by better management of animal and human waste. The use of BMPs, as well as increased regulation, enforcement, and penalties, can minimize or prevent entry of animal and human waste and other chemicals into groundwater and streams. Individuals should install and maintain properly functioning septic systems and use non-toxic pesticides, lawn and agricultural chemicals, and household cleaners.

Stream problems identified	Assawoman Bay	Isle of Wight Bay & St. Martin River	Sinepuxent & Newport Bays	Chincoteague Bay
Channel alterations	45 (66.0 km)	152 (288.7 km)	72 (108.3 km)	66 (43.0 km)
Inadequate buffers	44 (61.8 km)	118 (534.1 km)	70 (98.7 km)	63 (35.9 km)
Erosion	4 (0.04 km)	31 (3.9 km)	15 (4.3 km)	11 (2.6 km)
Exposed pipes	0	0	1	1
Pipe outfalls	4	1	21	2
Fish barriers	0	32	17	6
Unusual conditions	4	3	12	3
In/near stream construction	1	8	0	0
Trash dumping	1	4	6	6
Total problems identified	**103**	**349**	**214**	**158**

Recent surveys taken by the Maryland Department of Natural Resources observed potential problems in local streams. The first number refers to the number of potential problems observed and the number in parentheses is the length of the stream with potential problems. Assawoman Bay data include Delaware but St. Martin River and Chincoteague Bay data are only for those streams or stream portions in Maryland.[14,21,23,24]

Stream-side vegetation buffers filter nutrients and sediments before they reach the waterways.

Preservation and restoration of high-quality streams is also critical to improving the ecological quality of the Coastal Bays. Preservation can be accomplished through voluntary land management practices, voluntary restrictive conservation easements, zoning, or regulations. Conserving high-quality streams and improving the physical, chemical, and biological attributes of all Coastal Bays streams will lead to healthier Coastal Bays, cleaner drinking water, and better fishing, swimming, and enjoyment of our natural resources.

Existing wetlands need to be protected & lost wetlands need to be re-established

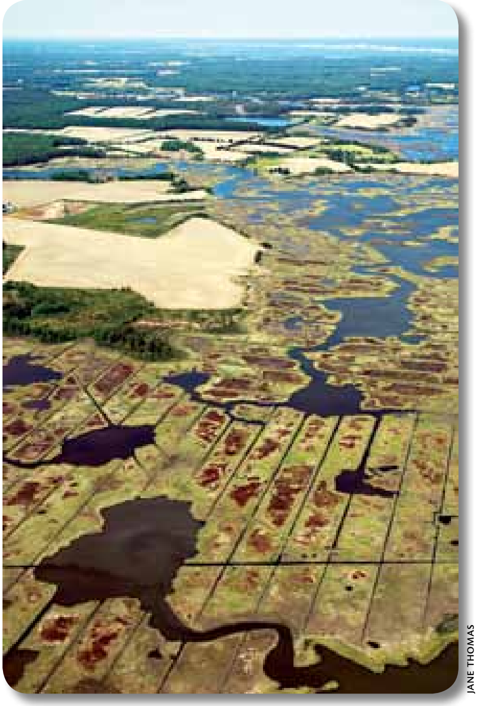
Wetlands provide important habitat for fish, wildlife, and plant species, including rare species. Habitat and biodiversity are best maintained through extensive, contiguous areas and corridors of wetlands, streams, forest, or other relatively undisturbed land. Common threats to habitat and biodiversity include filling, draining, and removal of vegetation, as well as introduction of exotic or invasive species. The results of ditching and channelizing streams has reduced the ability of some floodplain wetlands to perform flood attenuation and water quality functions. Additionally, the loss of adjacent vegetated buffer areas will prevent nature's ability to maintain biodiversity.

Approximately 600 ha (1,500 acres) of tidal wetlands and 10,100 ha (25,000 acres) of non-tidal wetlands have been lost in the Coastal Bays since the 1930s.[37] A goal to replace 4,050 ha (10,000 acres) has been adopted by the Maryland Coastal Bays Program. Since 1999, nearly 809 ha (2,000 acres) of wetlands have been created or restored largely through the USDA's NRCS Wetland Reserve Program.[10] Despite these significant gains, it represents less than 20% of the goal. For more information on wetlands, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Recommendations[15]

- Preserve the highest priority wetlands—existing or potential Non-Tidal Wetlands of Special State Concern and wetlands in or adjacent to Rural Legacy areas or green infrastructure.
- The highest priorities for restoration are sites with very poorly drained hydric soils with high organic matter and within or adjacent to the green infrastructure network, resource conservation, public, or similarly classified zoning. Restoring hydrology to drained or partially drained forested wetlands and wetlands that may be connected to Public Drainage Association-maintained ditches are included in the next highest priority category.

The E.A. Vaughn Wildlife Management Area in the Chincoteague Bay subwatershed protects 1,400 ha (3,500 acres) of marshes, forests, and fields.



Mosquito ditches draining the western shores of Newport Bay.

Requirements of successful marsh stabilization & re-establishment

- Use primarily sandy soil as a substrate for plants.
- Design and construct the project so that the low marsh is covered by open water during the mean high tide.
- Grade the site at 10:1 so that the low marsh extends to the mean low water line.
- Retain natural bank vegetation. Trim tree limbs as needed to prevent shading of marsh plants.
- Use a low profile structure. Do not place rocks directly on the marsh or as a revetment. Place the base of the sill channel-ward of the mean low water line. The sides of the sill should have an approximate 1.5:1 slope.
- The height of the sill should range from 0–30 cm (0–1 ft) above the mean high water line.
- Include opening through vents with staggered placement of rocks to allow for flushing, sediment accretion, and wildlife access.

- The Worcester County Technical Review Committee and Wetlands Planning Group should track the net gain (mitigation and establishments) and net loss of wetlands through impact permits.

Restoration of historic wetland losses

Since wetlands will generally not self-restore in a timely manner in the absence of human intervention, active restoration is necessary to replace historic losses. Accordingly, the Maryland Coastal Bays Program set a goal of restoring 4,050 ha (10,000 acres) of wetlands in the watershed. Public and private restoration projects began in earnest in the Coastal Bays watershed in the 1990s. The principal agencies active in Coastal Bays wetlands restoration are NRCS, Maryland Department of the Environment (MDE), Maryland Department of Natural Resources (MD DNR), Maryland State Highway Administration (MD SHA), and the U.S. Army Corps of Engineers.

At 21 ha (52 acres), the Coastal Bays watershed has the largest backlog of wetland mitigation in the state of Maryland. These wetlands are required by law to be replaced within the same watershed in which they were impacted or destroyed.[36]

Efforts to restore and create salt marsh should continue to be focused in the northern Coastal Bays, since losses there have been substantial and the natural processes that create and maintain salt marsh are impaired. However, restoration opportunities are limited and will require careful consideration of environmental and social impact trade-offs. Additionally, serious thought should be given to ensuring the long-term survival of these ecosystems by providing for landward migration as sea level rises.

Forested wetlands loss has also occurred on such a large scale that restoration is warranted in the Coastal Bays watershed wherever suitable sites exist. To improve water quality, restoration and creation of forested wetlands could be focused in the St. Martin River, Turville and Herring Creeks, and Newport Bay subwatersheds where they can intercept polluted groundwater and surface water.

Ocean Pines tidal wetlands restoration

The canals in the Ocean Pines community pose a significant problem for water quality and aquatic habitat (for more information, see Chapter 5—*St. Martin River*). In order to improve these conditions, Worcester County created three tidal wetlands by interrupting existing ditches, one of which was the Pintail Isle Wetland. This series of wetlands is located along Ocean Parkway and is tied into the canal system to allow the tidal flow to enter and leave the wetland areas. The movement of water helps sustain a thriving wetland ecosystem that provides suitable wildlife habitat for nesting birds, mussels, fish, and blue crabs.

This project was made possible through the Clean Water Act, Section 319 grant program. Worcester County became eligible for 319 funds by developing a watershed restoration action strategy (WRAS)—the Isle of Wight Management Plan. This plan identified a number of potential wetlands and riparian buffer areas for restoration and recommended actions for protecting and improving water quality and habitat in the watershed.

Isle of Wight Wildlife Management Area tidal wetlands restoration

In 1996, efforts were initiated to improve the southern end of the Isle of Wight Wildlife Management Area for both safety and recreational reasons. At the time, the site included 500 linear feet (150 m) of deteriorating steel bulkhead along the eastern shoreline and approximately 2,000 linear feet (600 m) of southern shoreline partially protected by dumped concrete rubble. The old steel was rusted and jagged. The concrete rubble included embedded asphalt and steel reinforcing rods.

Although people enjoyed the site, it posed serious safety concerns. The most unusual feature was located at the eastern end of the site: an empty concrete form nearly 450 ft long, 4 ft deep, and 35 ft across (137 m x 1 m x 10 m). The form was a remnant from 1972 when MD SHA used


CAROL CAIN

Four hectares (10 acres) of tidal salt marsh were created to enhance the Isle of Wight Wildlife Management Area. A fishing/crabbing pier and canoe launch site, along with parking areas, have significantly improved public access and use.


SANDY COYMAN

Restoration of Pintail Wetland in Ocean Pines. From left: Salt marsh (*Spartina alterniflora*) plugs to be planted during the restoration project in Pintail Wetland, Pintail Wetland under reconstruction; rock beds placed in the restored Pintail Wetland for mussel attachment and buffer plantings on the bank of the wetland, and the restored Pintail Wetland in January 2005.

the site as a staging and manufacturing area to build the beams for the Route 90 bridge spans.

A reasonable plan designed to preserve the natural setting and enhance the shoreline was developed by MD DNR. In 1997, while MD DNR was working with Worcester County and Ocean City to finalize the plan for making the site safer and more inviting for visitors, the U.S. Army Corps of Engineers proposed an environmental restoration project for the site in their Ocean City and Vicinity Water Resources Study. MD DNR then entered into a project agreement with the Corps to complete the project.

The full plan, embraced by the Corps, MD DNR, and Worcester County, included replacing the steel bulkhead with a stone revetment topped by a 150-ft (45-m) timber boardwalk, constructing a new access road and a 15-car parking area, installing a 500-ft (150-m) timber pier, and removing the dumped concrete rubble and replacing it with 2,000 ft (600 m) of stone breakwaters and sills. Using sand as fill material and planting the intertidal area with marsh grasses resulted in the creation of approximately 4 ha (10 acres) of tidal marsh.

State Highway Administration non-tidal wetlands restoration[31]

MD SHA is an active partner in the Maryland Coastal Bays Program. Its most visible commitment to environmental stewardship has been in building a safer Route 113 while applying every strategy and proven technique available to ensure that the improvements minimize impacts to the environmentally sensitive ecosystem of the Coastal Bays.

MARYLAND STATE HIGHWAY ADMINISTRATION

The stormwater management ponds created at the Routes 90 and 113 interchange (above) were part of a conscientious attempt to create habitat for wildlife that also complements the natural environmental features of the area (below).

MARYLAND STATE HIGHWAY ADMINISTRATION

MARYLAND STATE HIGHWAY ADMINISTRATION

This sequence of pictures from 2003 shows the restoration of Church Branch (a tributary of St. Martin River) along U.S. Route 113 and its floodplain after the old original box culvert was removed during construction of the dual highway. In order to protect the habitat of fish and other aquatic organisms, great care was taken during construction to ensure that water quality was not altered by sediment loss or chemical changes. During stream restoration projects, water is diverted around the construction zone to effectively isolate the work area from the downstream environment.

Approximately 50 ha (125 acres) of created wetlands were constructed during the Route 113 dualization highway project. All of the mitigated wetland acres were constructed within the Coastal Bays watershed. These wetlands were designed to replace the water quality and habitat functions that were lost as a result of highway construction. Permitting requirements stipulated that wetlands impacted during construction be replaced by significantly more wetlands than were lost, resulting in a net gain of wetlands for the Coastal Bays.

Large highway construction projects will invariably need to cross rivers or streams in order to maintain their directional alignments. The 24-mile (40-km) stretch of Route 113 had to cross 12 streams and required unique design elements and sensitive construction management practices to ensure that impacts to the bays were avoided or minimized. In addition, blockages were removed in order to restore the movement and migration of fish and other aquatic species up and downstream.

Natural shorelines are the critical link between land management & healthy waterways

Residential development along the shoreline does not have to degrade the very resources that attract people to reside on the waterfront. Waterfront property owners and local governments can protect the land and water resources they value by ensuring that new construction and re-development follows sensible and proven standards for building on sensitive waterfront property. Sensitive shoreline design should include the following components:[16,26]

- A building set back from the water to decrease impact on resources and protect roads and buildings from flooding and erosion.
- A vegetative buffer zone that complements the building setback as it allows for native plant establishment and wildlife enhancements.
- If natural shoreline erosion is unacceptable to the property owner, then the shoreline should be stabilized in an environmentally sensitive manner.

Traditionally, shoreline erosion control was accomplished using structural means, such as stone revetments and bulkheads. Structural armoring should be an option only along very exposed, high-energy shorelines or heavy boat traffic areas. If a shoreline is experiencing erosion but is located in a tidal creek and cove, it could benefit from a non-structural or 'living shoreline' approach.

ROMAN JESIEN

Hardened shorelines, such as this riprap along St. Martin River, offer fewer ecosystem benefits than natural shorelines.

Determining the ecological impacts when selecting one shoreline stabilization option over another depends strongly on site-specific conditions. If the property is one of a few natural stretches of shoreline in the region, it most likely is playing a significant role in providing habitat for aquatic resources. Selecting a project that either enhances or maintains those habitat functions would be optimal. If the area is quite pristine, where fringe marsh or seagrass beds are established less than 30 m (100 ft) from the property, a non-structural approach should be applied.

Maryland Shorelines Online (MSO) (*shorelines.dnr.state.md.us*) contains an interactive web mapping tool that is making it easier to determine the appropriate shoreline management options. This tool was developed to assist with identifying candidate shoreline reaches for non-structural and 'living shoreline' approaches. By using science-based assessments and mapping, selection of the living shoreline as the preferred shoreline management treatment for low-energy shorelines will be a major step towards protecting our valuable shoreline resources.

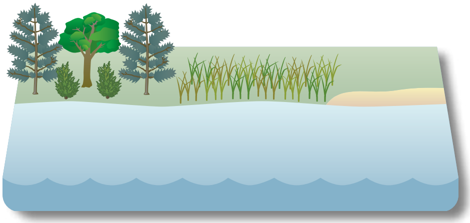
The Comprehensive Shoreline Inventory (*www.ccrm.vims.edu/index.html*)[43] is also a powerful management tool as it provides a regional perspective about the activities (shore stabilization, water access, boating facilities, etc.) and characteristics (bank height, buffer condition, shoreline habitat, riparian land use, etc.) of the shoreline.

MDE has prepared guidance and sample drawings for marsh creation to educate landowners about shore erosion control practices and habitat benefits. These guidelines were developed based on completion of an MDE-funded study to the University of Maryland. Sample drawings and the guidance are available at *www.mde.state.md.us/Programs/WaterPrograms/Wetlands_Waterways/index.asp*. Fact sheets are also available on contractor selection, practice selection, maintenance, and marsh creation. For more information on shorelines, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

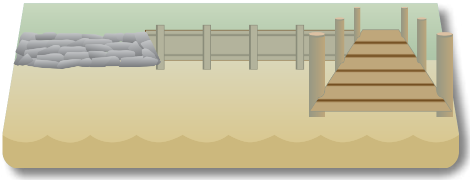
Recommendations[10]

- Use the Shorelines Online interactive mapping tool to delineate shoreline areas as low, medium, or high energy. Use the Shoreline Inventory study to determine existing shoreline structures and to look for opportunities to restore low-to-medium energy living shorelines. Work with the Worcester County Shoreline Commission, existing homeowners' associations, and

Soft & hard shorelines



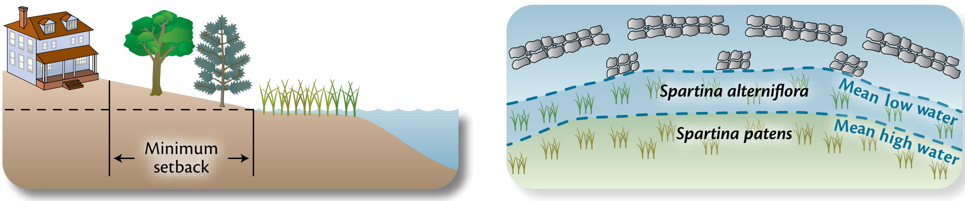
Soft shorelines—those with trees, shrubs, marshes, or sandy shorelines—benefit water quality, living resources, and habitat. Trees and shrubs shade the water and improve conditions for fish and shoreline birds. Fringe marsh protects water quality by slowing runoff, reducing erosion, and filtering nutrients which can cause algal blooms and reduce oxygen. Natural shorelines also provide critical habitat for fisheries species at both juvenile and adult life stages.



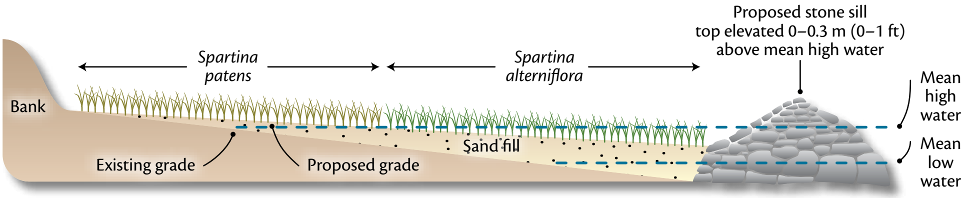
Hardened shorelines—those with riprap, bulkheads, docks, or piers—offer few benefits to water quality, living resources, and habitat, and in some cases can be damaging. They generally do not filter water before it reaches the Coastal Bays and provide little habitat for species such as nesting terrapins and horseshoe crabs. Bulkheads can result in increased erosion and scouring, and can also leach wood preservative chemicals into the water.

Guidelines for natural shore erosion control & marsh creation

Minimum setback **Offset or staggered vented sill**



Marsh creation with sill & existing bulkhead



A minimum setback from the shoreline mitigates the impacts of development on wetlands and salt marshes and increases flooding security (top left). While sills are often important for a successful project, it is essential that they be constructed in such a way that allows for flushing and wildlife access to the shore, while minimizing erosion from persistent wave action. Vents should be constructed such that they are placed in a dog-legged or staggered system (top right).[16] Profile of a typical stone sill stabilization project with sand fill and marsh plantings (bottom). Place additional rocks at base of bulkhead to prevent scouring if needed. Sites with high amounts of soft sediments (muck) may not be suitable for marsh creation. Be certain that existing substrate will support placement of sand without sinking. Additional investigation may be necessary to determine suitability.[16]

Characteristics	Low energy environment	Medium energy environment		High energy environment
Shoreline location	Creek or cove	Minor river	Major tributary	Main stem of bay
Water depth (m)	< 0.3	0.3–0.6	0.6–1.2	1.2–4.6
Fetch (km)	0.8–1.6	1.6–3.2	> 3.2	> 3.2
Erosion rate (m/yr)	< 0.6	0.6–1.2	1.2–2.4	2.4–6.1
Erosion control treatment options	*Non-structural projects* • Beach replenishment. • Fringe marsh creation. • Marshy islands. • Coir log edging, groins.	*Hybrid projects* • Marsh fringe with groins. • Marsh fringe with sills. • Marsh fringe with breakwaters. • Beach replenishment with breakwaters.		*Structural projects* • Bulkheads. • Revetments. • Stone reinforcing. • Groins and jetties.
Cost per meter	**$500–$825**	**$500–$975**	**$1,475–$1,975**	**$2,450–$4,000**

Erosion control project selection criteria.[26] To obtain the latest guidelines or requirements, contact Maryland Department of the Environment.

shoreline contractors to implement proper shoreline stabilization methods and materials most suitable for the Coastal Bays.

- To determine if areas are experiencing significant erosion (15–30 cm [0.5–1.0 ft] per year), reference points can be established using stakes or pipes along the shoreline. Surveys can then be conducted over two to three years to determine the rate of erosion. In areas not experiencing significant erosion, non-structural shore protection measures should be required.

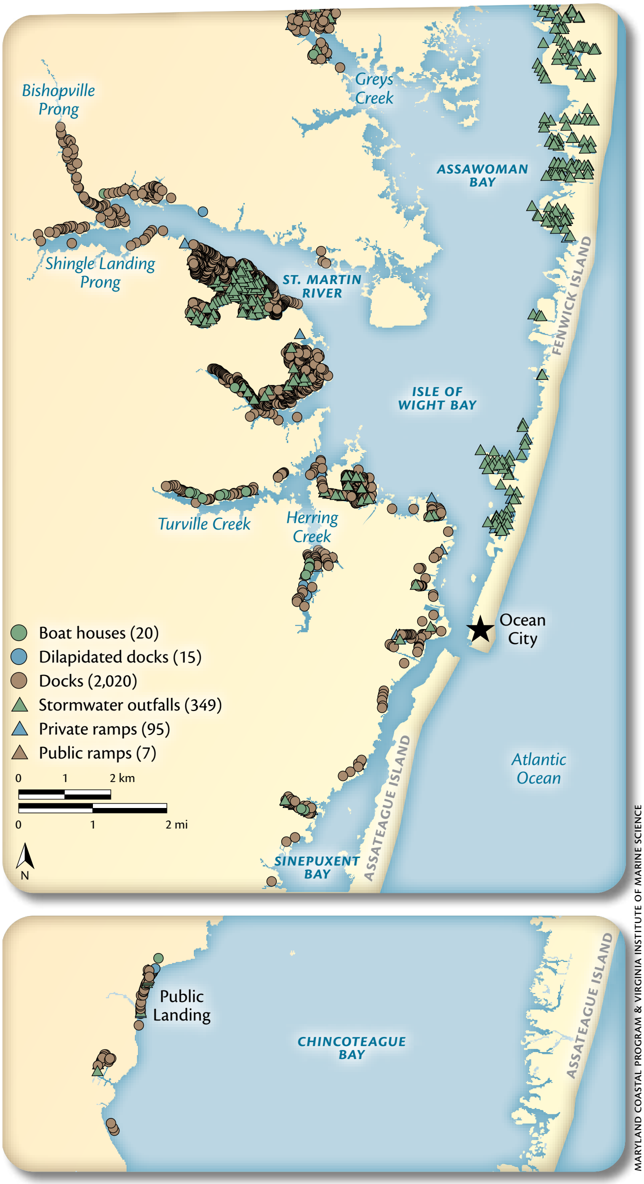
- Visit MDE at *www.mde.state.md.us/Programs/WaterPrograms/Wetlands_Waterways/index.asp* to see guidance and sample drawings for marsh creation.
- Every effort should be made to protect and preserve important shoreline habitats such as sandy beaches for the nesting of terrapins and horseshoe crabs.
- The effects of increased boating traffic and erosion by wakes must be emphasized through community education efforts.

The effects of long piers on the marsh ecosystem

With more and more development encroaching into our tidal wetland systems, the construction of piers to access state waters raises a number of environmental concerns about impacts on wetlands and the habitats they support, particularly for longer piers in excess of 30 m (100 ft). Provisions to prohibit long (greater than 30 m [100 ft]) piers over tidal wetlands were codified in the Worcester County Atlantic Coastal Bays Critical Area Law (Critical Area Law) in 2006. This prohibition was the result of concerns regarding the environmental sensitivity of Worcester County's extensive tidal marshes and the number of existing and proposed piers extending, at times, several hundred feet over tidal marsh. These types of projects can negatively affect the health and vitality of Maryland's coastal wetland resources through:

- Shading of vegetation that lies beneath docks, piers, and walkways.

Shoreline structures 2004



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Shoreline structures in the Coastal Bays. More than 275 km (171 mi) of shoreline was surveyed in 2004. Bulkheading and riprap was found to make up 52% of this area. Additionally, more than 2,000 docks exist, along with 394 stormwater outfalls.


WOODY FRANCIS

Long piers, like this one in Sinepuxent Bay, can impact adjacent tidal marshes.

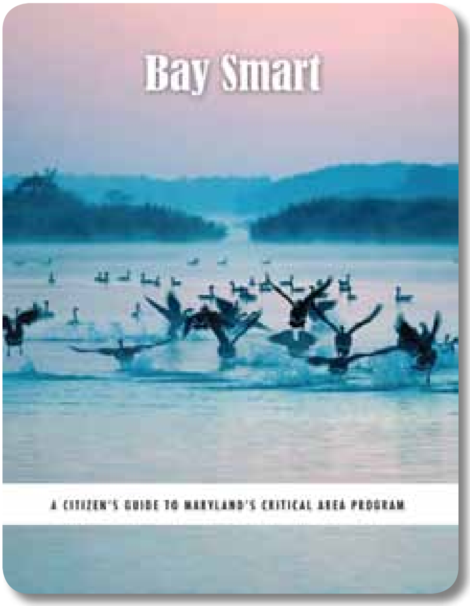
- Fragmentation of large expanses of marsh, which disturbs wildlife and provides access corridors for predators (cats, foxes, etc.).
- Navigational impediments.
- Barriers for trash and debris during large storm events as well as the potential for these long piers to break up during large storm events and contribute to debris.

As a result of workshops conducted by the National Oceanic and Atmospheric Administration (NOAA) on the effects of docks and piers on shoreline habitats throughout the East Coast, MDE funded a similar study to investigate effects on Maryland shoreline habitats. Study objectives were to investigate height, length, spacing between piers, age of piers, density of piers in contiguous marsh, type of marsh, fetch, orientation, adjacent water depth, and construction techniques. Also changes to sediment accretion and depletion, and plant and wildlife species diversity and abundance were evaluated.

During 2005, 32 sites were chosen with piers ranging in length from 100 ft (30 m) to 700 ft (210 m) and surrounding tidal vegetated marsh. Bird surveys and plant community assessments were conducted. Soil morphology was evaluated and sediment and water samples were taken and analyzed for phosphorus, arsenic, copper, chromium, zinc, salinity, chlorophyll *a*, and dissolved oxygen. The study confirmed that the construction of piers does impact marsh ecosystems through shading of the vegetation communities under and adjacent to the piers and in the composition of avian (bird) communities that use the area for both general habitat and feeding. For more information, see Chapter 7—*Sinepuxent Bay*.

The Coastal Bays were included in the Critical Area Act in 2002

The Critical Area Act, passed in 1984 (and amended in 2002 to include the Coastal Bays), was significant and far-reaching, and marked the first time that the state and local governments jointly addressed the impacts of land development on habitat and aquatic resources. The law identified the Critical Area as all land within 305 m (1,000 ft) of the Mean High Water Line of tidal waters or the landward edge of tidal wetlands and all waters of and lands under the Chesapeake Bay, Coastal Bays, and associated tributaries. The law created a state-wide Critical Area Commission to oversee the development



Bay Smart: A Citizen's Guide to Maryland's Critical Area Program is available from MD DNR at *www.dnr.state.md.us/criticalarea/download/baysmart.pdf*.

and implementation of local land use programs directed towards the Critical Area that met the following goals:

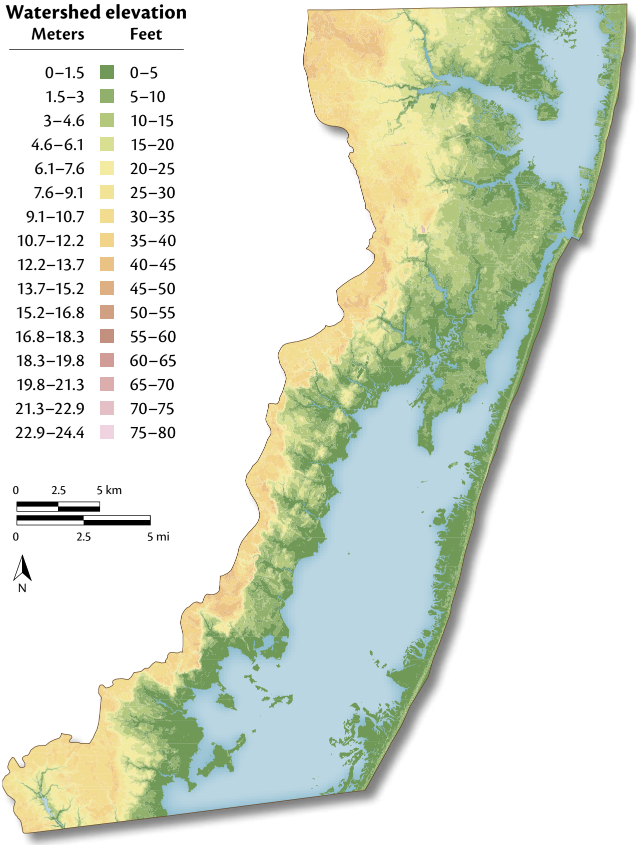
- Minimize adverse impacts on water quality that result from pollutants that are discharged from structures or conveyances or that have run off from surrounding lands.
- Conserve fish, wildlife, and plant habitat in the Critical Area.
- Establish land use policies for development in the Critical Area which accommodate growth and also address the fact that, even if pollution is controlled, the number, movement, and activities of persons in the Critical Area can create adverse environmental impacts.

The Critical Area Commission developed criteria that were used by local jurisdictions to develop individual Critical Area programs and amend local comprehensive plans, zoning ordinances, and subdivision regulations. The programs that have subsequently been adopted by local governments are specific and comprehensive. They are designed to address the unique characteristics and needs of each county and municipality and together they represent a comprehensive land use strategy for preserving and protecting tidal waters.

To implement the law, each local jurisdiction was required to map its Critical Area boundaries and designate existing land uses as one of three classifications. Except for land owned by the state or federal government, all land areas within the Critical Area were designated as Intensely Developed Areas (IDAs), Limited Development Areas (LDAs), or Resource Conservation Areas (RCAs). Worcester County has prepared maps showing which properties are affected by these designations. For more information, see *www.co.worcester.md.us/Critical%20Area/CriticalArea.htm*.[28]

Coastal areas are particularly vulnerable to storm surge & sea level rise

Over the past century, the Mid-Atlantic coastal region has seen a one foot (30 cm)



High-resolution elevation map of the Coastal Bays watershed in Maryland, which was the result of the LIDAR mapping. Elevations greater than 15.2 m (50 ft) above sea level are the result of man-made structures such as roads and the highest point on the map is the Berlin Landfill, at 22.9–24.4 m (75–80 ft).

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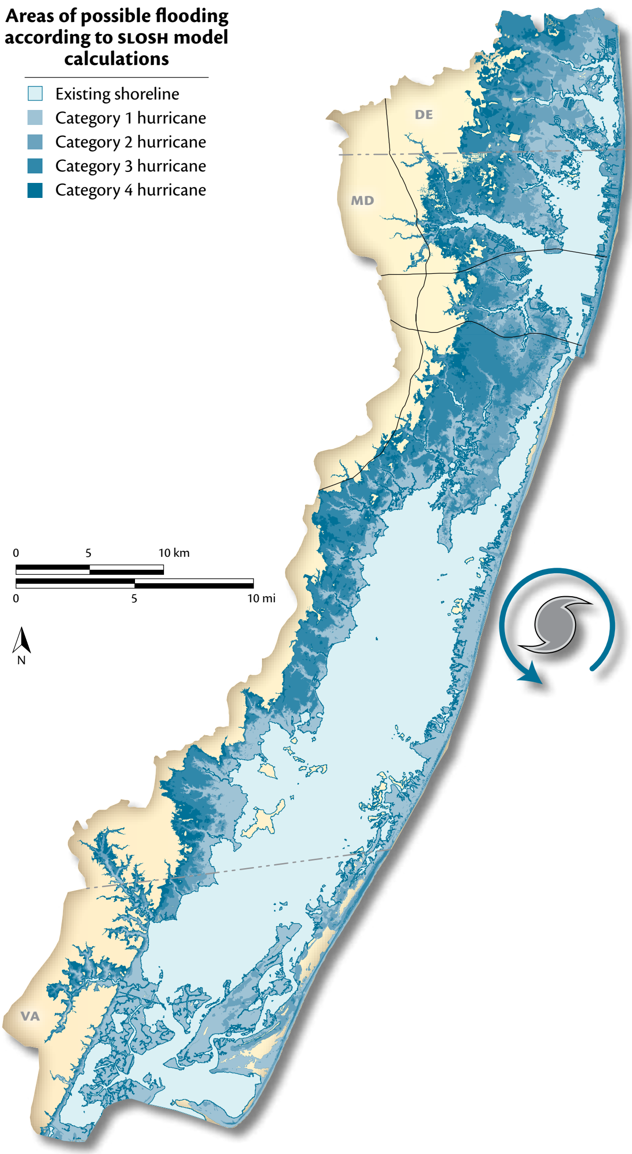
increase in sea level, which is double the global average. It is predicted that the area will see the sea level rise another 2–3 ft (60–90 cm) by 2100. MD DNR, the U.S. Geological Survey (USGS) and Worcester County collaborated to develop the Worcester County Sea Level Rise Inundation Model. The model, which is described fully in the Technical Report,[27] allows researchers, county planners, and emergency responders to see areas which may be affected by sea level rise in the future and serves as a tool for decision-makers as they consider response strategies, such as steering future development and infrastructure out of harm's way. The USGS used Light Detection and Ranging (LIDAR) to create a high-resolution topographical map of Worcester County. The map was then used to make a model to predict how sea level rise over the next century will affect storm surges, coastal flooding, and hurricane impacts. For more information on sea level rise, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*



This map shows areas of potential flooding in the Coastal Bays under different hurricane scenarios, using the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model. This model was based on the LIDAR elevation map on the facing page.

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WATER QUALITY & AQUATIC RESOURCES

The Clean Water Act sets up a process to achieve healthy waterways

We know intuitively that water quality is important. So as a community, how do we define a process to protect and improve the waterbodies that affect our lifestyles the most? Furthermore, who is responsible for taking action to jump-start the process?

Simply put, every citizen is responsible for our community's health, and with the help of local decision-makers, civic organizations, businesses, and state and federal agencies, we will make better choices now and in the future. In the Coastal Bays, we will use watershed restoration and nutrient reduction strategies to improve our community and comply with the federal Clean Water Act. The purpose of the Clean Water Act is to determine the status of all waterbodies, define a limit for pollution into those areas, and either protect clean water sites or remedy the existing problems.[40]

The Federal Water Pollution Control Act Amendments of 1972—the modern Clean Water Act—established a national commitment to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The Clean Water Act has been instrumental in improving the health of rivers, lakes, and coastal waters. It has stopped billions of pounds of pollution from fouling the water and dramatically increased the number of waterways that are safe for swimming and fishing.

Through substantive amendments in 1977 and again in 1987, the Clean Water Act has focused attention on protecting and restoring coastal resources through four programs in particular:

- The National Estuary Program.
- The Great Lakes Program.
- The Chesapeake Bay Program.
- The Nonpoint Source Program.

The significance of these specific programs is that they illustrate the formal recognition by Congress of issues such as population and development pressures, and not just pollution, as critical to coastal resources management.

The Clean Water Act guides almost everything states do to protect and restore their waters. Four important provisions of the law include: water quality standards, the 305(b) report, the 303(d) list, and the Total Maximum Daily Load (TMDL) program. It is helpful to visualize these provisions as a train, with water quality standards as the 'engine' and each car dependent on the one before.

The federal **Clean Water Act (CWA)** states "The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Maryland State water quality standards objectives state "Water quality standards shall provide water quality for the designated uses of … propagation of fish, other aquatic life, and wildlife." Terrestrial wildlife may be protected as a function of waterbody health.

A **Total Maximum Daily Load (TMDL)** establishes the maximum amount of an impairing substance or stressor that a waterbody can assimilate and still meet water quality standards. This load is allocated among pollution contributors, including natural sources.

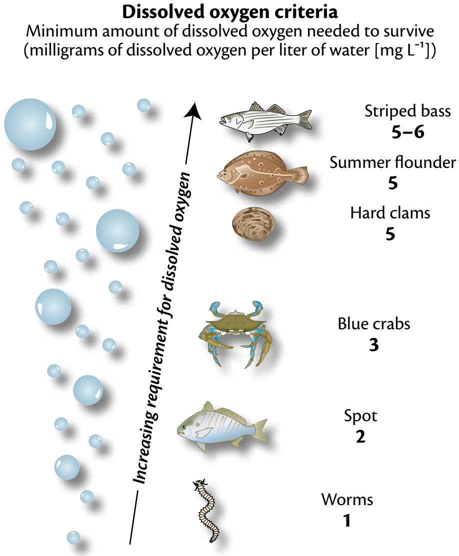
Water quality standards are established to meet "fishable & swimmable" conditions

Ultimately, all waters should be "fishable and swimmable," but what does this mean, and how would one measure it?

To answer these and other questions, Maryland has designated waterbodies according to their expected uses, determined the minimum water quality requirements for certain measurable conditions and formulated an anti-

The Clean Water Act

It is helpful to visualize the provisions of the Clean Water Act as a train, with water quality standards as the 'engine' and each car dependent on the one preceding it. Modified from Georgia Legal Watch.



Different organisms require different levels of dissolved oxygen in the water to survive.[4] Dissolved oxygen is a useful indicator of water quality.

degradation policy to protect each waterbody.

Locally, all non-tidal waters have been categorized as *Use I: Waters safe for recreational contact and protection for non-tidal warm-water aquatic life*. All marine waters are considered *Use II: Supportive of estuarine and marine aquatic life and shellfish harvesting waters*. Minimum requirements for the amount of dissolved oxygen, water clarity, bacteria levels, etc., can be determined to represent healthy goals for each waterbody.

Water quality problems are identified—305(b)

The Biennial Water Quality Report to Congress, or 305(b) report, is required from every state to provide a general summary about the quality of the state's waterways. This report lists every waterbody and whether each is "fully," "partially," or "not" supporting the designated use. The report also details which pollutants are causing problems and tries to determine potential sources of the pollutants.

The train analogy can be taken a step further by imagining two possible 'destinations' or goals: protection and restoration. Where high-quality waters exist, the goal is to implement an anti-degradation policy to hold the line on pollutant loading. For those waters found to be affected by excessive pollutants, a remediation plan must be established to meet the designated use.

Local water quality data are analyzed to determine status—303(d)

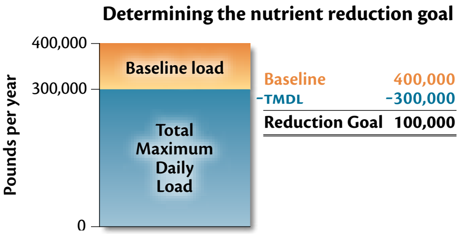
Where waterbodies are excessively impacted, a segment-by-segment listing of where impairments exist is compiled. These segments are listed for the criteria that are violated (e.g., bacteria levels) and given a priority status to determine the order in which clean-up plans (TMDLs) are proposed.

Allowable pollution loads are established to meet water quality standards—TMDL

A TMDL is essentially a pollution limit that needs to be set for every problem pollutant in each waterbody on the 303(d) list. The cap defines the maximum amount of each pollutant that the waterbody can receive and still meet water quality standards for all its designated uses.

Once the cap is set, allowable loading for each pollutant is divided up among the potential sources. This 'pollution budget' should include allocations for natural background conditions, permitted point sources (e.g., wastewater discharge), non-point sources (e.g., stormwater runoff, atmospheric deposition, etc.), future growth needs, and a margin of safety that accounts for uncertainties in the analysis and is protective of water quality (a typical margin of safety is 5% of the non-point source load).

With community input, a clean-up plan is devised to determine specifically how and where changes can be made

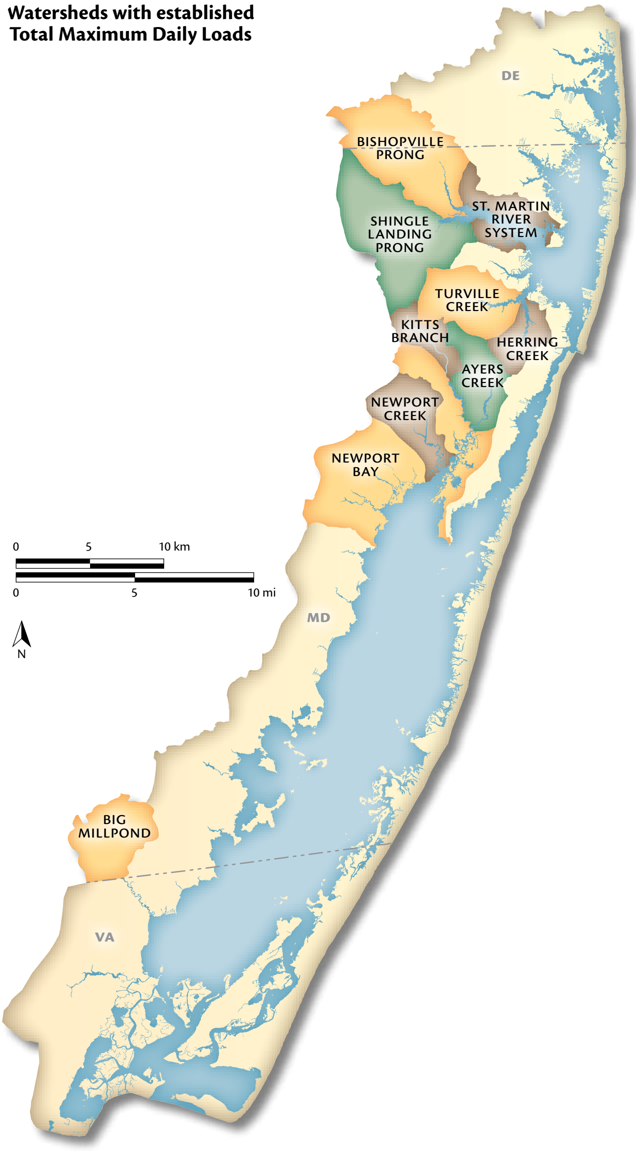


The nutrient reduction goal is the difference between the baseline load and the Total Maximum Daily Load (TMDL).

on the landscape to ameliorate excessive pollution loading. In the Coastal Bays watershed, Worcester County and the state of Maryland have spearheaded this effort by developing Watershed Restoration Action Strategies. The Strategies will serve as the jumping-off point for TMDL implementation by locating all septic systems, determining the amount of cover crops planted annually, and designating stormwater retrofits, among other actions.

The evaluation of TMDL implementation involves two assessments. First, verify that the pollution control practices deemed necessary to achieve the TMDL load reductions have been implemented. Secondly, water quality monitoring can determine whether water quality standards have been achieved. Regulatory monitoring should be conducted for a long enough period of time to account for potential lag-times before drawing conclusions (e.g., accounting for riparian reforestation maturity and groundwater flushing).

It is possible that the water quality standards will continue to be violated even after implementing all of the best management practices (BMPs) deemed necessary to achieve the TMDL. This may be caused by underestimating the 'current' baseline pollutant load, overestimating the effectiveness of the



Coastal Bays watersheds with established Total Maximum Daily Loads.

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Subwatershed	Nitrogen (kg/yr)			Phosphorus (kg/yr)	Sediment (m^3/yr)	Biological oxygen demand (kg/month)	
St. Martin River system[1]	100,747			18,658	None	None	
St. Martin River	23,797			8,499	None	None	
Bishopville Prong	29,459			4,296	None	None	
Shingle Landing Prong	47,491			5,863	None	None	
Herring Creek	4,330			560	None	None	
Turville Creek	11,917			1,782	None	None	
	June 1–Oct. 31	Apr. 1–May 31	Nov. 1–Mar. 31				
Ayers Creek (kg/month)	98	827	946	None	None	None	
Newport Creek (kg/month)	127	995	1,309	None	None	None	
Newport Bay (kg/month)	2,037	7,803	14,637	None	None	None	
						June 1–Oct. 31	Apr. 1–May 31
Kitts Branch (kg/month)			None	None	None	621	2,781
Big Millpond			None	399	932		None

Total Maximum Daily Loads for the impaired Coastal Bays waters. Total Maximum Daily Load = point source + non-point source + margin of safety (5% of non-point source loads).[11,12,13]

1. Includes St. Martin River, Bishopville Prong, and Shingle Landing Prong.

BMPs, and overestimating the assimilative capacity of the waterbody. If water quality standards are still being violated, then the standards themselves should be examined, and it should be determined whether or not the designated use itself is attainable.

In rural watersheds like the Coastal Bays, most pollutants tend to come from non-point sources which present a much greater challenge due to the many sources of nutrients. Everyone contributes pollution to a degree. Determining each person's responsibility, or which sources or activities provide the cheapest and easiest means to reduce the nutrient load has proven to be a challenge. The most basic approach to addressing TMDLs is that everyone should do their part—plant buffers, protect wetlands, seek out retrofits for drainage ditches, maintain stormwater management, maintain septic tanks or connect to a centralized sewer, reduce fertilizer use, and the list goes on.

Recommendations[10]

- Assess options for pollution reduction.
- Examine cost effectiveness.
- Track BMPs currently being implemented through agriculture and new developments.
- Determine a strategy to add BMPs.
- Refer to the MDE's 2006 TMDL Implementation Guidance Document for Local Governments for assistance.

The Nutrient Reduction Action Strategy is designed to achieve water quality standards

Monitoring to date has revealed that water quality shows many warning signs of ecosystem change, even though some areas currently still have relatively good water quality. In general, water quality is degraded within and close to the major tributaries in the north (Assawoman Bay, St. Martin River, Isle of Wight Bay, and Newport Bay). Additionally, the southern bays (Sinepuxent, Newport, and Chincoteague Bays), which had previously been regarded as nearly pristine, are experiencing increases in nutrients and chlorophyll in many areas (for more information on water quality, see Chapter 13—*Water Quality Responses to Nutrients*).

Excessive nutrients—nitrogen and phosphorus—are the cause of degraded water conditions. These nutrients, which are transported across the surface of the ground as well as through groundwater, come from septic systems, agricultural and lawn runoff, atmospheric deposition, and wastewater treatment plants. Water may take up to 10 years from the time it falls as rain until it reaches the bays via groundwater—if septic and agricultural runoff were ended today, effects from groundwater would still be seen over time. Once in the water column, excessive nutrients lead to hypoxia (low oxygen), limited fish survival, and phytoplankton (single-celled algae) blooms which limit seagrass growth in many areas.

Current nutrient levels show that nitrogen and phosphorus have exceeded the upper thresholds for seagrass growth. Intensified management along with continued monitoring will be required to avert increasing degradation. The Maryland Coastal Bays Program and its partners have developed a nutrient reduction strategy to reduce pollution. This strategy includes increased efforts to contain and prevent pollution from all sources and recommends the following:

Restoration framework

Total Maximum Daily Load

- Provides the impetus and end goals to reach water quality attainment and maintain permissible loading.
- Provides the regulatory authority to drive implementation at the local level.

Watershed Restoration Action Strategies

- Watershed Characterization Reports, Stream Corridor Assessments, and Nutrient Synoptic Surveys.
- Establishes benchmarks against which to measure management and restoration activities.

Coastal Bays Management Plan

- Promotes coordination and collaboration among local, state, and federal stakeholders.
- Seeks to prevent redundancy, overlap, or conflict among agency goals and priorities.
- Leverages funding and collaboration for restoration projects.
- Provides forum for public participation and education.
- Sponsors citizen water quality monitoring to supplement state efforts.

Worcester County & municipalities

- Local jurisdictions need technical assistance and guidance to implement TMDLs, identify potential projects and sites, and define priorities for resource allocation.
- WRAS documents can be highly effective in justifying funding requests.

Local problems require local solutions. A plan to restore local waterways will include the collaboration of many groups, including citizens and businesses. The plan will be based upon scientifically derived information, management goals, and monitoring for environmental improvement.

Wastewater point sources recommendations[10]

Point sources of nutrient loading to the Coastal Bays watershed consist of discharges from municipal wastewater treatment plants.

- Analyze the current treatment level and volume of the 10 major wastewater treatment facilities within the watershed. Upgrades to treatment, increased volume to accommodate growth, and changes from direct stream discharges (point sources) to reuse and spray irrigation (non-point sources) should be analyzed to determine the projected increases or decreases in nutrient loading.

- Investigate the impacts of designating Chincoteague Bay as an Outstanding Natural Resource Water (ONRW). Under the Clean Water Act, there are several categories (or levels) of protection available for surface waters. The highest level of protection comes from a designation as an ONRW. ONRW status means that no activity is permissible if it will result in lower water quality than already exists in the affected water. A wastewater discharge permit may only be issued if there is mitigation or offsets that result in no net increase in any substance that might impact or impair the ONRW values for which the body of water was designated.

Agriculture

There are a number of agricultural BMPs to help achieve water quality standards. This strategy will focus on the use of cover crops as a way to significantly reduce the amount of nutrients entering the waterways. The Coastal Bays watershed contains approximately 16,000 ha (40,000 acres) of agricultural land, and a realistic goal for cover crops is considered to be 6,100 ha (15,000 acres).

- Provide funding to the Cover Crop Program to guarantee that all operators within the watershed who apply are accepted into the Cover Crop Program.
- Maryland Department of Agriculture (MDA) should institute a mechanism to track cover crop implementation.
- MDA should conduct a survey of operators within the Coastal Bays watershed to identify specific action items that would promote their participation in the program. Results of the survey should be used to increase participation in the program.

Nitrogen sources	Budget (% of total annual loads)	Strategies & best management practices
Stormwater (from all land practices)	24%	Stormwater ponds, reduced impervious surface (green roofs, pervious pavement), retrofits in urbanized areas. *Agriculture:* cover crops, stream buffers, nutrient management plans. *Urban:* timing of lawn fertilization.
Groundwater (from all land practices, including septic)	39%	*Septic:* Requiring nutrient reduction systems in new developments, creating pump-out and education strategies, setting up a 'loan' program for replacement. *Groundwater:* protection of groundwater recharge areas, ditch management, wetland and forest buffers, protection of headwaters. *Agriculture:* cover crops.
Atmospheric	30%	Regional public transportation, regional power plant emission control, vehicle emissions testing, pedestrian- and bicycle-friendly communities and transportation corridors, energy conservation, poultry house emission control. Regional cost-sharing arrangements and new development regulations that take into account atmospheric sources. Investigate specific power plant strategies for reducing emissions.
Point sources	1%	Spray irrigation of effluent, wastewater treatment plant upgrades and maintenance.
Erosion	6%	Although erosion is a natural process, shoreline and stream stabilization using 'soft' techniques is the preferred method for remediation.

Strategies and best management practices for various nitrogen sources.[1,29]

Septic

Improve regulation and maintenance of onsite wastewater disposal systems such that nutrient loadings are reduced. This will require the use of advanced nitrogen removal systems as well as the conversion of some onsite systems to central sewer.

- Worcester County and MDE should encourage the retrofitting of current septic systems to advanced nitrogen removal systems.
- MDE and Worcester County should not allow new wastewater drainfields to be present within 30 m (100 ft) of tidal wetlands, tidal waters, perennial streams, perennial ditches, and ponds in line with perennial watercourses.
- Worcester County should seek financial assistance to offset costs of changing over from conventional septic systems to denitrification systems or to sewer.

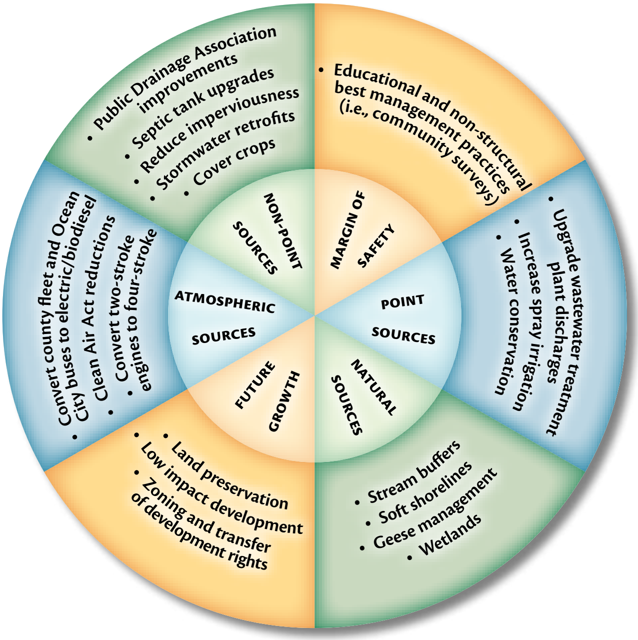
Stormwater

Stormwater is a significant source of pollutants as it flows over land and picks up heavy metals, bacteria, pesticides, suspended solids, nutrients, and floating materials. The impacts from stormwater are caused not only by the pollutants in the runoff, but also by its volume. As the water flows over land, it can erode soil and then redeposit that soil in streams, causing muddy water and degrading aquatic habitats.

- Worcester County should retrofit stormwater conveyances built prior to 2000 to address water quality and quantity. Stormwater retrofits are a series of structural stormwater practices designed to mitigate erosive flows, reduce pollutants in stormwater runoff, and promote conditions for improved aquatic habitat. For example, large impervious surfaces such as parking lots could receive landscaping strips.
- Stormwater utilities should be established by municipalities as well as by Worcester County. Utility fees could be used to fund retrofits, storm drain cleaning, education, personnel for inspection, enforcement, and maintenance as well as equipment needs.
- MDE should develop a program to assist homeowners' associations in the creation of a stormwater maintenance plan, as well as to assist in establishing a funding mechanism to meet financial obligations for the stormwater facility.

Fisheries management is by state & federal agreements, except blue crabs & hard clams

The shallow waters of Maryland's Coastal Bays have historically supported large



Pollution sources and associated Best Management Practices.

populations of juvenile finfish and shellfish. Adults of many species of fish are also seasonally common. Atlantic croaker, bluefish, spot, summer flounder, weakfish, shark, blue crab, and hard clam are important as both recreational and commercial species. Over 115 species of finfish, 17 species of molluscs, 23 species of crustaceans, and countless foraging/grazing organisms frequent these bays. Since 1972, MD DNR has sampled the Coastal Bays, supplying data for environmental reviews and resource management. For more information on the living resources of the Coastal Bays, see Chapter 14—*Diversity of Life in the Coastal Bays*.

In 1999, when the Comprehensive and Conservation Management Plan was adopted for the Coastal Bays, it distinguished this estuary as a separate,

Blue Crab Fishery Management Plan recommendations[12]

- Adopt a Coastal Bays overfishing threshold consistent with Chesapeake Bay that preserves a minimum of 10% of the blue crabs spawning potential and a fishing target that preserves 20% of an unfished population.
- Define the criteria under which a Marine Protected Area can be effective in protecting the ecological function of the Coastal Bays.
- Examine the utility of developing a public outreach indicator of blue crab abundance that can be used to inform the community on the annual status of blue crab stocks in the Coastal Bays.
- Develop and distribute a public outreach document to describe crabbing restrictions and access points for crabbing.
- Collect and analyze information about the crab parasite *Hematodinium*. Identify what intensity of infection causes mortality. Identify factors which influence *Hematodinium* proliferation, the full life cycle of the parasite, and produce a more specific diagnostic tool for identifying the parasite. For more information on *Hematodinium* infections in blue crabs, see Chapter 14—*Diversity of Life in the Coastal Bays*.
- Encourage research that examines the stock-recruitment relationship of blue crabs in the Coastal Bays, level of localized reproduction and entrapment of larvae, and effects of environmental parameters which influence fluctuations in crab abundance.

CAROL CAIN

Recreational and commercial fishing has a significant impact on the local economy. Seafood restaurants, tackle dealers, boat dealers, hotels, charter boats, and other businesses benefit substantially from local fishing activity.

NOAA'S AMERICA'S COASTLINES COLLECTION

Bushels of blue crabs are a familiar sight in the Coastal Bays.

Hard Clam Fishery Management Plan recommendations[20]

- Develop an action plan for improving hard-bottom habitat (i.e., shell or other suitable substrate) to reduce predation on small clams. The action plan will include the identification of planting materials and sources, enhancement areas, and funding sources.
- Develop and distribute a public outreach document illustrating recreational clamming areas, access points, methods, and harvest restrictions.
- Investigate the feasibility of planting seed stock to establish or enhance areas for recreational clamming.


NOAA'S ESTUARINE RESEARCH RESERVE COLLECTION

Hard clam is an important commercial and recreational species in the Coastal Bays.

unique ecosystem from Chesapeake Bay and recommended that MD DNR address fisheries issues specific to area.

In 2001, specific management plans were adopted for blue crab (*Callinectes sapidus*) and hard clam (*Mercenaria mercenaria*) populations. The purpose is to conserve the coastal stocks, protect their ecological and socio-economic values, and optimize the long-term utilization of the resources.

Aquaculture could emerge as an alternative to wild harvest

Aquaculture, or the production of aquatic plants and animals, has been a part of Maryland's history for over a century. The industry currently consists of a diverse array of products ranging from traditional shellfish such as clams to aquatic plants for use in water gardens and shoreline stabilization. In addition, the use of aquaculture products for the restoration of depleted or disrupted natural populations has been an area of increasing research and interest in recent years.

Legislation enacted during 2005 created the Maryland Aquaculture Review Board which provides regular interagency review of permits and issues across departmental lines. The Maryland Aquaculture Coordinating Council was also created, comprising 17 designated members from industry, academia, regulatory, and political categories. Among the tasks with which the Council was charged was the development of BMPs for all forms of aquaculture.[8]

BMPs are defined as methods of operating an aquaculture business to minimize, so far as practicable, pollution or environmental disruption. A key feature of aquaculture production is the reliance on clean water. Whether in the production of shellfish, finfish, or other aquatic life forms, water quality is a key parameter in the economic success of the business. In addition, aquaculture producers recognize the relationship between production and natural resources. These BMPs provide a voluntary set of standards and procedures for improving production while helping to preserve the environment. Further, these methods can serve as the foundation for a sustainable industry—a desirable state that ensures the long-term efficacy of the business.

These BMPs are formed from existing state and federal laws and regulations, as well as voluntary measures that are recommended. Their purpose is to provide producers with a base of knowledge regarding expectations of them in the development of their businesses. In all, they comprise a roadmap for those entering the aquaculture industry to follow as they grow their businesses in the state. These will be reviewed and


ROMAN JESIEN

Tiny seed clams are cultivated in raceways and upwellers at Gordon's Shellfish Company at Public Landing. The seed clams are brood stock for aquaculture farming, one of the fastest growing segments of agriculture according to the U.S. Department of Agriculture.

revised on a regular basis in the hope that the industry will continue to grow while maintaining a position of environmental compatibility.

Recommendation

- Conflicts between aquaculturalists, commercial watermen, waterfront landowners, and other natural resource user groups need to be resolved. The concept of expanded aquaculture should be supported with appropriate operational practices, state support, and with the collaboration of the various bay user groups.

Critical habitats deserve special protection

The Sensitive Areas Initiative stems from goals in the Recreation and Navigation Action Plan of the Maryland Coastal Bays Program's Comprehensive Conservation and Management Plan which seeks "to balance resource protection with recreational use."

Certain water-based recreational activities are thought to be incompatible with long-term protection of Coastal Bays resources. The presence of too many boats and personal watercraft in sensitive areas poses a threat to natural resources through direct impacts, increased pollution, and excessive noise.

A Sensitive Areas Technical Task Force was formed in 1999 and membership included resource experts from county, state, and federal agencies and universities, as well as citizens and Maryland Coastal Bays Program personnel. The Task Force took a resource-based approach to identify sensitive estuarine species and habitats, evaluate the risks from specific recreational activities, and develop appropriate measures to avoid conflicts while mitigating those threats.

The Sensitive Areas Initiative report describes the recognized sensitive resources in the Coastal Bays, provides maps of where these resources are located, ranks resources to identify sensitive areas, identifies gaps in information and data, and provides an initial review of threats.[22]

In 2005, a Sensitive Areas Management and Education Plan was produced to follow up on several overarching conflicts between aquatic resources and water-use activities. These conflicts included boating in shallow-water environments, building docks and piers in wetlands, recreational and commercial fishing activities, and contamination from boating activities. In this report, the recommendations are listed based on the action that is needed (e.g., policies and regulations, enforcement and enhancement, education and outreach, and research) for implementation.

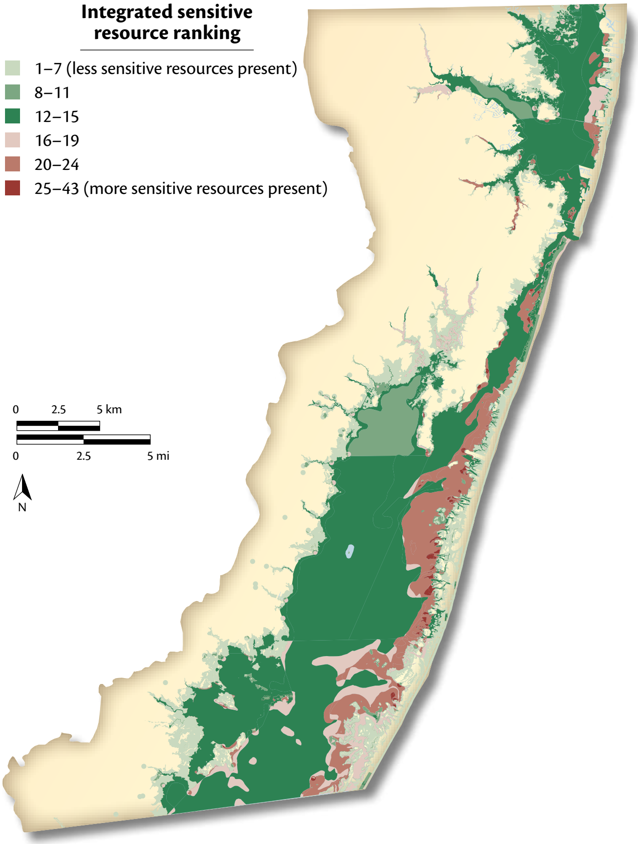
Recommendations[6]

- Develop a targeted education campaign so the public and local decision-makers will know about sensitive areas and species. Consider the economic and ecological importance of a diverse and healthy estuary.
- Designate and clearly delineate zones for specific uses such as areas that are appropriate for personal watercraft, aquaculture, marina channels, etc. Develop a maintenance schedule for buoys.

Resources define sensitive areas

The resources of interest included benthic organisms (non-commercial bottom-dwelling animals), blue crabs, colonial waterbirds, diamondback terrapins, finfish, horseshoe crabs, intertidal invertebrates (oysters and ribbed mussels), rare, threatened, and endangered species, seagrasses (submerged aquatic vegetation), shellfish (hard clams and scallops), shorebirds, and tidal wetlands.

- Identify sensitive areas where speed limits and no-wake zones might be beneficial to prevent environmental degradation (e.g., bank erosion). Enforcement of speed limits and rules may improve by requiring violators to attend a boating class in lieu of paying a fine.
- Develop a program for the retrieval and disposal of old/abandoned crab pots and fishing gear.
- Consider the effects of shoreline hardening, via bulkheading and riprap, and the proliferation of individual docks on sensitive areas. Define a minimum water depth requirement or a standard provision that a specific depth must be attained to allow for motorized craft to approach docks or piers. Determine a minimum depth to justify the installation of a boat lift.
- Define locations where blue crabs overwinter.
- Determine the best time to do maintenance dredging in relation to sensitive areas and boating traffic.
- Research the effectiveness of resource sanctuaries to improve sensitive habitats and species, including recreationally and commercially important fish and shellfish species within the Coastal Bays.
- Evaluate the potential outcomes of aquaculture on the Coastal Bays.
- Continue with additional research on the impact of biological threats to sensitive resources including macroalgae, harmful algae blooms, and invasive/non-native species.
- Research the potential impact of turtle-excluding devices on crab pots used in the Coastal Bays.



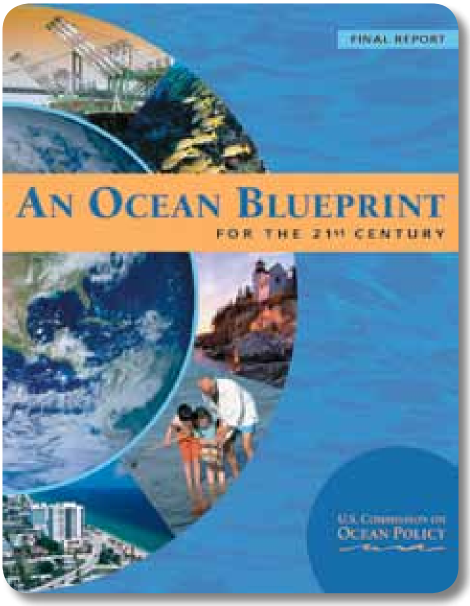
Map of the aquatic sensitive areas in the Coastal Bays. The higher the ranking number, the more sensitive resources are present.

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Ocean resources are an integral part of the Coastal Bays community

Over the last two decades, our nation has again acknowledged that proper stewardship of the ocean is critical to the long-term vitality of the United States. The ocean provides food and recreation, contributes to the nation's economic engine, is an element of national security, and is a major player in the global climate system. Despite its vast extent, the ocean is finite and cannot indefinitely absorb all the stresses being placed on it by the growing human population.

In 2000, Congress tasked the U.S. Commission on Ocean Policy to investigate and provide recommendations for a "coordinated and comprehensive national ocean policy." After extensive hearings, written input, and public comment, the Ocean Commission published An Ocean Blueprint for the 21st Century with more than 200 recommendations.[38] Upon consideration of these recommendations, the Administration developed the U.S. Ocean Action Plan, a broad plan that proposed a fundamental restructuring of ocean governance, research, and management intended to "engender responsible use and stewardship of ocean and coastal resources for the benefit of all Americans."



Released by the U.S. Commission on Ocean Policy on September 20, 2004, An Ocean Blueprint for the 21st Century contains the Commission's findings and recommendations for a new, coordinated, and comprehensive national ocean policy.

Six societal themes outlined in the Ocean Research Priorities Plan & Implementation Strategy[32]

- Stewardship of natural and cultural ocean resources.
- Increasing resilience to natural hazards.
- Enabling maritime operations.
- Ocean–climate interactions.
- Improving coastal ecosystem health.
- Enhancing human health.

One particularly important recommendation is to develop the Ocean Research Priorities Plan and Implementation Strategy.[32] This strategy will provide guidance on how the various ocean science sectors (government, academia, industry, and non-government entities) can and should be engaged, individually or through partnerships, to address the areas of greatest research priority and opportunity.

Currently six societal themes have been identified, along with 21 research priorities, that address the most compelling issues of interaction between society and the ocean. These research priorities focus on understanding critical processes and interactions and applying that understanding toward responsible use of the ocean environment.

The state of Maryland, like many other states, is set to examine issues surrounding the management of valuable offshore resources and uses such as commercial and recreational fisheries, marine mammals, energy resources (including wind power), sand resources (particularly for beach replenishment), transportation, and recreation. Considering the broad economic, cultural, and recreational ties of these issues to the local community, it will be imperative that local stakeholders and municipal leaders provide comments and feedback. The Maryland Coastal Bays Program will continue to facilitate these discussions and prompt necessary research and on-the-ground improvements at the local level.

Horseshoe crabs

Horseshoe crabs play a vital ecological role in the Atlantic Coast's shorebird migration, as well as providing bait for commercial fishers and blood for the biomedical industry. Local populations are stressed not only by harvest pressure but by loss of bayside spawning beaches. There have been increasing restrictions on the commercial harvest of these crabs including some state moratoriums around Delaware Bay. This challenges managers with the difficult task of allocating the stock for its ecological value as well as its commercial value, while maintaining a sustainable population.

Recommendations: Support current MD DNR efforts to continue to apply current fishery restrictions, monitor stock status, and work with the Atlantic States Marine Fisheries Commission. Enhance efforts to secure and protect spawning beaches.

Licensing of recreational saltwater anglers

Maryland requires a state fishing license for most recreational anglers that fish in Maryland's waters and tributaries of Chesapeake Bay. There is no licensing requirement for recreational anglers who fish in the Coastal Bays or ocean waters. Discussions are ongoing for ways to implement the recently reauthorized federal Magnuson Stevens Act, which requires coastal and ocean anglers to participate in a federal registry by 2011, at which time participation will be mandatory. The purpose of the registry is to identify and quantify fishing effort and catch so that more accurate data can be compiled for use in fishery management decisions.

Recommendation: MD DNR should work to resolve stakeholders' concerns and to transition to participating in the registry as quickly as possible so that the data can be incorporated into management strategies in a timely manner.


STEVE DOCTOR

Horseshoe crabs play a variety of important roles in the Coastal Bays.

White marlin fishery

The recreational white marlin fishery is a long-established tradition in Maryland through the Ocean City White Marlin Tournament. This fishery provides substantial economic value to Maryland and the coastal community throughout the offshore fishing season. The stock has suffered significant declines due to commercial overfishing in international waters, where 95% of marlin deaths occur, while recreational fishing contributes only a fraction of annual marlin losses. Despite the population decline, a 2006 population study by the National Marine Fisheries Service concluded that placing the species on the endangered species list is not warranted, and notes that while overfishing has been a problem historically, it is not taking place today. Credit for that improvement is given to management efforts that include wider use of catch-and-release recreational fishing and use of circle hooks (which decrease injuries and fatalities).

Recommendation: The next scheduled population study will be in 2010. All interested parties should remain vigilant

ROMAN JESIEN

White marlin shown with a satellite tag (white) being inserted into the fish by scientists from the National Marine Fisheries Service. A total of 11 fish were tagged off Ocean City and six off Oregon Inlet, North Carolina in September 2007 to learn about their migratory routes after they leave the Mid-Atlantic in the fall. Satellite tags remain on the fish for 150 days and record data on the depth of the fish and the temperature of the water. Tags then automatically pop off the fish, rise to the surface, and download their data to an Argosy satellite. Tags are provided through the Adopt a Billfish Program.

to observe the more recent management efforts that require circle hooks and size limits.

Alternative energy

Maryland has recently experienced dramatic increases in electricity bills, warnings of summer electricity shortages, and growing concern about potential environmental impacts of climate change. In July 2007, the Empower Maryland Initiative was introduced to detail new energy efficiency goals for the state in order to save taxpayers money, reduce stress on Maryland's energy markets, and improve the environment. The Initiative challenges the state to reduce energy consumption by 15% by 2015 and encourage an increase in the use renewable energy sources (solar, wind, geothermal, etc.) to 20% by 2022. The state is further working to take control of energy issues with plans to help Maryland consumers "keep their bills down, their lights on, and achieve their climate and environmental goals" through the Maryland Strategic Electricity Plan.

The Plan involves four central recommendations:

- Maryland needs a Strategic Energy Investment Fund to finance energy efficiency, promote renewable energy, and stimulate Maryland's emerging clean energy industry.
- Electric utilities would be required to reduce electricity consumption and peak demand by implementing energy efficiency programs, such as consumer rebates for ENERGY STAR appliances, incentives for home energy audits, and interruptible load devices on air conditioners.

- To keep the lights on, Maryland needs to invest in new power generation. Maryland should encourage new sources of renewable electricity by more than doubling the amount of clean, renewable electricity sold by Maryland's retail electricity suppliers by 2022. Maryland should also improve the residential solar and geothermal grant programs, encourage long-term contracts for new generation, and evaluate the need to require utilities to construct or purchase new generating capacity to meet summer peak demand.
- Maryland can do a better job of planning for the future to produce biennial comprehensive state energy plans, promote regional transmission planning, and stimulate the state's emerging clean energy industry.

Environmental & natural resource laws are only as good as our ability to uphold & enforce them

Currently 50% of the American population lives within 80 km (50 mi) of the coast. The population shift is placing increased demands on local inspection and law enforcement agencies to ensure that activities are conducted safely and in compliance with resource protection regulations. The Natural Resources Police (NRP) and MDE are perennially understaffed and lack resources for inspection and compliance personnel.

Local government employees are charged with inspection and compliance of the Critical Areas Law, sediment and erosion control, forest conservation, septic installation, development and zoning, and stormwater management. Federal and state agencies oversee programs

RON CASCIO

Natural resource laws are created to protect the community against egregious violations such as the buffer destruction and set-back violation above. Many laws are actually the result of community outrage and citizen-led efforts to protect their quality of life.

for wetlands and shorelines, wastewater discharges, hunting, fisheries, and boating safety, among others. Due to growth and development pressure, many divisions are so busy reviewing new projects and proposals that site inspections are less frequent. Consequently, violations can go unnoticed and even become considered acceptable practices.

The 2004 Assessment of Wetland Management in the Coastal Bays Watershed revealed that the work of the U.S. Army Corps of Engineers and MDE regulators and enforcement staff is severely constrained by understaffing and lack of resources, including computer technology.[36] The level of development activity in the watershed has increased so dramatically that the already-overstretched staff were even further taxed by the overwhelming need to address stormwater/erosion control issues, rather than upholding current wetland protection laws. Similarly, there has been steady deterioration in the quantity and quality of natural resources law enforcement, thus placing increasing pressure on efforts to conserve habitat and living resources.

In summary, the NRP and MDE have been under-funded for years, causing these departments to become less effective in their ability to protect natural resources and public safety. It is imperative that funding be put in place and that the structure, culture, and morale be restored among law enforcement personnel.

Recommendations[10]

- Filling the gaps in staff for enforcement and compliance of wetlands mitigation and preservation, shoreline changes, stormwater management, and sediment and erosion control. Perhaps some of the cost could be recuperated from assessing fees for follow-up inspections.
- Similarly, support for NRP enforcement is needed, particularly for seagrass protection. It is also imperative that funds generated from within NRP in the form of fines from violations be directed back to use for natural resources budgets.

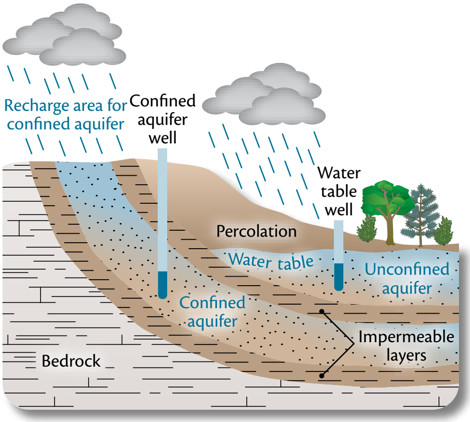
COMMUNITY STEWARDSHIP

Groundwater is an important resource that needs to be protected

Groundwater is the main source of water supply in the Maryland Coastal Bays watershed. The sources include the surficial aquifer and a few deeper aquifers that are overlain by fine-grained confining layers. The surficial aquifer is shallower and, therefore, is more susceptible to water quality problems from human activities than the confined aquifers, which are overlain by less permeable layers of silt, clay, and fine sand.

The most common water quality problem in shallow groundwater is high nitrate concentrations from agricultural fertilizers. Locally, problems may exist where shallow groundwater is contaminated from failing septic systems, improper disposal and spills of man-made organic compounds such as solvents, or leaking underground

Confined & unconfined aquifers



The Coastal Bays are underlain by both surficial (unconfined) and deeper (confined) aquifers.[42]

petroleum storage facilities. The main concern for water quality in the confined aquifers is naturally occurring iron and the potential for intrusion of saltwater from brackish deeper aquifers due to over-pumping.

Regular monitoring of public water supplies has revealed a wealth of information concerning water quality at these specific locations. Public water supplies include those supplies serving communities, schools, restaurants, places of employment, and campgrounds.

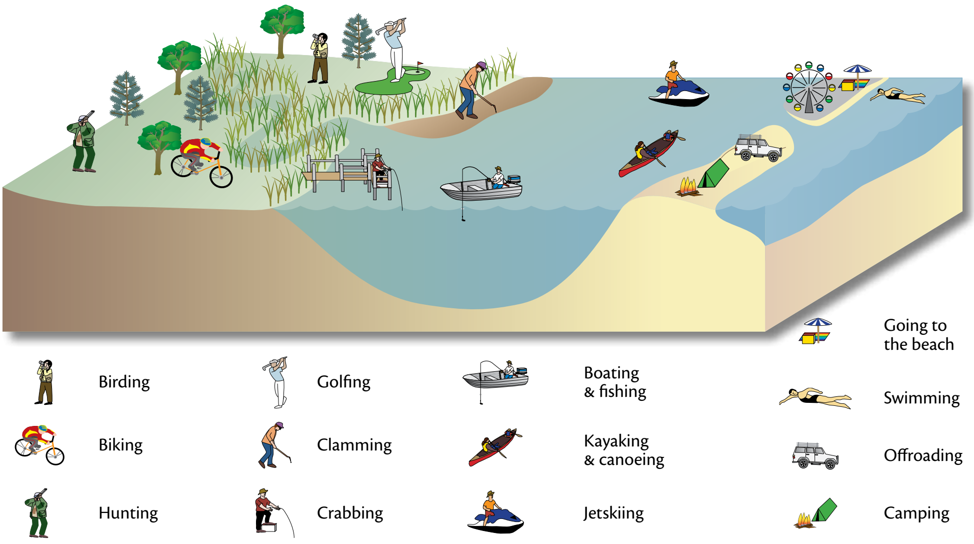
Reports identifying the risk of contamination of each public water system have been prepared by MDE and are available through the public library, the water supplier, and county health and planning agencies. More about this program is available through MDE's website at *www.mde.state.md.us/Programs/WaterPrograms/WaterSupply/index.asp*. MDE funding is available for community water systems that rely on the surficial aquifer system to establish wellhead protection programs. Individual well owners relying on the surficial aquifer system should consult with the county health department if they have questions concerning the water quality of their own well.

Tourism is a major economic influence in the region

The inherent value of living things notwithstanding, an independent consulting firm report prepared in 2001 shows what most knew all along—that the value of the Coastal Bays' natural resources to the local economy is staggering.[18] Still, some of the numbers may come as a surprise. Without the inclusion of beachgoers or most Ocean City-related activities, the total value of the Coastal Bays is around half a billion dollars annually.

Recreational activity, which does not include related boating, food, property, or lodging, was worth a total of $206 million in 2000. Commercial fishing was worth $7.9 million and recreational boating about $25.5 million. Full-time jobs related to the bays come in at 5,680. Some 5,114 of those are related to recreation and 516 support the commercial fishing industry.

Recreation in the Coastal Bays



The Coastal Bays are a popular recreational destination.

ALLEN SKLAR

Spectacular recreational fishing, evidenced by this record striped bass caught by Allen Sklar off Assateague Island, is supported by the Clean Water Act's water quality standards.

In addition, because of many other factors, the Coastal Bays have a much larger value to Worcester County than that indicated only by annual spending. Visitors' willingness-to-pay indicates that non-market values are more than $183 million. In addition, waterfront property, with an estimated value of the premium (only) for waterfront location is $360 million, with an annualized value of $36.6 million per year. Additional values can be estimated for the avoided costs of benefits provided by wetlands, which absorb pollution and storm energy, as well as government services related to protecting the area.

The Coastal Bays represent a resource of extremely significant value to the economy of Worcester County. In a sense, the values of the bays are, in the long run, inestimable since without the bays, the county would be a very different place. It would more likely resemble the many ocean seashore communities along the Atlantic Coast that have no protective shelter and few opportunities for safe waterborne and shore recreation. However, placing a dollar value on the impact of the bays on Worcester County represents one method for placing that impact in perspective.

A study, conducted by the Greeley-Polhemus Group Inc., was requested by the Maryland Coastal Bays Program with assistance from MD DNR. Funded through a grant from the National Oceanic and Atmospheric Administration, the study used the standard Impact for Analysis Planning Model to derive expenditures from 134 economic sectors. Surveys and

Visitors to the Coastal Bays stimulate the local economy

Of the 8.5 million people who come to Worcester County every year, more than two million participate in Coastal Bays-related activities. Sightseeing alone is worth about $21.4 million annually. For wildlife observation, including birding, around $20.7 million was the total impact in 2000. Recreational fishing, camping, hunting, and boating are also a significant part of the $500 million in goods and services purchased by consumers every year in the Coastal Bays watershed. Food, lodging, and transportation related to these activities have a yearly market value of around $114 million.

KEOTA SILAPHONE

Swimmers emerge from Chincoteague Bay near Public Landing during the annual Osprey Sprint Triathlon.

county and state sources of economic and demographic data provided much of the necessary input. For more information visit *www.dnr.state.md.us/coastalbays/res_protect/pubs/economic.html*.

Boating is a favorite activity of residents & visitors

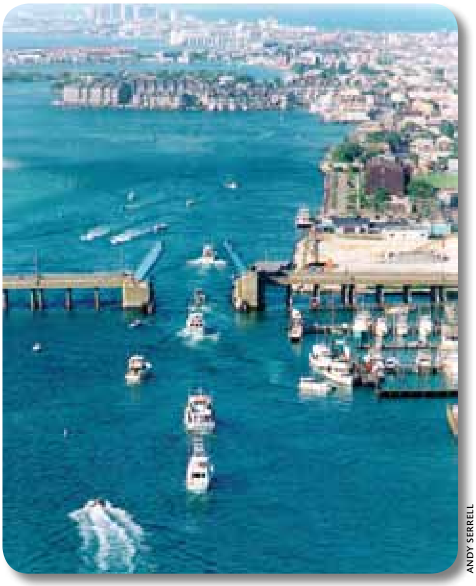
A survey of boaters using Maryland's Coastal Bays revealed their reasons for boating on the Coastal Bays (in descending order): close to home or other accommodation; good fishing; scenic qualities of the bays; peaceful location; to observe wildlife; good water quality; adequate channel markers; adequate water depth; and not a lot of other boating traffic.[5] These reasons highlight the importance of the natural features of the Coastal Bays to people's quality of life.

The primary activities of boaters in the Coastal Bays are cruising and fishing, but they also go crabbing, clamming, waterskiing, tubing, and swimming. Boaters attached relatively high importance to water quality affecting their enjoyment of their experience in the Coastal Bays.

Forty percent of survey respondents perceived that water quality in the bays had not changed in the five years up to 2002, although 28% thought it had deteriorated. A majority of respondents (61%) felt that the living resources of the bays (e.g., fish, clams, and crabs) had deteriorated over the five years up to 2002.

In general, the boaters surveyed were reluctant to support more regulations. Potential management options presented in the boaters' survey were ranked in descending order of support:

- Limit the number of jet skis using the bays.
- Add regulation to improve the bays' water quality.
- Restrict boat use in shallow water.
- Stricter limits on harvesting of fish, clams, and crabs.
- Zone waters to provide for certain uses in certain areas.


ANDY SERRELL

Recreational boating is a popular pastime in the Coastal Bays.

- Develop additional boat access to bays.
- Require bay-wide Salt Water Fishing Licence, with money going to improve fishing in the bays.
- Require a seasonal boating permit to bays, with money used for bay improvements.
- Limit the number of boats using the bays.

Recommendations

- Closely monitor 'hot spots' of crowding, conflicts, and environmental impacts.
- Strengthen educational efforts and enforcement regarding boating safety and courtesy, as well as resource conservation and proper disposal of vessel sewage, especially focusing on non-resident visitors.
- Monitor personal watercraft activity and develop systems to alleviate conflicts between personal watercraft users and other boaters.
- Develop a comprehensive dredging plan for the bays and provide adequate markings of shallow areas.

- Develop a system to monitor boaters' satisfaction levels, track user conflicts, and anticipate future conflicts.
- Address the issue of overcrowded boat ramps and plan for establishing more access points to the bays.
- Consider water zoning as a tool to minimize conflicts between certain bay uses.
- Develop a computerized system to track the growth trends of boat slips, docks, and other boat storage and access facilities around the bays.

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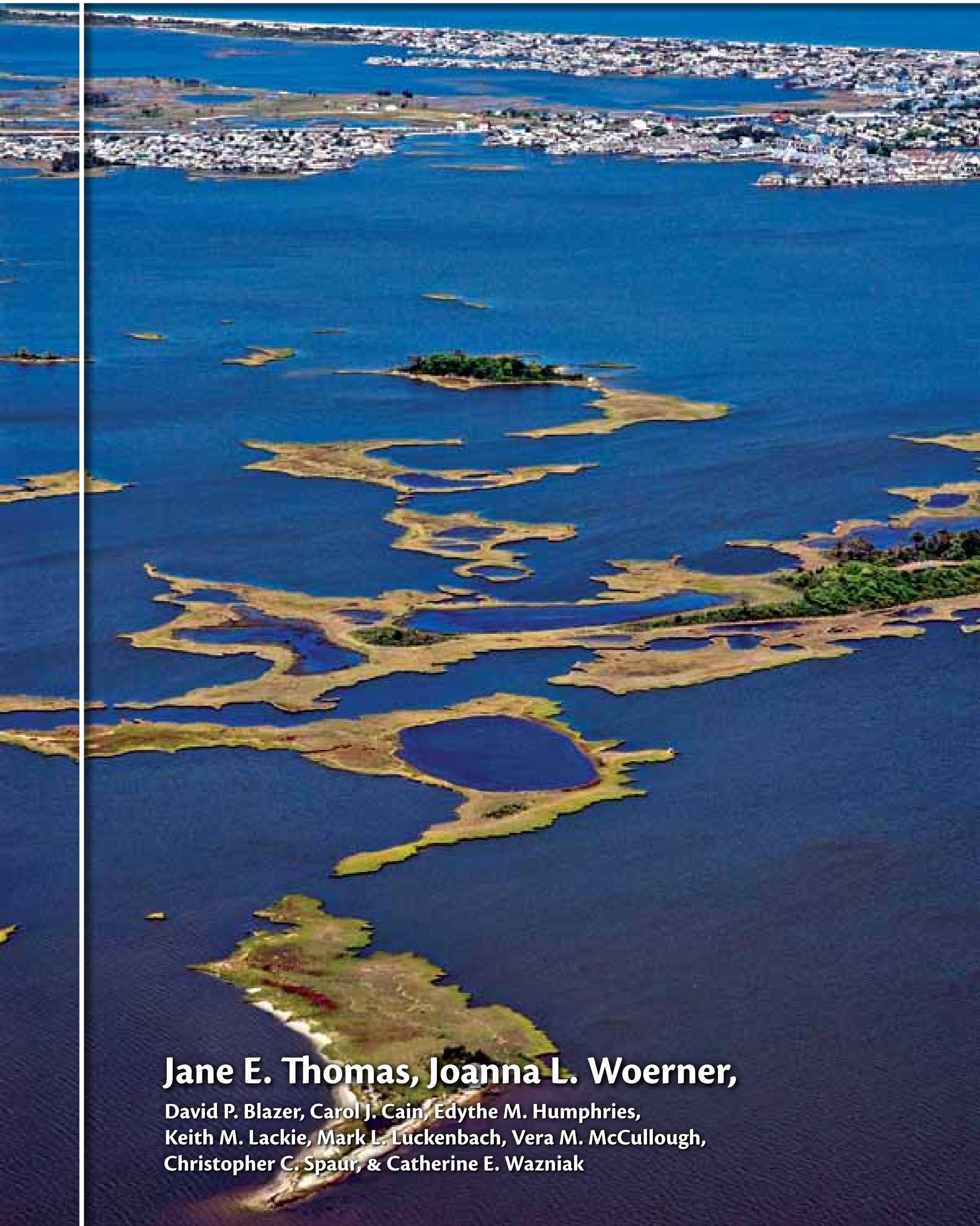
4. Assawoman Bay



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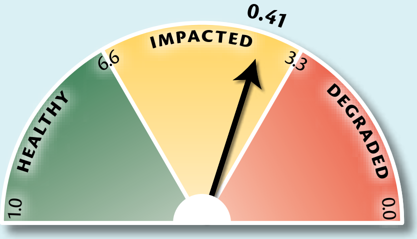
CONCLUSIONS

The ecosystem health of Assawoman Bay is impacted

Assawoman Bay had fair estuarine health. However, watershed health was the poorest in the Coastal Bays due to development in the watershed, with associated low forest and non-tidal wetland cover, large amounts of impervious surfaces, and poor stream health. This combination resulted in Assawoman Bay's overall ecosystem health ranking as second-to-last of the Coastal Bays. Assawoman Bay is directly connected to Little Assawoman Bay in Delaware through a channel known as 'The Ditch.' The extent of exchange between these two waterbodies is unknown, but wind and tides are thought to play an important role. Preliminary monitoring results suggest that Greys and Roys Creeks, as well as the Ditch, may contribute to the low water quality in the northern end of Assawoman Bay.[7] For more information, see Chapter 2—*Ecosystem Health Assessment.*

How healthy is Assawoman Bay?



ASSAWOMAN BAY ISSUES

Although the following issues are presented here as pertaining to Assawoman Bay, they also apply to other Coastal Bays subwatersheds.

Regional coordination should be implemented

Rapid land use change occurring around the Delaware, Maryland, and Virginia (Delmarva) Coastal Bays impacts local water quality, habitats, communities, and economies. Each jurisdiction has implemented varying degrees of

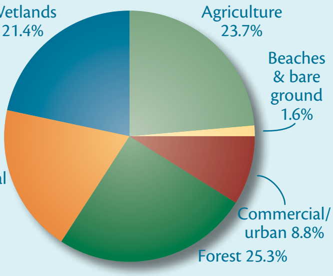

JANE THOMAS

Aerial view of Assawoman Bay, looking south towards Ocean City. Visible in the foreground is 'The Ditch'—the canal joining Little Assawoman Bay with Assawoman Bay.

Assawoman Bay & watershed facts

Watershed area (km²)	24.7
Average bay depth (m)	1.20
Surface area of bay (km²)	20.9
Watershed area : surface area	1.18
Bay water volume (m³ × 10⁶)	27.0
Watershed area : water volume	0.91
Flushing rate (days)	21.2
Population	MD: 11,541
	DE: 2,125

Land use in Assawoman Bay subwatershed (Maryland only)



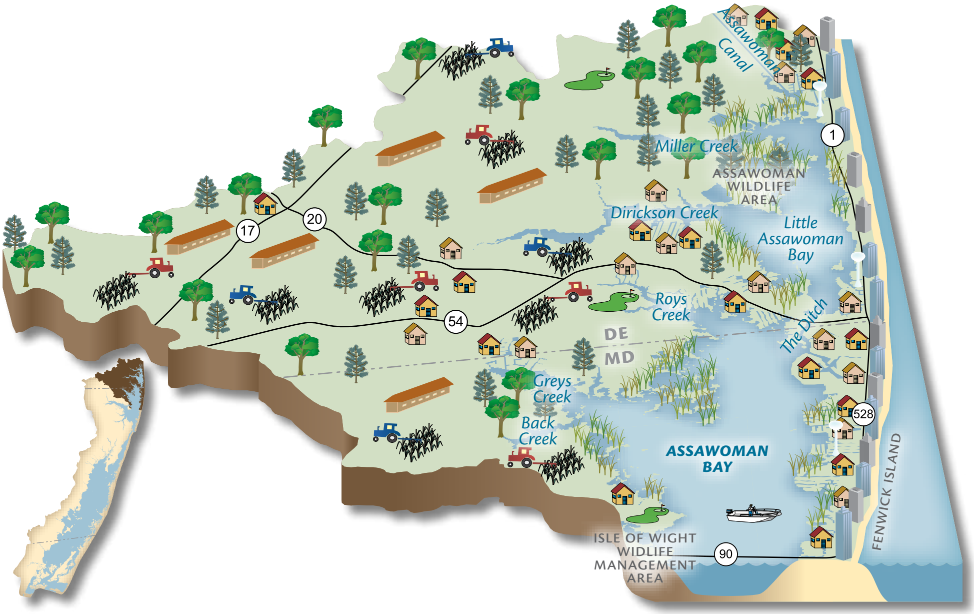
conservation and planning practices. However, the interconnectedness of land, water, and living resources between the states ensures that actions in one will affect resources in the others. Coordination between Worcester County (Maryland), Accomack and Northampton Counties (Virginia), and Sussex County (Delaware) is essential to maintain a healthy environment and community.

In 2005, local planners established an informal network that identified areas where collaborative efforts among jurisdictions could address issues affecting the Delmarva coast. The Delmarva Atlantic Watershed Network (DAWN) emerged with the goal of making citizens and elected officials aware of issues facing these coastal communities and better equipping them to make coordinated decisions related to natural resources.

To keep the community current on key issues, three key objectives were identified.

- *Technology.* Develop a regional technology network to share information on critical resource issues in a Geographic Information

Assawoman Bay & watershed



Conceptual diagram depicting general land use and features of Assawoman Bay and its watershed.

Systems (GIS) framework and ensure that all counties have access. Identify existing data, applications for the data, and future tools and projects.

- *Education and outreach.* Provide information to citizens and decision-makers on topics such as water quality and land use necessary to protect resources that support their community and economy.
- *Policy and planning.* Obtain support from elected officials and decision-makers, assess current directions/ actions and request a needs assessment, and develop a social marketing plan.

The DAWN project is now complete. More information about this project can be found at *www.mdcoastalbays.org/dawn*.

Coordination between the Maryland Departments of Environment and Natural Resources and the Delaware Department


JANE THOMAS

Aerial view of 'The Ditch' connecting Assawoman Bay (foreground) with Little Assawoman Bay (background).

Parameter	Delaware	Maryland	Maryland Coastal Bays Program STAC
Dissolved oxygen	5.0 mg L^{-1} daily average (minimum tidal) 5.5 mg L^{-1} daily average (minimum fresh)	5 mg L^{-1} minimum	3 mg L^{-1} minimum
Total nitrogen	1 mg L^{-1} (tidal); 3 mg L^{-1} (fresh)	to be determined	1 mg L^{-1}
Total phosphorus	0.1 mg L^{-1} (tidal); 0.2 mg L^{-1} (fresh)	to be determined	0.01 mg L^{-1}
Chlorophyll *a*	N/A	50 mg L^{-1}	15 mg L^{-1}

Comparison of established water quality thresholds for the states of Maryland and Delaware and the Maryland Coastal Bays Program Scientific and Technical Advisory Committee (STAC). Delaware nutrient target ranges for daily maximums are from the Total Maximum Daily Load (TMDL) analysis.[3]

Parameter	Surface water quality standards
Dissolved oxygen	5 mg L^{-1} daily average (minimum)
Dissolved inorganic nitrogen (during aquatic grass growing season: March 1–October 31)	0.14 mg L^{-1} (seasonal average maximum)
Dissolved inorganic phosphorus (during aquatic grass growing season: March 1–October 31)	0.01 mg L^{-1} (seasonal average maximum)

Delaware Surface Water Quality Standards as amended July 11, 2004, tidal portion of Assawoman Bay.

of Natural Resources and Environmental Control is essential for understanding and managing water quality issues in the contiguous waterbodies.

In November 2004, Delaware developed a Total Maximum Daily Load (TMDL) for nitrogen and phosphorus for Little Assawoman Bay. Non-point source nitrogen and phosphorus loads in the watershed are to be reduced 40%.

TMDL regulation for Little Assawoman Bay, Delaware

Intensive water quality monitoring performed by the state of Delaware, the federal government, various university and private researchers, and citizen monitoring groups has shown that surface waters of the Delaware Inland Bays watershed, including Little Assawoman Bay, are highly enriched with nitrogen and phosphorus. Although nutrients are essential elements for plants and animals, their presence in excessive amounts causes undesirable conditions.

Symptoms of nutrient enrichment in the Delaware Inland Bays have included excessive macroalgae growth (sea lettuce and other species), phytoplankton blooms (some potentially toxic), large swings in dissolved oxygen levels throughout the day, loss of submerged aquatic vegetation (SAV), and fish kills. These symptoms threaten the future of the Delaware Inland Bays, and may result in adverse impacts to local and state economies through reduced tourism, a decline in property values, and lost revenues. Therefore, excessive nutrients pose a significant threat to the health and well-being of the people, animals, and plants living in the Coastal Bays and watershed.

In the TMDL regulation, the non-point source nitrogen and phosphorus loads in the Little Assawoman Bay watershed are to be reduced by 40%. If retroactively applied to the three-year period of 1998–2000, this would have required a reduction of total nitrogen load in the watershed from 270 kg (594 lb) per day to 162 kg (357 lb) per day, and would have reduced total phosphorus load in the watershed from 22 kg (49 lb) per day to 14 kg (30 lb) per day.[2] For more information on TMDLs, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Monitoring recommendations

- Investigate funding opportunities to develop an integrated water quality monitoring and analysis effort between Delaware's Little Assawoman Bay and Maryland's Assawoman and Isle of Wight Bays.

JANE THOMAS

Condominiums and ocean beaches line the eastern side of Assawoman Bay.

Research recommendations

- Evaluate the need for additional flushing/exchange studies through the Ditch connecting Assawoman Bay with Little Assawoman Bay.
- Evaluate nutrient loading relative to land use in each state.

Management recommendations

- Evaluate and implement restoration and protection related to green corridors, habitat restoration, Public Drainage Associations, and stream and wetland restoration.
- Protect groundwater recharge areas.
- Coordinate land use, growth areas, and potential growth over the next 50 years.
- Continue and effectively monitor current regulatory practices regarding filling and dredging of marsh.
- Discourage shoreline hardening.

Apply best management practices to Public Drainage Associations

Land drainage has been closely associated with agricultural use of the landscape; however, many other land uses have added to the drainage network. Drainage systems for transportation, housing and municipal development, and stormwater management have been connected to or superimposed upon the existing agricultural drainage network on Delmarva.[1]

With increases in development and impervious surfaces within the watershed, the burden of conveyance of stormwater and maintenance of ponds and ditches has increased accordingly. Periodic flooding, at the parcel or neighborhood scale, requires municipalities and Public Drainage Association (PDA) managers to find better ways to manage and facilitate stormwater flows. Often, in efforts to provide efficient drainage of the landscape,


JANE THOMAS

Historically, proper drainage of frequently saturated soils has helped create more productive farmland, reduced localized flooding on individual parcels, and improved transportation infrastructure, in addition to supporting local economies and public health.

Montego Bay—A citizen's perspective

JANE THOMAS

The Montego Bay residential park in Assawoman Bay.

Drainage issues impact all communities. In the Montego Bay residential park on the north end of Fenwick Island, there are three main drainage issues—litter in storm drains, heavy boat traffic, and bulkheading of shorelines.

In order to understand the drainage issues, it is important to understand the features of Montego Bay. Montego Bay is a community of 1,523 dwellings and 5.1 km (3.2 mi) of bulkheaded canals and bay-front properties. There is also an 3.2-ha (8-acre) non-tidal, saltwater pond that was once tidal wetlands and open water on the shores of Assawoman Bay. The pond's water comes from three main sources—the bay during high spring tides, rainwater, and runoff—all of which affect water quality in the pond.

The biggest drainage-related problem for the community is the impact of vacationers and even Montego Bay residents who do not understand that their activities alter the delicate balance of the water. Litter on the streets migrates to the storm drains and eventually into the canals, and then into Montego Bay and Assawoman Bay.

Another issue impacting the community is oil pollution from boats or storm drains. The entrance to the Montego Bay canal is just south of the Fenwick Ditch where hundreds of watercraft travel every week, in addition to the boats that reside within Montego Bay itself. On the Delaware side of the Ditch, you will find jet ski and boat rentals, parasailing boats, and a pirate cruise ship. All of these crafts travel past the Montego Bay community on a regular basis. The heavy boat traffic could be a source of the oil slicks commonly found near Montego Bay.

Most of the bulkheads on the bay as well as in the canals were made with treated lumber containing toxic chemicals including copper, chromium, and arsenic. (Since 2005, the U.S. EPA has banned the use of wood containing these chemicals because of its toxic effects.) The constant wave action from the watercraft undermines these bulkheads and adds contaminants to the water. These contaminants then find their way to Assawoman Bay.

Additional factors that probably influence water quality in Montego Bay include stormwater runoff from the impervious streets and driveways and aging sanitary sewer infrastructure.

VERA M. MCCULLOUGH

Heavy boat traffic in Montego Bay may lead to oil slicks.

VERA M. MCCULLOUGH

Bulkheads constructed before 2005 contain chemicals that leach into the water.

it is forgotten that these channels deliver pulsed loads of nutrients and sediments to local waterbodies. The challenge is to find fair and efficient methods to provide drainage for agricultural and residential uses, while diverting the water to areas that can provide buffered treatment and storage. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Recommendations

- Implement Worcester County's Comprehensive Plan.[8]
- Establish a workgroup comprising PDA managers, landowners, and local, state, and federal agency representatives to determine site-specific opportunities for ditch and PDA improvements.
- Determine the feasibility of adopting the recommendations provided by the Public Drainage Task Force.[1]
- Where possible, reduce 'C-curve' drainage (a drainage curve type that removes runoff water from a drainage area within 24 hours) by retaining water on the landscape for longer periods of time overall. This promotes nutrient transformation and retention through chemical and biological processes, sediment deposition as opposed to transport, and increased water cycling to the atmosphere through evapotranspiration.
- Determine the potential of using water control structures, not just for water table management, but also for the diversion of water from ditches into neighboring habitat to create, restore, or expand existing wetlands.
- Examine the potential for impervious surface calculations to derive a fee contribution from residential areas along existing PDAS for maintenance costs.
- Where feasible, enhance and expand current efforts to control nutrient loading from source areas, both public and private lands, before the nutrients reach public drainage ditches.
- Use the Coastal Bays watershed as a pilot study area to model the amount

Aerial view of Assawoman Bay, looking south towards St. Martin River and Ocean City. Visible in the foreground are canal developments on Roys Creek.

Marsh islands in western Assawoman Bay showing complex edges that have high habitat value.

of nutrients reduced since 2000 via installation of best management practices, implementation of nutrient management plans, litter transport program, etc.

- Promote better watershed management practices to reduce inflow volume and pollutant loads. Incorporate low-impact development techniques, enhance infiltration, reduce impervious surfaces, increase buffers and conservation, and encourage source control (such as rain barrels).
- Investigate the wildlife habitat value of stormwater basins.

FEATURES OF ASSAWOMAN BAY & ITS WATERSHED

Assawoman Bay has substantial tidal marshes on the mainland

Substantial loss of tidal marsh occurred in Assawoman Bay prior to implementation of wetlands protection laws in the 1970s. Only small parcels of tidal marsh remain today on the bay shore of Fenwick Island. However, substantial areas of tidal marsh still survive along the mainland shoreline. The remaining marshes of this area are probably highly vulnerable to loss in association with rising sea level.[4] For more information, see Chapter 12—*Dynamic Systems at the Land–Sea Interface*.

The tidal marshes on the western shore of Assawoman Bay possess notably complex edges. Marshes with complex shorelines and good water quality typically provide high habitat value for a variety of organisms, including species of commercial finfish that utilize them as nursery grounds. However, when dissolved oxygen levels in bay waters are low, this general relationship fails.

Maryland Department of the Environment has worked to prioritize wetlands for preservation, restoration, and mitigation in the subwatersheds of the Coastal Bays, including assessing species and resources and identifying areas

The Roys Creek subwatershed at the northern end of Assawoman Bay, Delaware, has mixed land use.

where the most benefit could be gained.[5,6] For more information on wetlands, see Chapter 3—*Management of the Coastal Bays & Watershed* and Chapter 15—*Habitats of the Coastal Bays & Watershed*.

The Coastal Bays were included in the Critical Area Law in 2002

The Coastal Bays watershed was added to the Critical Area Act in 2002 because of growing concern about the decline of the water quality and natural resources of the Coastal Bays. Land use immediately surrounding the bays and their tributaries has the greatest potential to affect water quality and habitat. The Critical Area Act (originally passed in 1984 as the Chesapeake Bay Critical Area Protection Act) requires state and local governments to jointly address the impacts of land development on habitat and aquatic resources.

The law identified the 'Critical Area' as all land within 1,000 ft (305 m) of the mean high-water line of tidal waters or the landward edge of tidal wetlands. The law created a state-wide Critical Area Commission to oversee the development and implementation of local land use programs directed towards the Critical Area that met the following goals:

- Minimize adverse impacts on water quality that result from pollutants discharged from structures or conveyances or that have run off from surrounding lands.
- Conserve fish, wildlife, and plant habitat in the Critical Area.
- Establish land use policies for development in the Critical Area which accommodate growth and also address the fact that, even if pollution is controlled, the number, movement, and activities of people in the Critical Area can create adverse environmental impacts.

The Critical Area Commission developed criteria used by Worcester County and Ocean City to develop individual Critical Area programs and amend local comprehensive plans, zoning ordinances, and subdivision regulations. Worcester County and Ocean City developed and adopted specific, comprehensive programs designed to address the unique characteristics and needs of the Coastal Bays watershed while preserving and protecting the important natural resources of the Coastal Bays. The plans accommodate future growth within the Critical Area, while providing for conservation of fish, wildlife, and plant habitats and minimizing adverse water quality impacts. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Recommendations

- Improve education and outreach to waterfront property owners and builders on provisions of the law and regulations.
- Require expanded buffers in sensitive habitats.
- Improvement and continued enforcement of codes, with penalties for violations.
- Continued collaboration and communication between state and local jurisdictions on issues with implementation, compliance, and enforcement.
- Increased state funding (through annual grants) to help implement the public outreach and increased enforcement.
- Create a publication for homeowners and subcontractors (landscapers, pool installers, etc.) describing the buffer size and restrictions in the Critical Area. Describe the purpose of the law, promote sensitive areas and species, water conservation techniques, and native species for landscaping.

~

ACKNOWLEDGEMENTS

The authors would like to thank Roman Jesien and Dave Wilson from the Maryland Coastal Bays Program for their comments helpful in the completion of this chapter.

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5. St. Martin River

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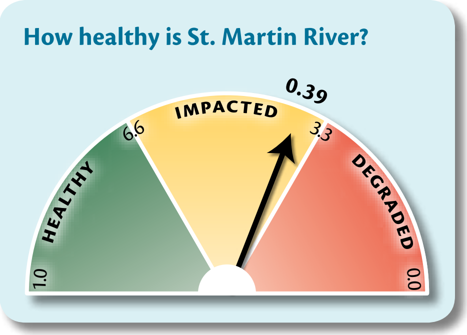
CONCLUSIONS

The ecosystem health of St. Martin River is impacted

St. Martin River ranked last in the Coastal Bays for estuarine health as a result of intensive land use (development and agriculture). It had the lowest scores for water quality, bay benthic index, hard clam density, sediment quality, and seagrass coverage. Watershed indicators were marginally better with relatively low impervious surface. However, stream nitrate was high, and forest cover was the lowest in the Coastal Bays. This resulted in St. Martin River's overall ecosystem health ranking as last of the Coastal Bays. A combination of poor flushing, heavy nutrient loading from both agriculture and development, and poor management practices previously implemented probably contributed to the current impacted health and steady decline of St. Martin River. For more information, see Chapter 2—*Ecosystem Health Assessment*.


How healthy is St. Martin River?

ST. MARTIN RIVER ISSUES

Although the following issues are presented here as pertaining to St. Martin River, they also apply to other Coastal Bays subwatersheds.

Total Maximum Daily Loads have been established for St. Martin River

The Delaware Department of Natural Resources and Environmental Control has identified the water quality of Buntings Branch as impaired due to elevated


JANE THOMAS

Aerial view looking from Bishopville Prong down St. Martin River towards Isle of Wight Bay and Ocean City.

nutrient levels and low dissolved oxygen concentrations.[2]

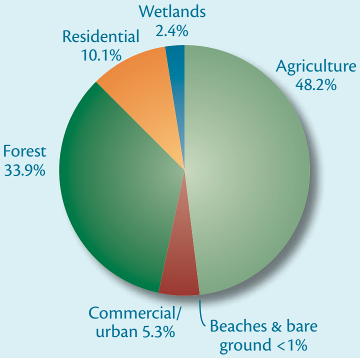
Buntings Branch watershed is located mostly in Delaware, with a small southern portion in Maryland. The stream flows southeastward through Selbyville and empties into the headwaters of Maryland's Bishopville Prong. The drainage area within Delaware is 2,550 ha (6,300 acres) and is about 58% of the total drainage area of Bishopville Prong. There are no active point sources discharging nutrients into Buntings Branch, therefore all nutrients are coming from non-point sources.

The Maryland Department of the Environment (MDE) developed Total Maximum Daily Loads (TMDLs) for nitrogen and phosphorus for Bishopville Prong in April 2002.[4] The analysis determined that non-point source loads should be reduced by 31% for nitrogen and 19% for phosphorus to meet Clean Water Act goals. Delaware has also conducted a TMDL load analysis and has established the same percentage reduction goals as Maryland.

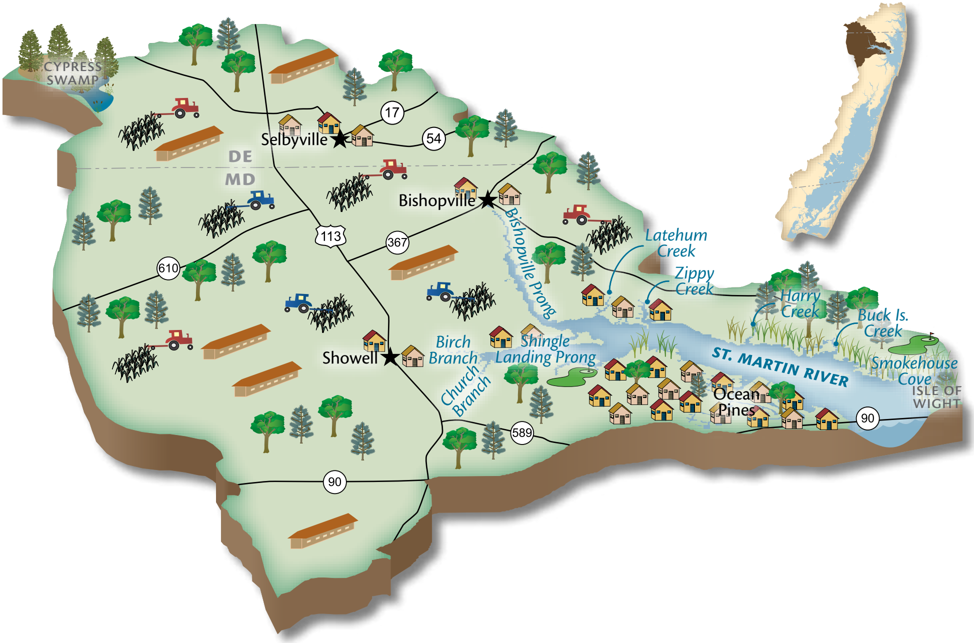
St. Martin River & watershed facts

Watershed area (km^2)	95.5
Average bay depth (m)	0.67
Surface area of bay (km^2)	8.40
Watershed area : surface area	11.4
Bay water volume ($m^3 \times 10^6$)	5.63
Watershed area : water volume	16.96
Flushing rate (days)	12
Population	9,953

Land use in St. Martin River subwatershed (Maryland only)



St. Martin River & watershed



Conceptual diagram depicting general land use and features of St. Martin River and its watershed.

Delaware will implement the requirements of its TMDL through cooperation with the state of Maryland and development of a Pollution Control Strategy. Maryland is pursuing nutrient reductions through Watershed Restoration Action Strategies. For more information on TMDLS, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Restoration of Bishopville Prong is planned

A stream and wetlands restoration project near the town of Bishopville is close to the construction phase. The project area extends from the head of tide of Bishopville Prong to approximately 2.4 km (1.5 mi) upstream and includes a dam removal and restoration of an abandoned sand mine.

There is an existing sheet pile dam located where Route 367 (Bishopville Road) crosses Bishopville Prong. Originally built to create a mill pond, Bishopville Dam has been in existence, in one form or another, for over 130 years. The dam restricts the upstream movement of fish, including both seasonal spawners

SHIH-NAN CHEN

Bishopville Dam is at the head of Bishopville Prong, St. Martin River. This dam is the subject of a $1.7 million restoration project, a cooperative effort between local, state, and federal agencies to remove the existing dam, landscape the area, and restore the stream and streamside vegetation.

ROMAN JESIEN

Attempting to collect fish below Bishopville Dam. The dam is behind the Bishopville Road bridge.

and residents. Upstream of the existing dam, Buntings Branch has been ditched or channelized, as have nearly all the tributaries flowing into Buntings Branch (e.g., Slab Branch, Carey Branch, Sandy Branch, Polly Branch), to hasten the movement of baseflows and stormflows (see stream corridor assessment section later in this chapter). These alterations greatly lessened the opportunity for ecological services such as water quality and habitat.

The restoration site, known as Lizard Hill, was mined for many years for sand and other aggregates but has not been actively mined since 2001. The mine site is triangular in shape and abutted on two sides by streams (Buntings Branch to the southwest and an unnamed tributary to the north). There are numerous groundwater seeps that emerge at the mine site and are currently conveyed off the site and outleted to Buntings Branch by a number of ditches built by the mining company.

The upper St. Martin River has been highly impacted by human activities for a long time and the quality of the water and the habitat available for fish and other wildlife have suffered. The proposed project serves as an excellent opportunity to reverse this trend by restoring areas in and adjacent to the river and providing significant improvement to fish passage, instream habitat, water quality, floodplain function, and the restoration of globally rare vegetative communities such as Atlantic white-cedar (*Chamaecypris thyoides*) swamp. Atlantic white-cedar swamps were historically common on the Delmarva Peninsula. This site offers a rare and unique opportunity to re-establish this type of habitat and community. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed*.

The project involves four separate, but integrated, activities that consist of: 1) removal of the existing dam that will maintain an off-line pond yet provide fish passage and open approximately 11 km (7 mi) of upstream fish habitat; 2) restoration of a portion of the upstream pond to a stream and floodplain corridor (approximately 150 m [500 ft] and 1.2 ha [3 acres] of tidal/non-tidal wetland); 3) restoration of the existing floodplain above the dam to re-establish floodplain/stream hydrology and connection (16.6 ha [41 acres]); and 4) establishment of Atlantic white-cedar wetlands and adjacent buffer in the now-abandoned mine site which will include 8.1 ha (20 acres) of wetlands and 6.1 ha (15 acres) of associated buffer.

In an effort to spark conservation and restoration of critical and declining habitats in this area, the Maryland

JANE THOMAS

St. Martin River subwatershed supports many poultry farming operations.

Coastal Bays Program is partnering with Maryland Department of Natural Resources, Worcester County, U.S. Fish and Wildlife Service, Maryland State Highway Administration, and the National Aquarium in Baltimore to complete the $3 million project. Construction is projected to begin in the fall of 2009.

Shoreline stabilization should utilize 'soft shoreline' techniques

Shoreline stabilization seeks to stop the loss of land to encroaching waters. Moving water, whether through wave action or currents, erodes adjacent uplands. Steadily encroaching water, through sea level rise or land subsidence, has the same effect. Waterfront property owners seek to prevent erosion wherever it occurs, or even where it looks like it might occur.

In the past, the stabilization method of choice was the bulkhead, a vertical wall sharply separating upland from water. Better understanding of the negative effects of extensive bulkheading led to increased use of stone revetment, or riprap. Less ecologically damaging than bulkhead, riprap provides some habitat value but still offers only a poor connection between uplands and waterways. Recent studies indicate that 'living shorelines' or shorelines that connect uplands to waterways via a marsh system achieve water quality benefits as well as provide habitat that can be superior to riprap.[1,3,6] Although no one method of shore stabilization is suitable for all situations, non-structural or hybrid shorelines that consist of offshore low-profile stone sills that protect the leading edges of marshes can be applied in a variety of locations.

Effective October 1, 2008, the Living Shoreline Protection Act of 2008 (Maryland House Bill 973; Chapter 304) requires that shoreline erosion control projects consist of non-structural or 'soft' shoreline stabilization measures, except in areas designated by MDE as appropriate for structural or 'hard' stabilization measures (bulkheads, riprap, etc.) or in areas

This vast green expanse is the Great Cypress Swamp in Delaware, the very eastern edge of which (in the foreground) is in the St. Martin River subwatershed. This photo is looking west, with Route 113 and the western edge of Selbyville in the foreground.


JANE THOMAS

Aerial view looking towards the mouth of St. Martin River. Fenwick Island is in the background.

where a person can demonstrate to MDE's satisfaction that non-structural measures are not feasible.

The future of the Coastal Bays as habitat and a destination for wildlife, fish, and anglers depends to a large extent on the protection of the remaining natural shoreline. New policies and techniques need to be applied in the Coastal Bays which will stem the loss of waterfront land while maintaining harmony with nature. Projects that create or restore fringe marsh, placing hard structures offshore instead of on land, or covering bare ground with vegetation can slow or stop a receding shoreline. Restricting shoreline stabilization to cases where erosion actually occurs is another potential reform.

MDE will release new guidance and regulatory changes in 2008–2009 for use of natural shoreline stabilization practices as the preferred approach for shoreline stabilization. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Stream corridor assessment identified potential problems

In 2001, a Stream Corridor Assessment (SCA) was conducted in the St. Martin River watershed.[5] The SCA is a rapid overview of the entire non-tidal stream network to determine the location of potential environmental problems and to collect some basic habitat information. The value of these surveys is found in placing individual stream problems into their watershed context and can be used by a variety of resource managers to cooperatively plan and prioritize future restoration work. Results of the recent surveys will be used in the development of Watershed Restoration Action Strategies for each subwatershed of the Coastal Bays. Information on the Watershed Action Strategies can be found on the Maryland Department of Natural Resources' website (*www.dnr.state.md.us/watersheds/wras*).

During the SCA survey, potential environmental problems identified included channel alterations, inadequate stream buffers, fish migration barriers, erosion sites, construction sites within the stream corridor, and trash dumping sites.

Channel alterations and inadequate stream buffers were the most commonly reported problem during this survey. Channel alterations, best described as agricultural ditches, were found to be widespread throughout the headwaters of the watershed. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed*.

While streams in the St. Martin River watershed have been extensively altered, they were also fairly stable with erosion problems reported in only a few locations. The low incidence of erosion problems is due in large part to the flat terrain and low stream slopes in the area. This result suggests that streams in the area may be more amenable to manipulation than streams in areas where the land has much steeper slopes and water in the streams flows with greater force.

The majority of fish migration blockages were characterized as being either temporary or partial fish migration barriers. Most of the fish migration blockages were also given a minor or low severity rating. The only exception was at Bishopville Dam which was given a severe rating because it was interfering with the migration of anadromous (ocean fish that breed in freshwater) fish. Plans to modify this dam to enable fish passage are described earlier in this chapter.

Recommendations

- Maryland Coastal Bays Program partners should continue to pursue the Nutrient Management Action Plan by instituting a multi-agency working group to target watershed needs with funding and resources to restore and conserve sensitive areas within the watershed.

Discharges into St. Martin River have contributed to degraded water quality

Currently there are no point source discharges into upper St. Martin River, but point sources have contributed to degraded water quality in the past and

JANE THOMAS

The former Perdue poultry processing plant on Middle Branch of Shingle Landing Prong, St. Martin River. This plant stopped production in September 2004; however, the wastewater treatment plant continued to operate for many months after that as the plant was cleaned and equipment removed.

JANE THOMAS

Shingle Landing Prong in the St. Martin River. The Perdue Processing Facility at Showell discharged treated industrial wastewater into Church Branch, a tributary of Shingle Landing Prong.

clean up has been slow. Discontinued point sources include the Selbyville, Delaware, Wastewater Treatment Plant (WWTP), the Perdue Processing facility at Showell on Shingle Landing Prong, and the Bishop Processing Company located on an unnamed tributary of Carey Branch which flows into Bunting Branch. The Selbyville WWTP discharged treated effluent into Poly Branch, a tributary of Buntings Branch, but since the new plant was constructed in 1989, effluent has been discharged into the ocean at Rehoboth, Delaware.[7]

The Perdue poultry processing facility at Showell discharged treated industrial wastewater into Church Branch, a tributary of Shingle Landing Prong. Operations ceased at the facility in 2004 and building proposals include conversion of the facility to treat human waste generated by residents of proposed and existing housing units in the area. The Maryland Coastal Bays Program is working to get the treated human waste land-applied to cropland to the west, rather than directly discharged.

The Bishop Processing Company began operations in 1955 about 1.3 km (0.8 mi) north of Bishopville. The property drains to an unnamed tributary of Carey Branch, which flows into Buntings Branch. The facility processed chicken offal into bone meal and usable oils, and animal and vegetable waste oils into usable product. The operation ceased in 1981 and the property was sold. A series of surveys at the site from 1983 through 2000 indicated high levels of iron, chromium, and arsenic, low levels of volatile organic compounds (VOCs), such as vinyl chloride, and extremely low (acidic) pH in groundwater. Surface water samples on-site had high levels of iron, aluminum, and arsenic and slightly elevated levels of organics and soil samples contained PCBs (polychlorinated biphenyls) as well as low levels of VOCs. Contaminated soil was identified and removed from the site and a Voluntary Cleanup Program application was submitted in 2004 seeking a No Further Requirements Determination. The application is currently pending. For more information, see *www.mde.state.md.us/assets/document/brownfields/Bishop_Processing.pdf*.

The site is considered a 'brownfield.' Brownfields are previously used land parcels located in areas that are appropriate for redevelopment, but which have a real or perceived site contamination problem. Because of the costly liability associated with waste cleanups, businesses do not want to take a chance on locating their businesses at such sites. With appropriate resources, MDE can undertake a variety of actions to make these brownfield sites attractive to new or expanding businesses. In this way, MDE's brownfields redevelopment efforts help meet the needs of economic development while directing growth to appropriate areas. For more information, see *www.mde.state.md.us/Programs/LandPrograms/ERRP_Brownfields/bf_info/index.asp*.

There is one point source discharge into lower St. Martin River—the wastewater treatment plant at Ocean Pines. For more information, see section on the wastewater treatment plant later in this chapter.

FEATURES OF ST. MARTIN RIVER & ITS WATERSHED

An oyster reef was established

The Assateague Coastal Trust, in partnership with the National Oceanic and Atmospheric Administration, the Maryland Coastal Bays Program, and others, began a project in 2000 to establish a 4-ha (10-acre) oyster reef near the mouth of St. Martin River. By 2005, the reef was approaching 0.8 ha (two acres) in size and was a mixture of oyster shell, clam shell, and concrete rubble. Each summer, one-year-old oysters grown by participants in the Oyster Gardening Program were placed on the reef. Although small numbers of oysters can be found in intertidal areas such as bridge abutments, riprap shorelines, and in marshes, the St. Martin River reef was the only subtidal reef in the Coastal Bays. For more information on oysters, see Chapter 14—*Diversity of Life in the Coastal Bays*.


JOAN MULLER, NOAA

Very few oysters live in the Coastal Bays, but a few can be found in intertidal areas on bridge abutments, riprap, and in marshes.

Surveys on the St. Martin River reef initially indicated that the oysters were alive and growing. However, in 2005, the number of oysters started declining. In addition, colonization of the reef by benthic organisms was minimal due to heavy accumulation of sediment and macroalgae, which suffocates organisms when it decomposes. Low oxygen levels in the summer of 2006 may have also contributed to the decline of the reef's health. For more information, see *www.actforbays.org/pages/oyster2.php?id=139_0_5_0_C*.

The program was discontinued in 2007 due to the difficulties in placing reef materials and the lack of survival of the young oysters. Disease, sedimentation, and poor water quality prevented success of this particular oyster reef; however, much was learned about conditions at the mouth of St. Martin River.

Ocean Pines wastewater treatment plant was expanded in 2006

The planned community of Ocean Pines opened for business in July 1968 along St. Martin River and Isle of Wight Bay. A privately owned sewage treatment plant was built to serve the community, with the effluent being discharged into the lower portion of St. Martin River. By 1987, capacity of the sewage treatment plant was expanded to half a million gallons of wastewater per day (MGD) and Worcester County undertook ownership of the plant. Another plant upgrade was completed in 1994, which brought the capacity to 1.5 MGD. The treatment plant was brought to the present capacity of 2.3 MGD in 2003 and is a state-of-the-art facility, removing nitrogen to a level of three parts per million (or 3 mg L^{-1}), which is equal to the best wastewater plants in Maryland.

In 2008, there were more than 15,000 full-time residents with approximately 7,500 more summer residents. The community has its own police and fire departments, as well as a yacht club, swim and racquet club, beach club, and golf and country club. Just outside Ocean Pines is a commercial area with a wide range of businesses that serve the community. Initially, the treatment plant was to treat residential wastewater, but area businesses have requested to tie into the plant. Efforts to incorporate a larger area in the treatment plant are currently being debated. The debate centers on the high cost of conversion to sewer for current residents on septic systems. However, new businesses and developments would welcome extension of the sewer line.

The Ocean Pines treatment plant was expanded in 2006 to allow it to process up to 2.5 MGD. This design will be able to accommodate all of Ocean Pines sewer needs at build-out and full occupation. An additional 200,000 gallons of treatment capacity is available for the Greater Ocean Pines Sewer Service Area. Because of the extra treatment capacity, homes and business within the Sewer Service Area should be strongly encouraged to hook up to the treatment plant, rather than to continue to rely on traditional septic systems, and use the extra capacity to accommodate new home construction.

~


TIM CARRUTHERS

The Ocean Pines community has a recently expanded sewage treatment plant that can treat up to 9.5 million liters (2.5 million gallons) of wastewater per day.

ACKNOWLEDGEMENTS

The authors would like to thank Ron Pilling (Assateague Coastal Trust), Edythe Humphries (Delaware Department of Natural Resources and Control), Dave Wilson (Maryland Coastal Bays Program), and Sherm Garrison and Kevin Smith (Maryland Department of Natural Resources) for comments helpful in the completion of this chapter.

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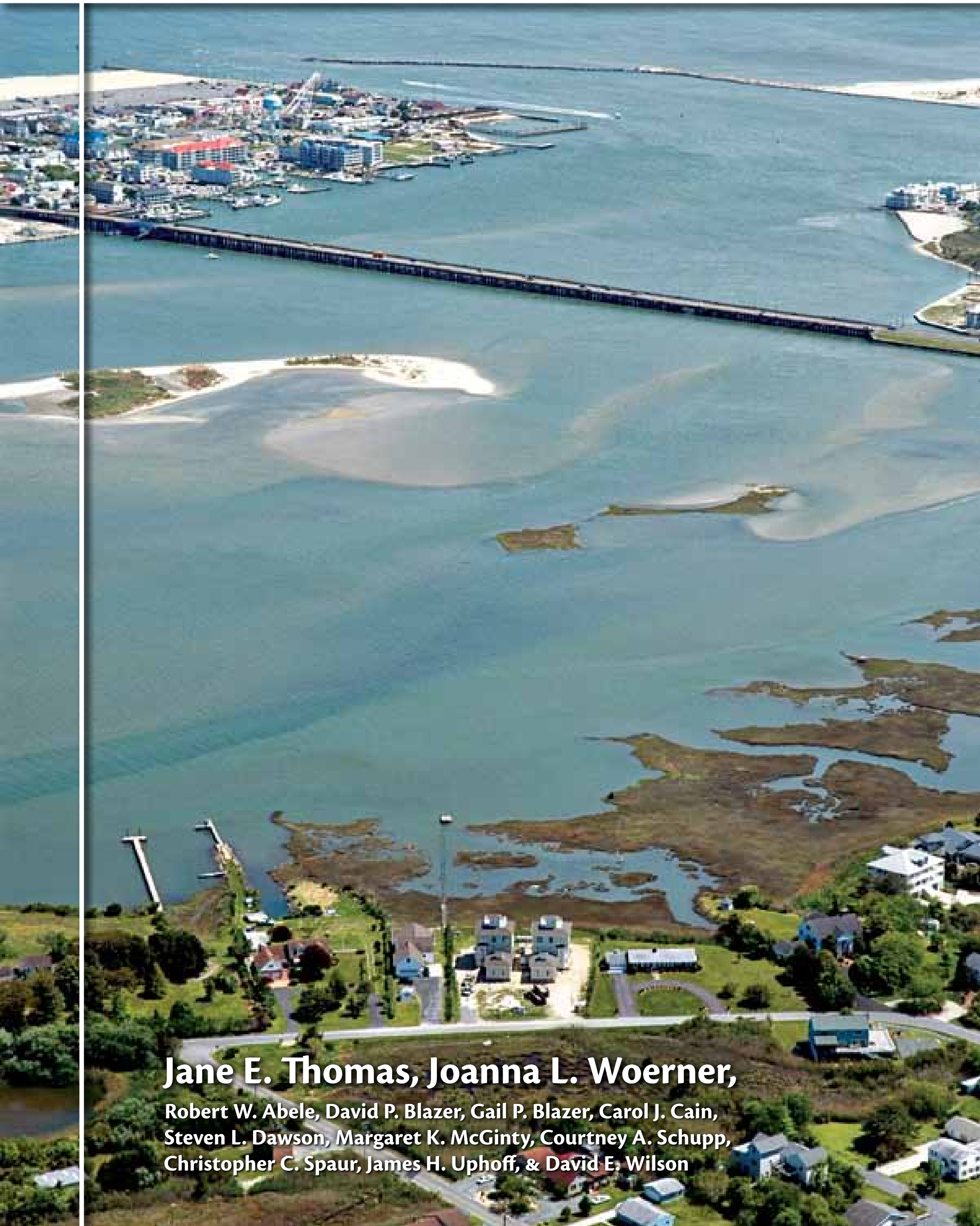
6. Isle of Wight Bay



Jane E. Thomas, Joanna L. Woerner,

Robert W. Abele, David P. Blazer, Gail P. Blazer, Carol J. Cain, Steven L. Dawson, Margaret K. McGinty, Courtney A. Schupp, Christopher C. Spaur, James H. Uphoff, & David E. Wilson

CONCLUSIONS

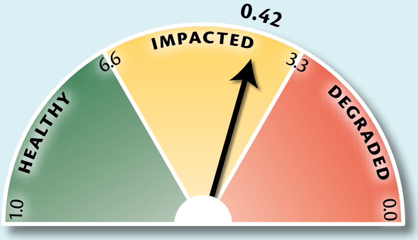
The ecosystem health of Isle of Wight Bay is impacted

Isle of Wight Bay ranked as impacted for both estuarine and watershed health. Water quality was better in the well-flushed open bay than in the tributaries, and good scores for bay benthic communities and sediment quality were balanced by poor results for brown tide, hard clams, seagrass, and stream benthic communities. This resulted in Isle of Wight Bay's overall ecosystem health ranking as fourth of the Coastal Bays. For more information, see Chapter 2—*Ecosystem Health Assessment.*

ISLE OF WIGHT BAY ISSUES

Although the following issues are presented here as pertaining to Isle of Wight Bay, they also apply to other Coastal Bays subwatersheds.

How healthy is Isle of Wight Bay?



Dead-end canals can create ecological problems

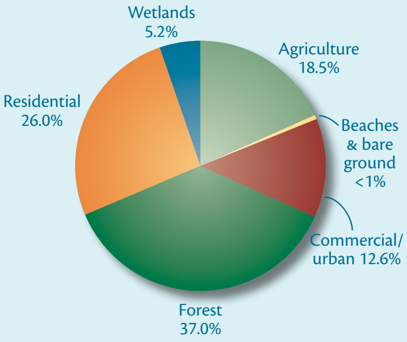
There are at least 111 canals adjacent to the Coastal Bays, 59 of which are in Isle of Wight Bay. Most of these canals were built between 1960 and 1980 by development projects that dug the canals to create residential waterfront lots. Dead-end canals are problematic for several reasons. They usually have only one opening. Most were dug through wetlands with the


JANE THOMAS

Aerial view of Isle of Wight Bay, with Ocean City and the inlet in the background.

Isle of Wight Bay & watershed facts

Watershed area (km²)	51.8
Average bay depth (m)	1.22
Surface area of bay (km²)	21.1
Watershed area : surface area	2.45
Bay water volume ($m^3 \times 10^6$)	22.85
Watershed area : water volume	2.27
Flushing rate (days)	9.45
Population	18,570

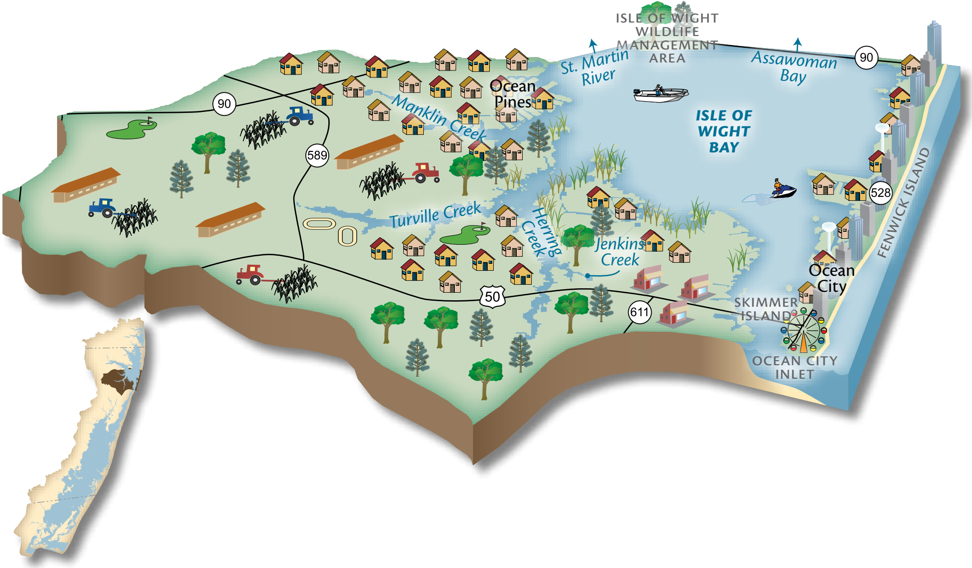


Land use in Isle of Wight Bay subwatershed

material being side-cast to build elevation. The canals were often dug deeper than their receiving waters, creating lower bottom elevation and poor flushing. This causes canal water to stagnate and become depleted of dissolved oxygen, which is essential for organisms to survive. The canals receive pollutants from stormwater runoff. The Ocean Pines community alone, located in both Isle of Wight Bay and St. Martin River watersheds, has 322 km (200 mi) of ditches, mostly draining into 19 km (12 mi) of canals that serve to remove stormwater from 8,300 properties.

While the amount of waterfront has increased dramatically by this development, the result is that non-point source pollution from all residences has increased as well. Additionally, the loss of wetlands associated with this development has meant a decreased ability to filter out nutrients and pollution before reaching the bays. Animal waste, lawn trimmings, fertilizers, fishing waste (scraps and bait), and trash are all major sources of pollution.

Common problems with dead-end canals include poor flushing, excessive nutrients and algae, fish kills, trash accumulation, low dissolved oxygen and poor habitat for fish and crabs, heavy metals and sediment from stormwater runoff, leaching of bulkheads, watercraft



Isle of Wight Bay & watershed

Conceptual diagram depicting general land use and features of Isle of Wight Bay and its watershed.

pollution, and silting of canal mouths and ends. The question of who is responsible for maintaining the canals is ambiguous.

Most canals are stabilized with bulkheading (vertical walls that deflect all wave action and cause scouring of the canal bottom). Scouring can undermine the bulkhead and exacerbate erosion. Furthermore, bulkheading was historically made with treated lumber containing toxic chemicals, including copper, chromium, and arsenic. A study of Maryland and Delaware bays found that some bay sediments were contaminated with metals (arsensic, copper, nickel, zinc), pesticides (chlordane, dieldrin, DDT [dichloro-diphenyl-trichloroethane]), and other chemicals (PCBs [polychlorinated biphenyls], PAHs [polycyclic aromatic hydrocarbons]).[3] The most severe contamination was found in areas with boating activity (such as marinas, where boat paints and sacrificial anodes on boats and crab pots are sources of pollution) and intense urbanization (bulkheads, auto-part wear, stormwater runoff, and atmospheric inputs). This same study found that more than 55% of the area in dead-end canals had bottom dissolved oxygen less than the state standard of 5 mg L^{-1}. Thirty percent of the dead-end canal area had concentrations of less than 2 mg L^{-1}. Low oxygen stresses organisms. When researchers examined the canals for marine life they found that 78% had only two organisms—pollution-tolerant worms and algae.

Although ecological conditions within the canals are degraded, they effectively function as an unintentional best management practice by preventing release of pollutants into the Coastal Bays themselves. Accordingly, correcting problems within the canals would require the tradeoff that these materials would be exported into the bays. The recommendations below only address improvement of conditions within the canals, not how to limit impact of pollutants within the canals on the Coastal Bays.

JANE THOMAS

Fenwick Island contains many dead-end canal developments.

Policy recommendations

- Determine who has jurisdiction and maintenance responsibilities for canals and non-federal channels. How often should maintenance be conducted?
- Investigate the feasibility of a Navigation and Dredging tax district.
- Investigate the feasibility of replacing old bulkheading using soft shoreline stabilization techniques.
- Provide best management practices for dredging and maintaining canals. Discourage the practice of spot-dredging holes for boat docks and boat lifts. These holes in shallower canals cause water quality problems.
- Fill canal depressions with dredge material to mean canal depth. Maintain a depth and slope to meet natural bay conditions. Remove sediment sills from the mouths of the canals to improve flushing and water quality.
- Direct roof and road stormwater runoff away from canals. Many canal-front homes have buried downspout pipes that discharge roof-top rainwater directly into the adjacent canal. These pipes should be disconnected to allow water to soak into the ground or be diverted to small rain gardens where the water can be absorbed by plants and shrubs.
- Determine if dredge material is suitable for wetland/island creation projects.
- Increase public education and involvement by making homeowners and associations aware of the impact of their practices on water quality. Engage them in seeking solutions and remediation practices.
- Explore pollution prevention methods, particularly in dead-end canals in residential areas.

Navigation & dredging activities should be coordinated

Responsibility for navigation and dredging in the Coastal Bays is shared by several federal, state, and local agencies as well as private communities, businesses, and individuals. The lack of overall planning and coordination in the past contributed to a variety of problems, including public confusion about these issues, inadequate environmental safeguards, failure to make full beneficial use of dredged material, and non-standard channel maintenance and marking. Locally based planning, coordination, and vision was needed to enhance the


JANE THOMAS

Condominiums and amusement parks are a typical Isle of Wight Bay vista.

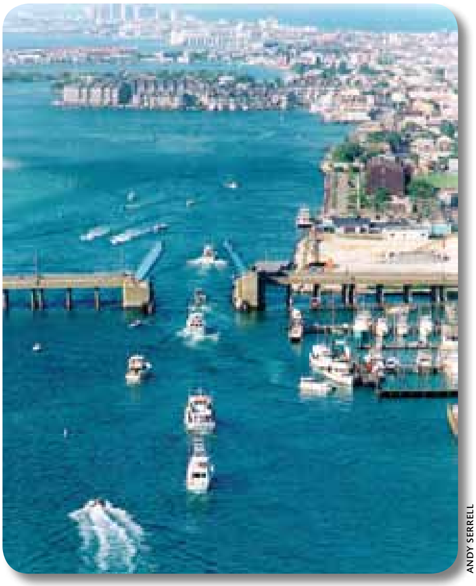
management of navigation and dredging and minimize adverse effects on the Coastal Bays.

Dredging of Isle of Wight Bay and Ocean City Inlet aids boaters in navigating the sandy shoals that form behind the island, and transforms the shoals from a navigation hassle into a key component of island restoration. The sand bodies—tidal deltas—form seaward and landward of tidal inlets as a result of the sudden drop in water velocity that occurs where the flooding tide meets the bay and where the ebbing tide joins the ocean.

In order to restore sand transport processes, which were disrupted by the stabilization of the Ocean City Inlet with jetties, the Long-Term Sand Management Program dredges sand from portions of the tidal deltas within the bay, the inlet, and the nearshore areas of both Ocean City and Assateague Island. It is then deposited offshore of a sand-starved section of Assateague Island and several erosional hotspots in Ocean City.

This sand bypassing method attempts to restore sand movement using natural processes such as wave movement and longshore currents. The restoration project also provides bathymetric surveys of the inlet and the tidal deltas every two years. This data quantifies changes in the location and volume of sand bodies in the bays and around the inlet. For more information on the Long-Term Sand Management Project and the changes resulting from the construction of the Ocean City Inlet jetties, see Chapter 12—*Dynamic Systems at the Land–Sea Interface*.

Due to the relatively shallow nature of the Maryland Coastal Bays, the maintenance of navigable waterways to support recreational and commercial boating is a critical regional need. Improved planning and coordination between federal, state, local, and private interests is needed to enhance the economic and recreational benefits of navigation improvements and dredging while minimizing their adverse effects on natural resources.


ANDY SERRELL

Recreational boating is a popular pastime in the Coastal Bays, requiring navigation and dredging maintenance.

A Navigation and Dredging Advisory Group was created to develop a Master Plan to guide the management of navigation and dredging in the Coastal Bays, provide a forum for public input into related decision-making, and enhance and protect natural resources either at risk or that may benefit from navigation-related activities. This committee developed a master plan that now needs to be implemented.[6] The committee needs to continue to organize as the forum of diverse Coastal Bays users and agencies responsible for navigation and dredging in a way that allows concerns, needs, obstacles, and benefits to be highlighted, discussed, and coordinated. By doing so, navigation and dredging actions can be expedited and provide the greatest benefits at least cost to bay users and the bay ecology. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Recommendations

- Promote and implement the recommendations of the Master Plan to guide the management of navigation and related activities in the Coastal Bays.

- Provide an ongoing forum for communication between agencies and organizations with responsibilities for, or interest in, navigation and dredging to enhance coordination and consistency.
- Design and distribute a Navigation and Dredging Planning Guide to address the following issues:
    - Dredged materials management.
    - Use recent studies to identify and secure dredge placement sites.
    - Prioritize areas that require dredging.
    - Link areas that require dredging to areas in need of fill material.
    - Track total dredge material disposal needs by volume, location, and sediment type.
    - Encourage citizen participation in project monitoring.
- Develop educational materials that describe best management practices for dredging, including time-of-year restrictions, preferred methods, safeguards for sensitive areas, and contaminated sites management. Ensure that these materials are available to the public and updated periodically.
- Develop and distribute a map identifying federal and marked private navigation channels. Include information regarding sensitive species areas and personal watercraft restricted areas.
- Prioritize areas to improve channel markers, especially small channels leading to and from boat access points and the federal channel in Chincoteague Bay. Using a coordinated effort, identify and secure needed funding for marker upgrades and new installations. Provide the opportunity for public reporting of marker and channel conditions via agency phone numbers and websites.
- Make timely updates to nautical charts. Determine the frequency needed to collect meaningful bathymetric data. Identify long-term funding sources and responsible agencies.
- Develop educational materials outlining permit details, including information needed, permit review time, contacts, appeals process, and public participation opportunities.

Wetlands should be managed, preserved, & restored

Isle of Wight Bay has incurred substantial loss of wetlands from development and agriculture. Although wetlands regulations now serve to protect direct loss of wetlands, permitted losses do occur. The vast majority of permitted impacts have been in the Isle of Wight Bay watershed, which has the smallest wetland extent. For more information on wetlands, see Chapter 3—*Management of the Coastal*

Subwatershed	Drainage area (acres)	Total wetland area (acres)	Wetland extent (%)
Assawoman Bay	6,104	2,746	45
Isle of Wight Bay & St. Martin River	36,077	5,648	16
Sinepuxent Bay	6,598	4,023	61
Newport Bay	27,923	6,546	23
Chincoteague Bay	34,842	15,530	45
Coastal Bays total	**111,544**	**34,493**	**31**

Extend of wetlands in the Coastal Bays watershed.[10,12]

Bays & Watershed and Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Permitted non-tidal wetland losses and conversion impacts from 1991–2006 totalled 89.34 acres in the Coastal Bays:

Losses	-89.34
State mitigation (gain)	+25.20
Landowner mitigation (gain)	+57.56
Additional voluntary gains	+6.07
Total backlog of non-tidal wetlands	-0.51

Mitigation

The Coastal Bays watershed has the largest compensatory mitigation backlog in Maryland. Permittees can pay into the state compensation fund where wetland impacts are minor or when the landowner has no other option (e.g., residential developments). However, when the opportunity is available, permitees are required to replace lost wetlands. Completion of mitigation projects and their success was not well documented until 2007, when Maryland Department of the Environment (MDE) completed a review of the effectiveness of its mitigation program. Mitigation has generally been found to be successful and MDE is increasing its monitoring and follow-up efforts. There has been no penalty applied to date for failing to carry out mitigation monitoring or file reports. In general, wetland scientists agree that mitigation often fails to replace the function of the lost wetland, particularly if the original wetland was not degraded. However, MDE's program, when adequately staffed, can document that and oversee establishment of wetlands that are on the right path to replacing lost wetland functions.

Preservation & restoration

In the cases of some new developments, when a permit is issued for wetland impacts, a deed restriction on the remaining wetland area on the property is applied. Estimates run to a few thousand acres. There are difficulties in enforcing these restrictions—this is the job of the compliance/enforcement divisions of the regulatory agencies. Deed restrictions are also subject to reversal in the courts, and thus represent a somewhat tentative layer of protection.

A goal to replace 4,050 ha (10,000 acres) has been adopted by the Maryland Coastal

JANE THOMAS

The U.S. Army Corps of Engineers, Maryland Deparment of Natural Resources, and Worcester County worked together to restore approximately 4 ha (10 acres) of saltmarsh on the southern tip of the Isle of Wight Wildlife Management Area, seen in the foreground. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Bays Program. Since 1999, nearly 809 ha (2,000 acres) of wetlands have been created or restored largely through the USDA's NRCS Wetland Reserve Program.[6]

The Isle of Wight Bay subwatershed contains a Non-Tidal Wetland of Special State Concern—West Ocean City Pond. The primary management goal for this wetland is to preserve the water quality of the pond by maintaining a 30-m (100-ft) forested buffer around the pond.[9]

MDE has worked to prioritize wetlands for preservation, restoration, and mitigation in the subwatersheds of the Coastal Bays, including assessing species and resources and identifying areas where the most benefit could be gained.[7,8]

With their location at the land–water interface, wetlands are particularly vulnerable to sea level rise, especially if they are prevented from migrating landward by existing development. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Management

Problems with wetland management are present within permitting, enforcement, and preservation. Confusion about requirements and costs could be reduced by requiring an environmental assessment or certified wetland delineation report submittal at the outset for large projects. Mapping of both tidal and non-tidal wetlands is deficient and outdated, and accurate updates are needed. Compliance suffers from a lack of immediate penalty for wetland violations and lack of any imposed penalties for failures in wetland mitigation. Preservation through deed restrictions suffers from lack of oversight.

Recommendations

- Implement Worcester County's Comprehensive Plan.[14]
- Regulation and enforcement:
    - Begin a large-scale public education initiative with property owners.
    - Increase staffing resources to follow up on projects, violations, mitigation, etc.
    - Return to the system of ticketing violators on the spot.
    - Establish monitoring/reporting of violations from the air by Maryland Department of Natural Resources during other flight missions.
- Permitting:
    - Institute a formalized process of environmental assessment or certified wetland delineation report submittal at the outset of each large or complex project.
- Mapping:
    - Update the current tidal wetlands maps to reflect changes in sea level, shorelines, etc.
    - Revise the non-tidal wetland maps.
- Mitigation:
    - Institute a bonding requirement and/or penalty to reduce non-compliance with mitigation monitoring requirement. MDE now requires that bonds be submitted before permits are issued.
    - Consider instituting a watershed-wide mitigation banking system.
    - Establish a program of acquisition or easement on lands for future programmatic mitigation sites to avoid the current difficulties in finding sites in a reasonable time frame.
    - Perform more detailed functional loss assessments in determining the mitigation required, especially on larger projects—improvements to the assessment procedure for wetlands proposed for impact are under development by MDE.
    - Raise the wetland compensation fund payment schedule to a more reasonable payment to reflect current land values.
    - Wetland mitigation should be conducted according to

    recommendations already published.[7,8]
- Buffer mitigation:
    - Reconsider current buffer mitigation exemption, especially where a wetland remains after its buffer is destroyed.
- Database/records management:
    - Tidal permits:
        - Improve form of records and clarify organization.
    - Non-tidal permits:
        - Make available subsets of databases and more extensive data analysis.
        - Document the time at which wetland impacts begin in order to ensure maximum overlap of functioning mitigation wetland area and to record projects that did not occur.
        - Add the following information not now collected: area protected via deed restriction; functional losses for Letter of Authorization permits; and completion/success of creation, restoration, and enhancement projects for cases where mitigation is not required.
- Staffing:
    - Address staffing and funding needs to implement some of the above recommendations.

There are large amounts of impervious surfaces

Impervious surfaces increase runoff, erosion, sedimentation, thermal pollution, excess nutrients, toxic metals, and detrimental organic compounds in aquatic systems.[1,11] Impervious surfaces are any surfaces (pavement, rooftops, and compacted soils) that prevent water from penetrating into the ground. In Chesapeake Bay tributaries, bottom-layer dissolved oxygen and fish communities decreased significantly as impervious surfaces increased.[13] In addition, PCB contamination in white perch increased with impervious surfaces.[5]

JANE THOMAS

Increasing development threatens wetlands along the shores of Turville (foreground) and Herring Creeks.

JANE THOMAS

Isle of Wight Bay has a high proportion of impervious surfaces, as shown here on Fenwick Island.

Impacts of agricultural practices and extensive stream channelization have degraded and will continue to impact stream ecosystems in the Coastal Bays. Future development could exacerbate these problems, particularly in areas where impervious cover is likely to be substantial. Research from streams elsewhere in the state indicates that significant biological degradation can be expected to occur where stormwater runoff is not adequately managed and impervious cover in a watershed exceeds 10%.[11] Impervious surface in the Isle of Wight Bay watershed is currently at this 10% threshold (see Chapter 2—*Ecosystem Health Assessment*). In the northern bays, where the greatest volume of stormwater runoff from developed areas is received, frequent exchange with ocean water occurs, which may limit the impacts of stormwater runoff. Additionally, flat slopes and large areas of sandy soils serve to somewhat limit runoff impacts. Estuarine waters that are not as well flushed may accumulate pollutants more readily.

Land use planning is largely under local control and is often conducted on a project-by-project basis that does not consider watershed-wide impervious surface and its associated impacts on aquatic resources. It is not known if stormwater or restoration technology can negate or reverse these impacts, particularly on biological communities and their habitats. Because of these uncertainties, effects of impervious surfaces on aquatic systems should be considered in the planning process. Studies in similar habitats have recommended avoiding the 10% threshold by applying a safe margin of 2–3% less than 10% in order to reduce the risk of biological impairment.[1,13] However, avoiding the 10% impervious threshold is unrealistic for some areas to be developed, but maximizing development density will reduce demand for rural land elsewhere. Studies have not been conducted to determine impacts of impervious cover on the Coastal Bays, but research on Chesapeake Bay tributaries and South Carolina tidal creeks have indicated threshold effects and it is only prudent to consider those examples in planning future development in the Coastal Bays.[4,5,13]

Maryland is among the most progressive states in the nation with regard to stormwater management. MDE regulations require new development in rural areas and redevelopment in already existing developed areas to mitigate impacts of stormwater runoff. The regulations set goals for pollutant removal, maintenance of groundwater recharge, and controlling impacts to receiving streams. The latter considers reducing or preventing increased channel erosion and stream overbank flooding. Thus, redevelopment of older areas in accordance with MDE's new policies would be anticipated to gradually reduce impacts of stormwater runoff from these older areas. New development done in accordance with current MDE stormwater management guidelines will probably not cause the severe problems that older development done prior to modern guidelines/requirements did. However, in spite of the strength of these MDE requirements, the long-term effectiveness of stormwater management measures is yet to be determined. Additionally, it is likely that cumulative effects of large-scale new urbanization will gradually impair surface and groundwaters since their pollution generation rate is greater per acre.

Recommendations

- Implement Worcester County's Comprehensive Plan recommendations regarding impervious surfaces.[14]
- Initiate research projects to define successful measures for preventing or restoring degraded habitat in brackish and marine waters. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Stormwater best management practices should be implemented in Ocean City

Maryland Department of Natural Resources (DNR) and MDE have developed stormwater management procedures for Ocean City. MDE requires water quality volume treatment and DNR requires proof of pollutant reduction and habitat enhancement. Therefore, best management practices (BMPS) must be utilized on new development and redevelopment projects to meet the intent of both regulations. The MDE stormwater regulations start at lots 460 m^2 (5,000 ft^2) in size and DNR's regulations affect anything over 23 m^2 (250 ft^2) of disturbance. Therefore, 99% of all development/redevelopment in the town must incorporate some sort of BMP that treats stormwater.

The choices of BMPS in Ocean City are very limited. Lot size and value are the main restrictions. Buildings are located setback to setback, and after parking and landscaping requirements and location of utilities, stormwater management is the last to be incorporated into the site plan. Another consideration in choosing BMPS is the location of Ocean City. Ocean City is a flat barrier island with 100% urban land use, and all of the storm drains empty into the Coastal Bays, not the ocean. The ocean side of the island is very sandy; however, the bay side is man-made land, using dredge material. Soil infiltration rates,


GAIL BLAZER

A summer thundershower floods the Coastal Highway in Ocean City. Sitting only a few feet above sea level, Ocean City floods frequently, especially when rain events occur at high tide.


DAVE WILSON

A stormdrain lies under nine inches of water in downtown Ocean City during a nor'easter storm in February, 1998.

TOWN OF OCEAN CITY

Pervious pavers used in a parking lot in Ocean City. These pavers are used to reduce impervious surface and act as an infiltration trench.

TOWN OF OCEAN CITY

Bioretention in an urban environment. Bioretention utilizes soils and plants to remove pollutants from stormwater runoff.

TOWN OF OCEAN CITY

One way to reduce impervious surface is to have driveway tracks, instead of paving the whole surface.

	Vehicle exhaust	**Power plants**	**Tire and vehicle parts wear**	**Vehicle oil, grease & fuel**	**Road surfaces & de-icing salts**	**Household, lawn, & garden chemicals**
Lead	✓	✓	✓	✓		✓
Zinc			✓	✓	✓	✓
Arsenic		✓				
Copper			✓	✓		
Cadmium		✓	✓			✓
Chromium		✓	✓			
Nickel		✓	✓	✓	✓	
Manganese		✓	✓			
Mercury	✓	✓				✓
Iron			✓			
Cyanide						✓
Nitrogen & phosphorus	✓	✓				✓

Common pollutants and their sources. Many of these pollutants can be found in stormwater runoff.

property slope, groundwater elevation, and other site requirements have to be considered in stormwater management design. Designers are encouraged to utilize pervious paving techniques to jointly meet parking and stormwater requirements, and include bioretention techniques in landscaping plans to meet landscaping requirements.

With this in mind, the following are the BMPs from the 2000 Maryland Stormwater Design Manual that are viable in Ocean City:[2]

- Infiltration:
  - Exfiltration trench (minimum two feet clearance to water table).
  - Pervious pavers can be designed as an infiltration trench.
  - Bioretention (as infiltration).
- Filters:
  - Bioretention.
  - Sand filters.
- Non-structural techniques:
  - Disconnection of rooftop runoff:
    - Swales, raingardens, and other landscaped areas.
  - Disconnection of non-rooftop runoff:
    - Direct flow from impervious surfaces to swales/bioretention areas, etc.
  - Maximum impervious surface requirements.
  - Pervious paver, pervious deck design, pervious sidewalks, pervious concrete, and asphalt.
- Ponds/wetlands:
  - Pocket ponds and wetlands.

FEATURES OF ISLE OF WIGHT BAY & ITS WATERSHED

Isle of Wight Bay and its watershed are the most heavily used of the Coastal Bays. Bounded on the east by densely developed Ocean City, it is also bounded on the west by very dense residential development.

The north boundary is Route 90 with two in-line bridge spans leading from the mainland to Cape Isle of Wight and then to north Ocean City. The south boundary

JANE THOMAS

Unlike the southern bays, seagrass distribution is relatively stable in Isle of Wight Bay.

is the Route 50 bridge, bringing traffic into south Ocean City.

Flowing into Isle of Wight Bay are waters from Herring Creek, Turville Creek, and St. Martin River, all with increasing residential development.

Skimmer Island is a haven for birds

Just north of the Route 50 bridge is Skimmer Island, a protected sanctuary for skimmers, ibis, egrets, herons, and terns. The shallows north and west of the island are reserved for recreational clamming. Commercial and recreational crabbing and clamming are also active in the bay. For more information, see Chapter 14—*Diversity of Life in the Coastal Bays.*

Isle of Wight Wildlife Management Area has been restored

Between the spans of the Route 90 bridge is the Isle of Wight Wildlife Management Area, a restored, county-owned park area where 4 ha (10 acres) of salt marsh were created and where the public can enjoy a beautiful view in a natural setting. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Isle of Wight Bay is a tourist destination

Tourism in Isle of Wight Bay is big business. With some 300,000 weekend visitors to its eastern flank, the bay hosts recreational interests of all varieties from Ocean City. Personal watercraft, power and sail boats, kayaks, and canoes frequent the bay with users being both visiting tourists and residents. Near the Route 50 bridge and along the thoroughfare, hundreds of boaters ply the bay for flounder, sea trout, and rockfish during the busy June–September tourist season. Isle of Wight Bay is where most of the fishing in the Coastal Bays occurs.

From the bridge, anglers drop lines all day and even most of the night when rockfish prowl the water for baitfish. Jet skis buzz between anglers and add to the fray with stops at Ocean City's numerous bayside bars and restaurants. Waterskiing is also popular in Herring and Turville Creeks where 'weekend warriors' compete for water space with residents from Cape Isle of Wight, the Riddle Farm, and Ocean Pines—all on the bay's western side. Party fishing boats and scenic tours help add to the bay's multi-million-dollar contribution to the local economy.

Seagrass is expanding in Isle of Wight Bay

Seagrasses have been increasing their distribution in Isle of Wight Bay. In spite of the many activities and growth, seagrasses have remained stable or increased in the bay; however, they still remain well below their potential in Isle of Wight Bay. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

~

ACKNOWLEDGEMENTS

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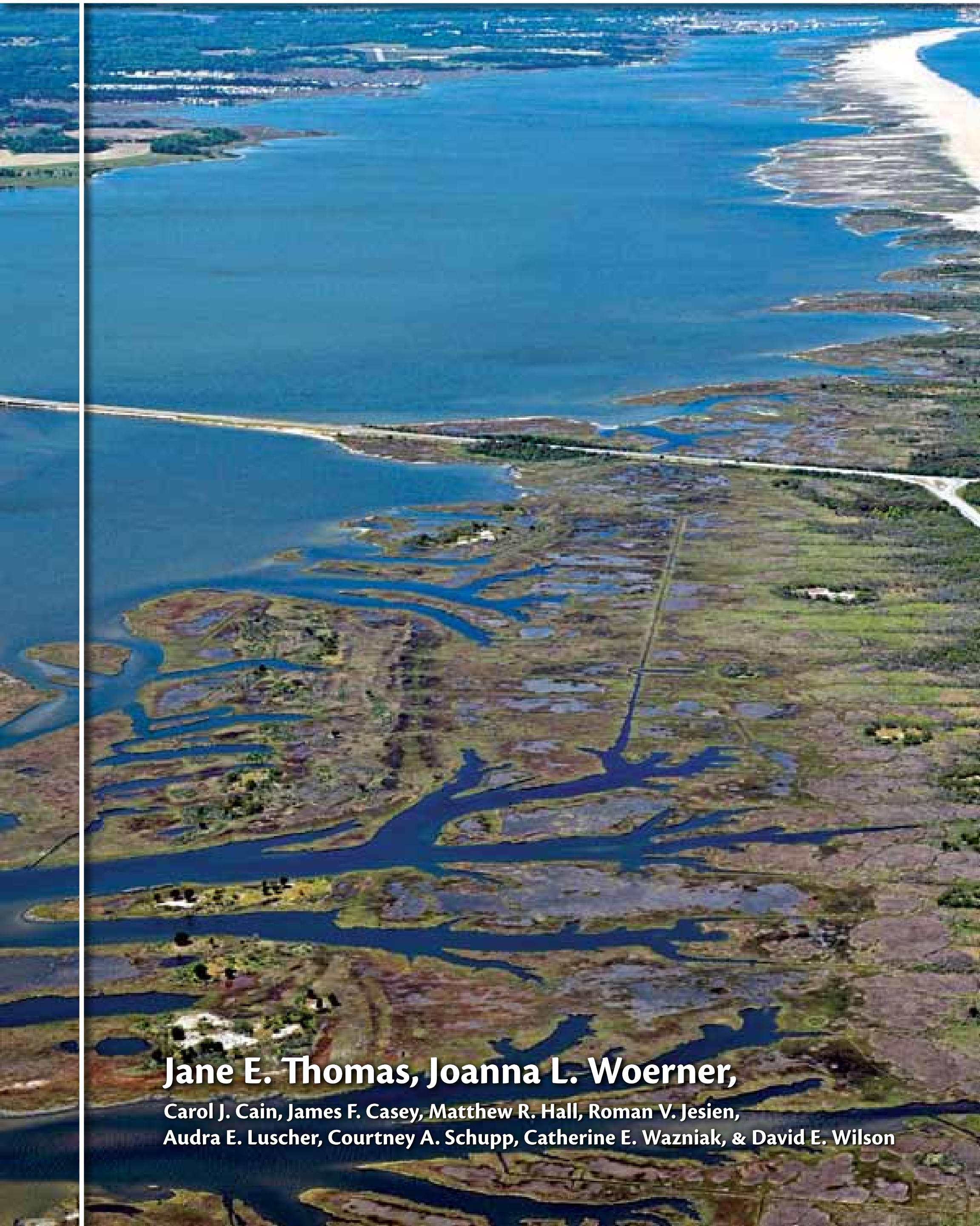
7. Sinepuxent Bay



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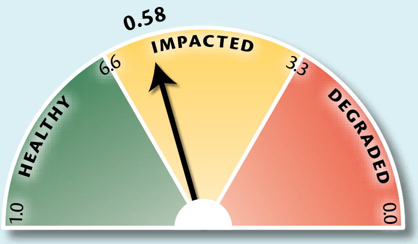
CONCLUSIONS

The ecosystem health of Sinepuxent Bay is the best of all the subwatersheds

Sinepuxent Bay ranked first in the Coastal Bays for estuarine health and second for watershed health, with the best water quality, highest density of hard clams, and greatest seagrass coverage—likely due to its small, relatively undeveloped watershed and good oceanic flushing through the Ocean City Inlet. This resulted in Sinepuxent Bay's overall ecosystem health ranking as the best of the Coastal Bays. Despite this relatively high ranking, the ecosystem health of Sinepuxent Bay is still impacted. For more information, see Chapter 2—*Ecosystem Health Assessment*.


How healthy is Sinepuxent Bay?

SINEPUXENT BAY ISSUES

Although the following issues are presented as pertaining to Sinepuxent Bay, they also apply to other Coastal Bays subwatersheds.

Docks & piers can impact habitat

Information compiled by the National Oceanographic and Atmospheric


JANE THOMAS

Aerial view looking north along Sinepuxent Bay, with the Route 611 bridge to Assateague Island in the background and the old ferry landing in the middle.

Administration indicates that researchers and coastal managers consistently note environmental, navigational, and aesthetic concerns regarding the cumulative impacts of docks, piers, and wetland walkways. In particular, overly large structures increase the likelihood of navigational problems, increase pollution to sediments and surface waters, and increase shading of wetland vegetation and submerged aquatic vegetation.

While one large structure individually may have a small adverse impact, the cumulative effects of these structures become more significant as they become more numerous. Preliminary results of surveys conducted in Worcester County indicate that marsh-dependent birds are negatively impacted by long piers. In an effort to minimize cumulative impacts, Worcester County prohibits private piers longer than 30 m (100 ft) over marsh and community piers longer than 90 m (300 ft). For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Research recommendations

- Assess impacts of docks and piers.
- Research the effects of docks and piers over riparian/ terrestrial habitats.

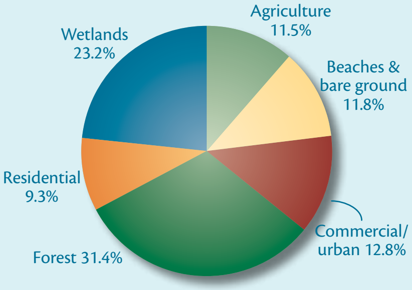
Management recommendations

- Consider the use of combined piers (i.e., community piers), rather than the 'porcupine effect' of multiple private piers.

Sinepuxent Bay & watershed facts

Watershed area (km^2)	26.7
Average bay depth (m)	0.67
Surface area of bay (km^2)	24.1
Watershed area : surface area	1.1
Bay water volume (m^3 × 10^6)	16.5
Watershed area : water volume	1.62
Flushing rate (days)	unknown
Population	4,420

Land use in Sinepuxent Bay subwatershed



Sinepuxent Bay & watershed

Conceptual diagram depicting general land use and features of Sinepuxent Bay and its watershed.

Monitoring recommendation

- Monitor marsh functionality around docks and piers, fragmentation, and habitat disturbance.

Coastal hazards affect the Coastal Bays

Coastal hazards include both natural and man-made events that threaten the health and safety of coastal ecosystems and communities. This definition includes, but is not limited to hurricanes, nor'easters, sea level rise, erosion, oil spills, harmful algal blooms, and pollution. Coastal areas have long been subject to environmental, social, and economic impacts from coastal hazards and it has become increasingly evident that increased decision-support capabilities for coastal managers and emergency responders must be better coordinated. Coordinated efforts are imperative because coastal communities can suffer human, environmental, and economic impacts from both man-made and natural hazards. In addition, a coordinated effort means that the hazard-risk and vulnerability data, information, and application needs can be developed and shared. A coordinated effort would also mean that coastal managers, emergency responders, and local officials gain the knowledge and skills to develop and implement hazard mitigation policies and practices. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Management recommendations[1]

- Implement Worcester County's Comprehensive Plan.[3]
- Consider developing a regional council of county and town emergency managers and planners. Encourage this council to participate in the Delmarva Emergency Management Task Force.
- Engage emergency managers with local planning commissions to better link emergency response activities with local hazard mitigation and comprehensive planning activities.
- Improve public and local access to data and information by communicating coastal hazard vulnerability and risk through multiple media outlets. Provide the results of technical analyses (modeling, floodplain mapping, etc.) through public workshops, brochures and websites.
- Promote Shorelines Online (*shorelines.dnr.state.md.us*) as an internet mapping application to allow the public to view data and determine risks.
- Develop a registration system for vulnerable individuals (handicapped, elderly, etc.) who need assistance during emergency and evacuation activities.
- Refer to the Federal Emergency Management Agency (FEMA; *www.fema.gov*) for resources and information.

Assateague Island is moving landward

Since 1850 (when the first accurate coastal charts were made), the bay shoreline of northern Assateague Island has migrated westward into Sinepuxent Bay while the mainland shoreline has lost very little land (less than 100 m [330 ft]) to erosion, thereby narrowing the bay by up to 1 km (0.6 mi) in some places. Approximately 600 m (1,970 ft) of this migration has occurred since 1942.

Assateague Island is migrating westward primarily due to overwash, a natural process in which waves combine with high tide or storm surge and carry sand from the beach and frontal dunes across the barrier island. The migration of the sand across the island provides the mechanism for the landward migration of the entire island system as sea level rises. This landward migration of Assateague Island has accelerated at the northern end of the island since the opening and subsequent stabilization of the Ocean City Inlet in 1933, which disrupted sediment transport to the northern end of the island.

Some sand is deposited in the interior of the island, maintaining or building island elevation and serving as a source of loose windblown sand that is critical to the formation of new dunes. Sometimes, sand is also carried completely across the barrier island and deposited in Sinepuxent Bay, thereby widening the island. The resulting sand platform or tidal flat provides the base for growth of salt marshes. The overwash sand can bury or partially bury vegetation on the island. Depending on the thickness of the overwash deposit, existing vegetation may survive and grow up through the sand.

Assateague Island National Seashore surveys the position of the Sinepuxent Bay shoreline at least twice a year. This data is used for mapping purposes and to quantify rates of shoreline change and the widths of the Sinepuxent Bay and Assateague Island. For more information, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*

Horseshoe crabs spawn in the Coastal Bays

During the latter part of May through mid-June, adult horseshoe crabs in the Mid-Atlantic region migrate inshore in search of sandy beach areas where they dig nests and deposit eggs for fertilization. Horseshoe crabs frequently nest on the shores of Sinepuxent Bay because of its close proximity to the inlet. Optimal egg development requires sufficient tidal activity to keep the eggs moist, salinity levels of at least 8 ppt, water temperature above 15° C (59° F), and a gentle beach slope for larvae to reach the water's edge. Horseshoe crab eggs are also an


MARY HOLLINGER, NOAA.

Horseshoe crabs migrate inshore to nest in late May to mid-June.


JANE THOMAS

Development continues in the Sinepuxent Bay subwatershed.

JANE THOMAS

Aerial view looking east across Sinepuxent Bay, with the Route 611 bridge to Assateague Island on the left. Also shown here are some of the many shoals in this shallow bay, some seagrass meadows (the dark areas underwater), and ditches and marshes on Assateague Island.

important food source for many migratory birds which stop over in the Coastal Bays. For more information, see Chapter 14—*Diversity of Life in the Coastal Bays*.

Recommendations

- Monitor horseshoe crabs, especially nesting sites and areas on Assateague Island.
- Protect horseshoe crab nesting habitat (bay beaches).
- Continue research into alternatives to horseshoe crabs as whelk bait.
- Educate residents and visitors about minimizing disturbance to horseshoe crabs during breeding, especially at developed bay beaches around Ocean City.

Invasive & non-native organisms can threaten native species

In the Coastal Bays, at least two exotic aquatic species have been detected and identified—the European green crab (*Carcinils maenav*) and the Japanese shore crab (*Hemigrapsus sanguineus*).

In Maryland, the green crab is currently only found in Isle of Wight Bay.[2] Green crabs can be purchased as bait in Maryland and they are frequently used as bait for tautog. Since this is a non-native species, leftover baits should be discarded shoreside and not returned to the water. The same method of discard applies to other live baits (minnows, worms, etc.) that are not native to the particular body of water where they are being used. There are currently no local surveys to monitor the spread of green crabs or their effects on local clam populations.

A native of the western North Pacific, the Japanese shore crab has been documented in Isle of Wight, Sinepuxent, and Chincoteague Bays.[2] As this crab is new to the East Coast, its ultimate impact is still unknown. For more information, see Chapter 14—*Diversity of Life in the Coastal Bays*.

Recommendations

- Develop and implement a monitoring plan for invasive and non-native species.
- Research the impacts of non-native crabs on native crab species.
- Educate anglers to not release live crabs, as this assists their spread.

FEATURES OF SINEPUXENT BAY & ITS WATERSHED

Sinepuxent Bay offers many recreational opportunities

Sinepuxent Bay's long, thin dimensions give its recreational qualities a dichotomous feel. On its northern end, near the Ocean City Inlet, yachts and commercial fishing boats depart for sea from the sprawling West Ocean City Harbor. A public boat ramp there also brings jet skiers and recreational boaters from around the East Coast. Good fishing in the inlet and the northern half of the bay make for crowded conditions in July and August north of Assateague Road.

South of there, campgrounds, shallow water, and limited development change the scene to a rural one. Crabbing from shore, clamming, and some fall croaker fishing are the rule here. On Assateague Island, canoe and kayak rentals put paddlers in the bay near Sinepuxent Bay's southern end. A federal law prohibiting jet skis behind Assateague Island limit their numbers in this part of the bay. Due to Sinepuxent Bay's wide range of recreational interests, its health remains of critical importance to the local economy.

Assateague Island provides an undeveloped refuge

On the eastern border of Sinepuxent Bay lies one of the East Coast's true gems—Assateague Island National Seashore. The barrier island, known for its wild horses, is a refuge for both wildlife and the two million people who visit the island every year. Detached from Ocean City during a 1933 hurricane, the island was once slated for development. However, after


JANE THOMAS

Golf course in Sinepuxent Bay watershed. Newport Bay is visible in the background.

the building of hundreds of homes and roads, a 1962 nor'easter crushed the island with severe flooding and hurricane-force winds, destroying the man-made structures. Protesting renewed development calls, citizens rallied around the state and federal governments to protect the island, and in 1965 it became a National Seashore with its southernmost portion becoming Chincoteague National Wildlife Refuge.

Despite becoming a significant tourist attraction, the island remains an internationally important stopover for millions of migrating shorebirds, songbirds, hawks, and falcons. Thousands of acres of seagrass enjoy refuge on its western flank and its 68 km (42 mi) of unspoiled beach make it a haven for endangered birds, turtles, and insects.

The island's natural shores remain the sanctuary that citizens intended them to become some four decades ago. For more information, see Chapter 12—*Dynamic Systems at the Land–Sea Interface*.

Sinepuxent Bay has the best water quality of the Coastal Bays

Sinepuxent Bay's small, relatively undeveloped shoreline and flushing from the Ocean City Inlet give it the best water quality among the Coastal Bays. With the lowest nitrogen levels, Sinepuxent Bay enjoys healthy fisheries and abundant seagrass. However, warning signs are emerging in the bay with increasing nutrients and brown tide. For more information, see Chapter 13—*Water Quality Responses to Nutrients.*

Seagrass is widespread

At 787 ha (1,945 acres) of seagrass in 2006 and almost 70% of its seagrass goal met, Sinepuxent Bay has the best seagrass coverage in the Coastal Bays. Generally good water quality, sandy soils, and persistent flushing from the Ocean City Inlet make this bay a perfect habitat for eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) growth. Habitat is constantly changing due to island overwash, which buries some beds while creating sandy habitat in other areas. Chincoteague Bay follows closely with 50% of its seagrass goal met in the Maryland portion and an impressive 3,133 ha (7,743 acres) of seagrass meadows (Maryland and Virginia) in 2006.

However, of concern is the decline seen in seagrasses bay-wide since 2005. The unprecedented gains that occurred in the southern bays during the 1980s and 1990s have slowed or reversed. This combined with currently degrading water quality trends serve as warning signs for the overall health of the bays.

~

ACKNOWLEDGEMENTS

The authors would like to thank J.J. Orth from the Virginia Institute of Marine Science for comments helpful in the completion of this chapter.

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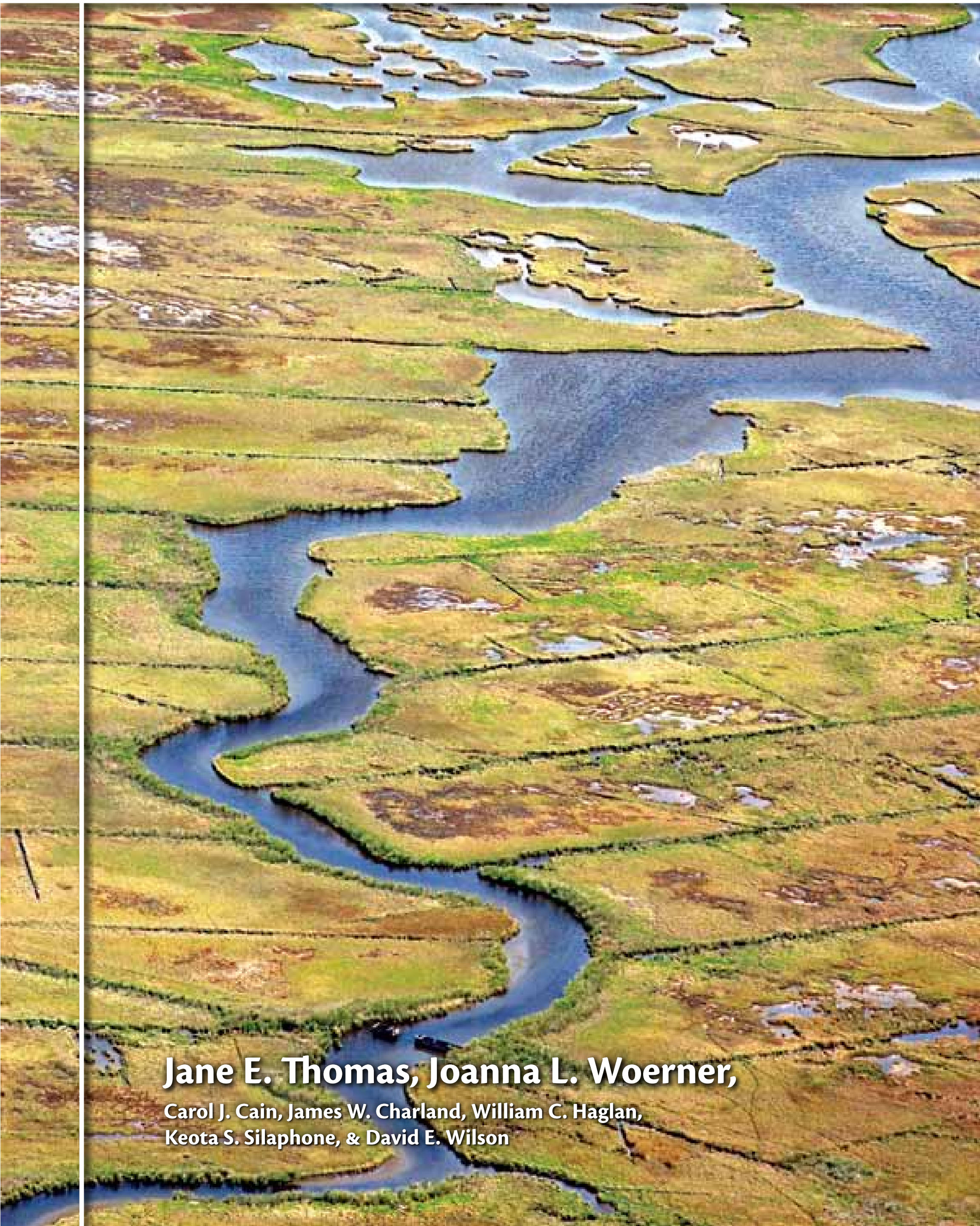
8. Newport Bay



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CONCLUSIONS

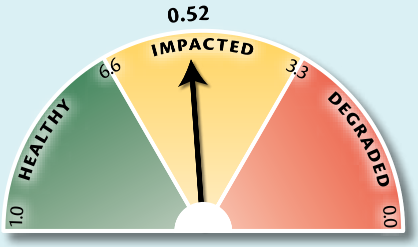
The ecosystem health of Newport Bay is impacted

Newport Bay ranked third of the Coastal Bays for estuarine health and second for watershed health. Intact natural shorelines, high wetland coverage, and low impervious surfaces were balanced by degraded water quality, low densities of hard clams, and poor seagrass coverage. This resulted in Newport Bay's overall ecosystem health ranking as third in the Coastal Bays. For more information, see Chapter 2—*Ecosystem Health Assessment*.

NEWPORT BAY ISSUES

Although the following issues are presented here as pertaining to Newport Bay, they also apply to other Coastal Bays subwatersheds.

How healthy is Newport Bay?



Stormwater management & retrofits were investigated in Berlin

The Town of Berlin has experienced flooding in the Bottle Branch and Kitts Branch subwatersheds for years. Flooded streets and neighborhoods are a common occurrence during even small rain events. Past studies have determined that flooding is the result of inadequate storm drain

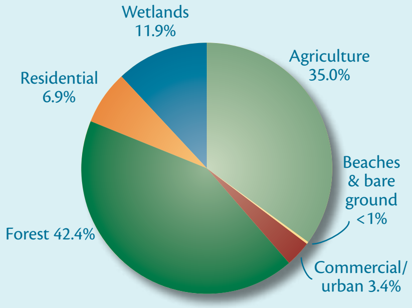
JANE THOMAS

Aerial view of Newport Bay, showing the mostly natural shoreline and expansive marshes.

Newport Bay & watershed facts

Watershed area (km^2)	113
Average bay depth (m)	1.22
Surface area of bay (km^2)	15.9
Watershed area : surface area	7.1
Bay water volume ($m^3 \times 10^6$)	19.4
Watershed area : water volume	5.82
Flushing rate (days)	unknown
Population	17,711

Land use in Newport Bay subwatershed



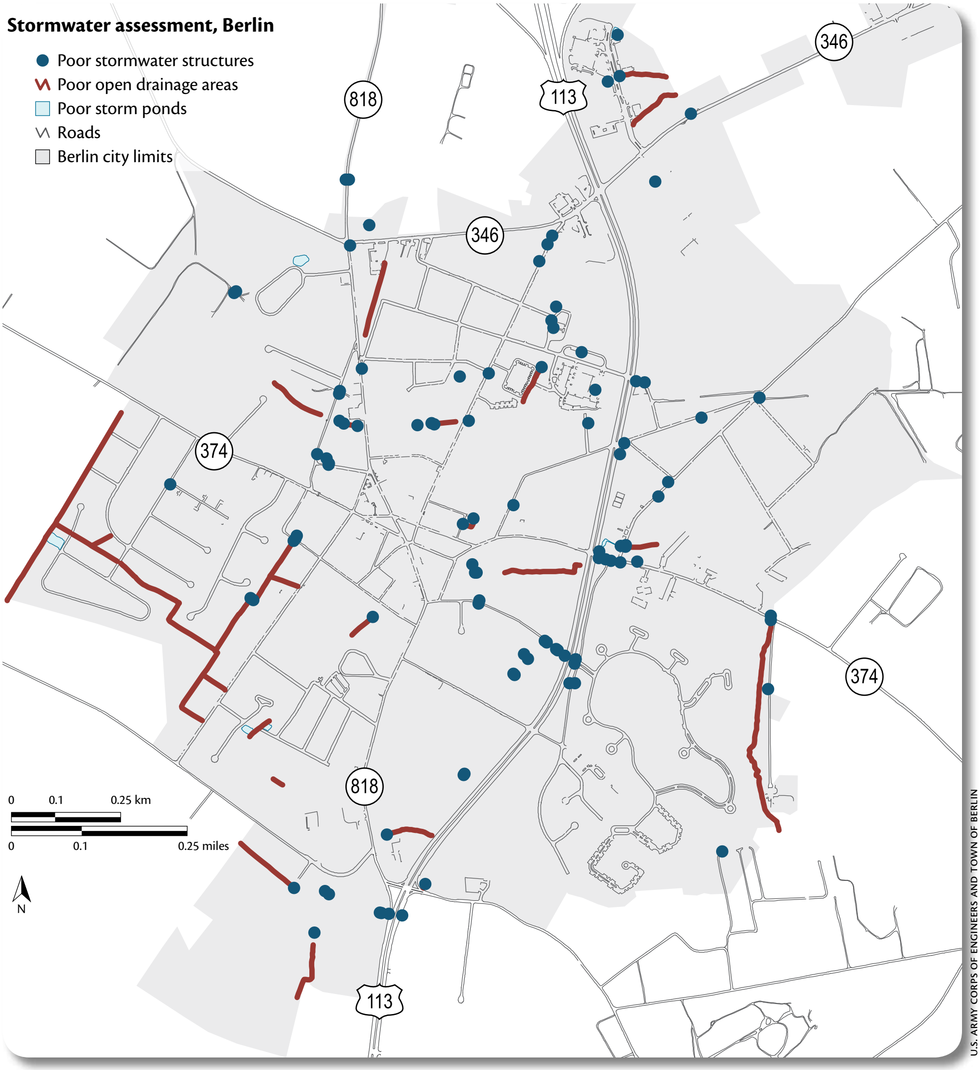
systems and debris jams in culverts and ditches. The Town and the U.S. Army Corps of Engineers have completed a comprehensive investigation into these problems, inventorying stormwater basins and making recommendations to alleviate the flooding issues.[9,10]

The three-phase investigation sought to:

- Compile and review existing stormwater management plans of all of the subdivisions, topographic mapping, aerial mapping, previous studies, etc.
- Conduct a field survey of the stormwater collection and drainage system within the Bottle Branch and Kitts Branch subwatersheds in order to develop complete connectivity of drainage. The location and condition of stormwater structures such as inlets, ponds, and drainage ditches will be confirmed.


Newport Bay & watershed

Conceptual diagram depicting general land use and features of Newport Bay and its watershed.



U.S. ARMY CORPS OF ENGINEERS AND TOWN OF BERLIN

The U.S. Army Corps of Engineers and the Town of Berlin have assessed the condition of stormwater structures in Berlin.

- Use various models and calculations to simulate the stormwater system's behavior under varying rainfall frequencies to define the problems within the system. Both the existing conditions and future conditions will be modeled.
- Identify and prioritize problem areas based on the results of the modeling (and validated by actual flood occurrences).
- Identify system-wide concept plans that would improve flow conditions and reduce or eliminate the flooding problems. Concept-level cost estimates would be developed for decision-making and budgeting purposes.

To date, more than 6 km (3.8 mi) of open drainage ditches have been identified as being in poor condition. Similarly, there are 130 storm structures (grates, pipes, and outfalls) that are rated as poor, as well as seven stormwater ponds that are performing poorly.

The 2007 U.S. Army Corps of Engineers study estimates that a range of $1.43–$1.90

million may be needed to remediate high- and medium-priority areas throughout Berlin.

The key to solving the water quality problems associated with the town's stormwater will not be to direct the water as rapidly as possible to the bays, but to hold it and clean it with buffers in a location and manner that does not induce flooding.

Research recommendation

- Support the creation of digitized land use maps to the level of driveways and sidewalks and buffers.

Low-impact development will improve the environment of the Coastal Bays

Low-impact development is the practice of using techniques in building and construction that minimize stormwater runoff and the effect that development will have on the quality of the surrounding environment. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

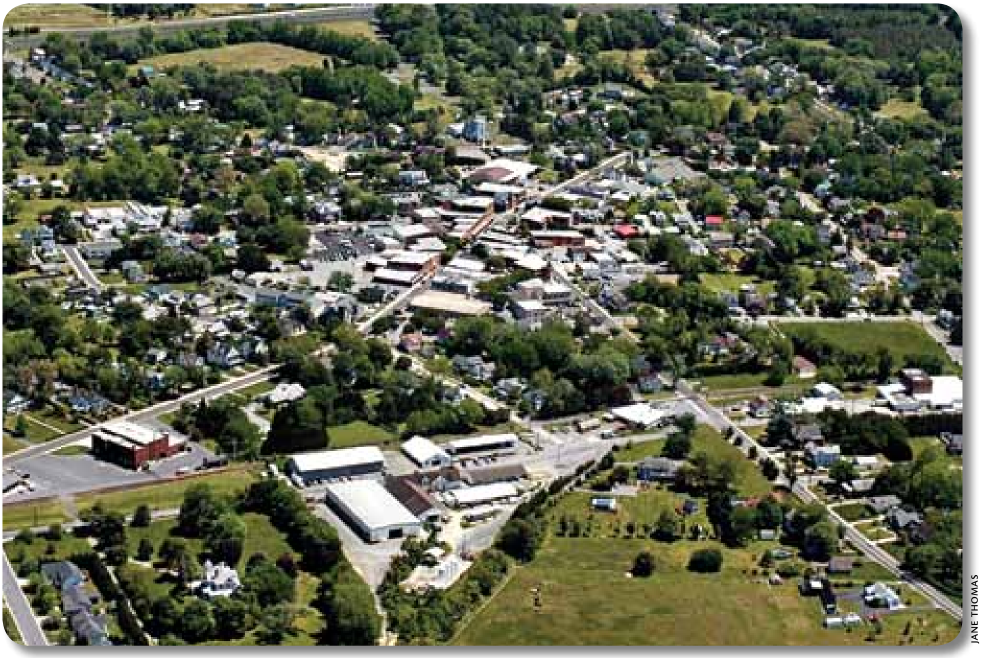
Policy recommendations from Model Development Principles for Worcester County, a.k.a. Builders for the Bay Roundtable included:[2]

- Assist Worcester County in implementing the recommended Model Development Principles for the county, particularly the creation of a Coastal Bays watershed education and certification program for the development community with the following elements:
  - Include local government officials, developers, environmental groups, and Coastal Builders for the Bay in the committee to design and support this program.
  - Target developers with an education campaign that includes the importance and benefits of better site design techniques, with an emphasis on the economic benefits. 'How-to' resources should also be included.
  - Create a certification process through which a constructed development can receive 'green development' award/recognition.
  - Include a list of better site design elements and a predetermined certification points system in the education materials.
  - Create two levels of recognition/certification to recognize/reward those developments that include better site design elements and those that go 'above and beyond.'

JANE THOMAS

The extensive marshes in Newport Bay are rapidly eroding.

    - Consider participation incentives such as free marketing via newspapers and websites, public recognition, referral system for developers, sign/flag to display at development site, etc.
    - Verify design elements at time of construction.
- Assist Worcester County in implementing the recommended Model Development Principles for Worcester County, particularly the creation of a Coastal Bays watershed landowner/manager education and stewardship program with the following elements:
    - Include local government officials, developers, environmental groups, realtors, chambers of commerce, existing educational groups, and the Maryland Coastal Bays Program in the design and support of this program.
    - Target the education and stewardship campaign to landowners/managers, including homeowners, homeowners' associations, commercial landowners, and professional property management companies.
    - Develop a certification process for landowners/managers that rewards use of better site design techniques.
    - Require new development and encourage existing homeowners' covenant language to protect stream buffers in perpetuity and provide buffer maintenance requirements. Create adaptable template language that can be used by homeowners' associations and provide it to them through the program.
    - Create adaptable buffer 'notification' language that is provided to landowners/managers at the time of sale by homeowners' associations that outlines the specific landowner's responsibilities and applicable regulations associated with natural areas on or adjacent to their properties.



JANE THOMAS

The historic town of Berlin, in the Newport Bay watershed.


JANE THOMAS

Aerial view of Trappe Creek, looking towards upper Newport Bay.

- Create/adapt materials targeted to landowners/managers on:
    - Benefits and responsibilities of living in a coastal community.
    - Importance of proper maintenance requirements for stormwater management measures (ponds, vegetated channels, etc.).
    - Specific coastal-friendly behaviors (downspout disconnection, reduction/minimization of impervious surface, preventing buffer encroachment, reforestation, afforestation, etc.).
- New residents of the county should receive a 'Welcome to Worcester County' package, which should include many of the above elements. The process to achieve this will need to be determined—perhaps through the realtor industry or chamber of commerce.

Total Maximum Daily Loads have been established for Newport Bay

Total Maximum Daily Loads (TMDLs) are the amount of nutrients (or other pollutant) that a given waterbody can receive while still maintaining its health. Many waterbodies receive more than this ideal amount and are impacted by the additional load. The idea is to calculate how much pollution a river or bay can accommodate in an average day, and work to reduce the amount of pollution discharged (from both point and non-point sources) to that amount. For example, if a river can accommodate 45 kg (100 lb) per day of a particular pollutant but the factories and other sources in the watershed discharge 90 kg (200 lb) per day, the total discharge must be cut in half. The TMDL does not say which factories will reduce their discharge by what amount, only that the total reduction must be 45 kg (100 lb).

TMDLs were originally developed to clean up discharges from point sources, such as factories and wastewater treatment plants. However, in the Coastal Bays, most pollutants come from non-point sources. Non-point sources include septic tanks, farm fields, lawns, cars, and a host of other sources of nutrients and chemicals. The principle remains the same—determine an acceptable daily load, and work to reduce the load to that amount. Non-point sources, though, present a much greater challenge.

There are many sources of nutrients in the Coastal Bays watershed, and everyone contributes to a degree. Determining each person's responsibility, or which sources or activities provide the cheapest and easiest means to reduce the total, has proven elusive. The TMDLs for the Coastal Bays are guideposts—milestones on the path to clean and healthy bays. The will to find solutions and reduce pollution must still come from the people of the watershed. TMDLs have also been established in St. Martin River, Isle of Wight Bay, and Chincoteague Bay. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Recommendations

- Implement Worcester County's Comprehensive Plan.[11]
- Review wastewater treatment plant permits as the plants expand or modify, to examine other options to reduce nutrient loads coming out of those point sources.
- Develop water quality and hydrodynamic models to distinguish between the impacts of various alternatives.
- Determine the impact of winter point source discharges.
- Encourage effective land application of wastewater (e.g., spray irrigation of agriculture).
- Minimize the total load to the ecosystem.
- List the major loads into Newport Bay, and then look for nutrient reductions at every possible opportunity. The largest sources should be addressed first for the most impact.
- Address issues with wastewater treatment plants in the permitting stage, as opportunities to review the sites will not occur for several years after the permit is given.

Nuisance waterfowl species threaten the bays

Since early colonization of North America, new species have been introduced at an ever-increasing rate. These species have arrived through a variety of pathways, including through the ballast of ships (e.g., zebra mussel), in the wooden packing material of imported goods (e.g., Asian long-horned beetle), and through deliberate import for various uses (e.g., green crab). While most of these introduced species are benign, about 15% become invasive.

An invasive species shows a tremendous capacity for reproduction and distribution throughout its new home, and also has a negative impact on environmental, economic, or public welfare priorities. Many introduced species do not show a propensity to

DAVE WILSON

Resident Canada geese are found throughout the Coastal Bays year-round.

JANE THOMAS

Ditches and eroding marshes in Newport Bay.

become invasive for several generations, so species that were once thought to be beneficial, such as grass carp, European starlings, mute swans, and nutria, have demonstrated the characteristics of invasiveness long after their original introduction. These and other species are proving difficult to control in their competition against native species for food, shelter, water, or other resources, and their impacts on economic interests and human welfare. Without the disease and predators that they contend with in their native habitats, the spread of these species can be rapid and the efforts to control them can reach billions of dollars.

When ecologists talk about the impact of introduced species on native species and habitats, they mean that the introduced species is reproducing and distributing itself so efficiently that it is out-competing native species' use of the same habitats. Even native species can become nuisance species when their populations increase due to human-induced changes to their environment, e.g., increased availability of food. Nature is a very delicate balance, much altered by humans, and the protection of remaining natural interactions between native species and their habitats are the responsibility of local, state, and federal agencies, as well as all citizens.

Two species of nuisance waterfowl—mute swan (*Cygnus olor*) and resident Canada goose (*Branta canadensis*)—are widely distributed in Maryland waters. Throughout Maryland, mute swans peaked in 2003 at approximately 3,600 birds and resident Canada geese numbered around 75,000 birds in 2004.[6,8] Mute swans eat seagrasses, which compromises this valuable habitat and reduces the amount of food available for native migratory waterfowl. They also aggressively defend their nests, often displacing native waterfowl from their breeding areas. The normally migratory Canada goose has established large year-round resident populations in the Coastal Bays and neighboring Chesapeake Bay. Like

Golf course in the Newport Bay watershed. In the background are Sinepuxent Bay and Assateague Island.

the mute swan, these resident Canada geese impact food and habitat for native migratory species.

Conflicts between humans and these two invasive species include: damage to agriculture, parks, golf courses, and residential properties; bird strikes with airplanes and automobiles; and potential disease transmission.

Snow goose (*Chen caerulescens*) is another native species which has become a problem in some areas. A large and increasing population of snow geese overwinter in the Coastal Bays, and have caused significant damage to marsh—their primary food source—in northern Newport Bay and Chincoteague Bay, lowering marsh elevation, increasing erosion, and enlarging open water areas.[1,3]

Management of mute swans, resident Canada geese, and snow geese complements other efforts to protect and restore wild habitats and is a necessary part of any comprehensive restoration effort.

Recommendations

- Continue public outreach to recognize mute swan, resident Canada goose, and snow goose population impacts to the environment and humans.
- Continue resident Canada goose population management (egg addling, removal of adults, habitat modification, resident Canada goose hunting) to protect property and agricultural crops, minimize human safety issues, and reduce health concerns.
- Manage mute swan, resident Canada goose, and snow goose populations at sustainable and appropriate levels for environmental and sociological conditions to minimize impact to native wildlife and habitat.
- Continue to monitor the population and distribution of mute swan, resident Canada goose, and snow goose populations and evaluate the effectiveness of management actions.

FEATURES OF NEWPORT BAY & ITS WATERSHED

Newport Bay has extensive marshes & minimal shoreline development

Newport Bay, one of the smallest of the Coastal Bays, sports wide and productive marshes on both banks. The bay's many tributaries come together in a vast complex of wetlands, channels, ponds, and uplands. However, extensive mosquito ditches are also present in these marshes, which compromise natural drainage.

The wide marshes and many tidal channels have largely held back shoreline development, leaving Newport Bay with a large proportion of marsh. The miles of tributaries, stretching far into the surrounding landscape, make the bay vulnerable to pollution. Agricultural runoff, urban runoff, and discharges from towns and factories find their way to Newport Bay. Yet the bay's marshes have survived, giving Newport Bay excellent prospects for preservation and restoration.

The Newport Bay subwatershed contains a Non-Tidal Wetland of Special State Concern—Porter Neck Bog. The primary management goal for this wetland is to protect the freshwater spring and its drainage and maintain the structure and species composition of the seep.[7]

Maryland Department of the Environment has worked to prioritize wetlands for preservation, restoration, and mitigation in the subwatersheds of the Coastal Bays, including assessing species and resources and identifying areas where the most benefit could be gained.[4,5] For more information on wetlands, see Chapter 3—*Management of the Coastal Bays & Watershed* and Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Newport Bay has large forested areas

With 42% forested land, Newport Bay has the second-highest proportion of land covered with woodland of any subwatershed of the Coastal Bays. Add to this the watershed's diverse hardwood forests and lack of loblolly pine monocultures, and the area emerges as one of the most important forest hubs in the Coastal Bays watershed.

While Berlin anchors the watershed's northern side, the expansive tidal guts, marshes, and forests on Newport Bay's southern side help it rival Chincoteague Bay in wildlife diversity. Like its southern cousin, its expansive marshes and riparian forest provide critical habitat for birds, reptiles, amphibians, and rare plants. Extensive hardwood forested wetlands on the watershed's northeastern and southeastern sides make it a particularly appealing target for conservation. About 325 ha (800 acres) of forest (7% of the total forestland) are currently protected in the 11,000-ha (27,400-acre) watershed.

~

ACKNOWLEDGEMENTS

The authors would like to thank Cathy Wazniak and Larry Hindman from the Maryland Department of Natural Resources for comments helpful in the completion of this chapter.

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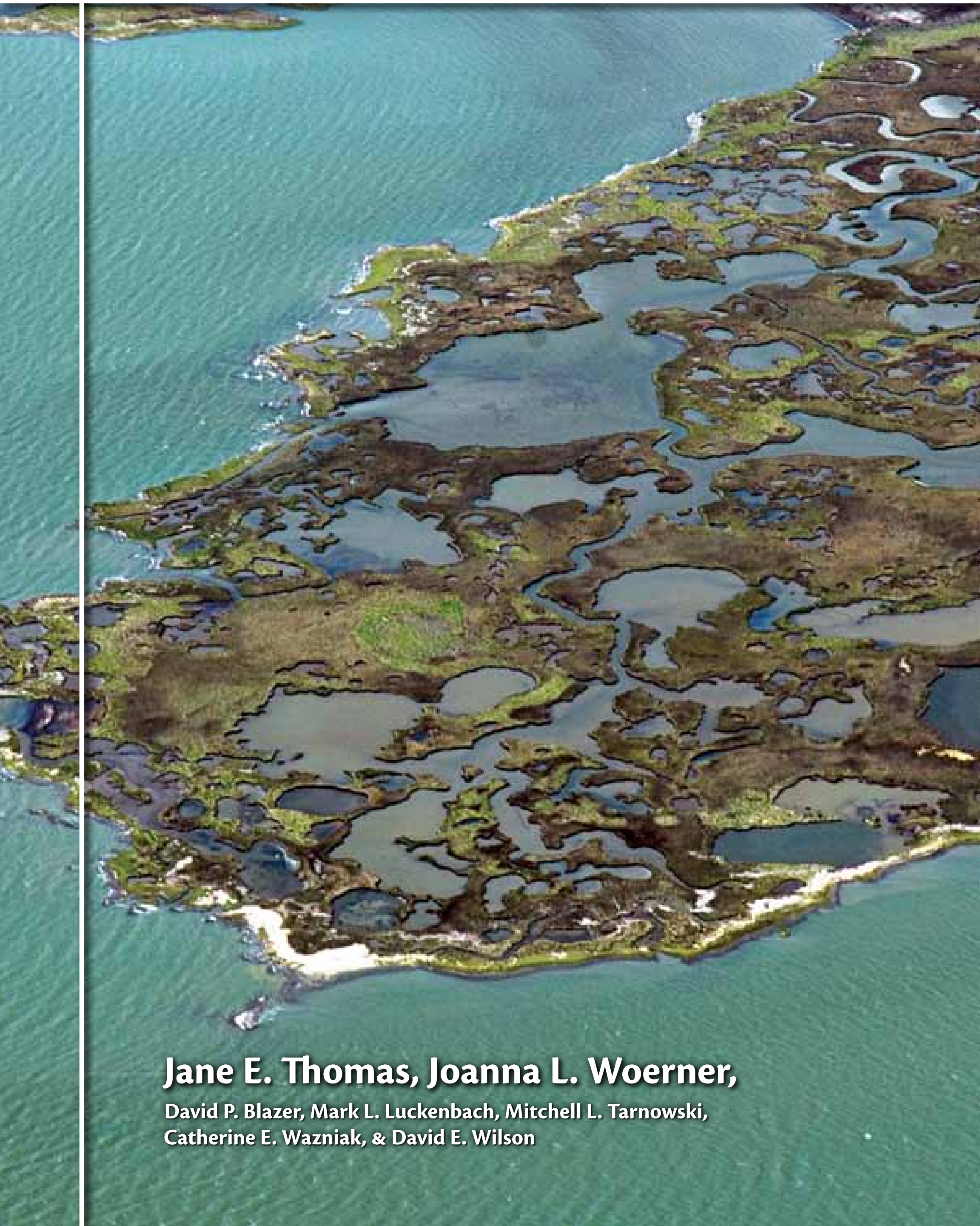
9. Chincoteague Bay



Jane E. Thomas, Joanna L. Woerner,

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CONCLUSIONS

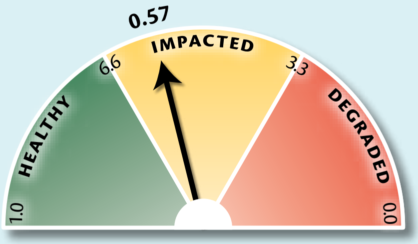
The ecosystem health of Chincoteague Bay is impacted

Chincoteague Bay ranked second in the Coastal Bays for estuarine health and first for watershed health, with nearly all watershed indicators ranked highest in this watershed. However, high stream nitrate and decreased water quality and seagrasses reduced its overall rating. This resulted in Chincoteague Bay's overall ecosystem health ranking as second in the Coastal Bays. For more information, see Chapter 2—*Ecosystem Health Assessment*.

CHINCOTEAGUE BAY ISSUES

Although the following issues are presented here as pertaining to Chincoteague Bay, they also apply to other Coastal Bays subwatersheds.

How healthy is Chincoteague Bay?



Regional coordination should be implemented

Chincoteague Bay faces transboundary challenges, with approximately one-third of its watershed in Accomack County, Virginia. To address these and other challenges, local planners formed an informal network called the Delmarva Atlantic Watershed Network (DAWN). For information about DAWN, see Chapter 4—*Assawoman Bay*.

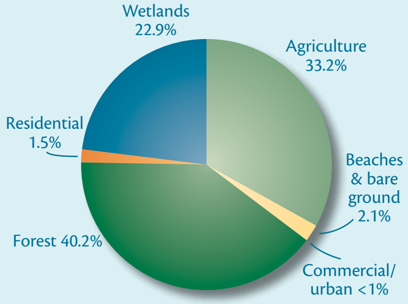
JANE THOMAS

The Chincoteague Bay watershed is primarily agriculture and forest.

Chincoteague Bay & watershed facts

Watershed area (km²)	315.5
Average bay depth (m)	1.22
Surface area of bay (km²)	377
Watershed area : surface area	0.84
Bay water volume ($m^3 \times 10^6$)	374.5
Watershed area : water volume	0.84
Flushing rate (days)	63
Population	MD: 10,468 VA: 7,767

Land use in Chincoteague Bay subwatershed (Maryland only)



Aquaculture is an emerging industry

Southern Chincoteague Bay was one of the first and most extensive areas in Maryland where aquaculture was practiced. Oyster culture was the primary source of the succulent bivalves, as the wild Chincoteague Bay populations were limited and could not sustain a fishery. During the late 19th and early 20th centuries, trainloads of cultivated oysters were sent to market;[10] by 1912 there were 40 growers in the region.[9] Problems associated with the opening of the Ocean City Inlet led to the demise of Coastal Bays oysters and their culture.[1,22] For more information, see Chapter 14—*Diversity of Life in the Coastal Bays*.

Shellfish aquaculture is attempting a comeback in the Coastal Bays, encouraged by the success of clam farming in Virginia and the decline in wild hard clam

Chincoteague Bay & watershed

Conceptual diagram depicting general land use and features of Chincoteague Bay and its watershed.

populations. As of 2008, approximately 100 ha (250 acres) of bay bottom have been leased, primarily for on-bottom hard clam culture, although one enterprise is raising oysters with floating gear. Actual market production is still extremely limited.

Numerous obstacles confront aquaculture in the Coastal Bays. The regulatory process inhibits the granting of leases and permits. With the Assateague Island National Seashore side of the bay potentially closed to aquaculture, there is a shortage of suitable habitat (shallow, sandy areas). Suitable habitat for aquaculture is further limited by the potential encroachment of seagrasses into leased areas, which makes the bottom unusable for clam culture, both pragmatically and by lease agreement. Deteriorating water quality, including the proliferation of harmful algal blooms (HABs), is another concern. Neighboring property owners have voiced strong objections on aesthetic and user-conflict grounds. Human activities impact aquaculture sites both directly (poaching, vandalism, accidental disturbance) and indirectly (indiscriminate use of fertilizers, pesticides, and herbicides, malfunctioning septic systems, and loss of waterfront accessibility and infrastructure to development).

To address many of the real and perceived problems associated with aquaculture, the Maryland Aquaculture Coordinating Council has developed a code of best management practices based on a 'good neighbor' policy i.e., minimizing impacts to adjacent properties and the environment.[11] More egregious or persistent issues can be further resolved through the judicious use of regulations.

On the other hand, shellfish aquaculture can have beneficial effects.[19] Clams and oysters are primary grazers, filtering phytoplankton from the water and reducing turbidity. Some of the filtered plant nutrients are incorporated into the sediments where they are sequestered or utilized by other organisms; the remainder is removed from the ecosystem by such means as denitrification and assimilation

JANE THOMAS

The town of Chincoteague, Virginia, on Chincoteague Island. Visible in the foreground are clam aquaculture plots.

by the bivalves, which are ultimately harvested. The harvested clams are replaced by a new cohort which continues the process of nutrient removal, resulting in an ecologically sustainable operation. Also, hard clam grazing has been shown experimentally to be capable of controlling HABs such as brown tide at high densities.[3] Although localized improvements in water quality may be possible, whether the cultured populations will be of sufficient magnitude to significantly improve water quality bay-wide is another issue. However, since hard clams reach sexual maturity before they are harvested, they can help repopulate the wild stocks, building up the overall filtering capability. Shellfish culture can provide a source of livelihood to the rural inhabitants of the Coastal Bays, allowing them to maintain economic and cultural ties to the water, especially the commercial clammers displaced by the 2007 legislation banning mechanical harvesting gear in these bays.

Water quality is declining

Large areas of what was thought to be pristine habitat are showing significantly degrading water quality trends and living resource impacts. Despite past improvements, nutrients and phytoplankton have been increasing in recent years throughout Chincoteague Bay. Similarly, seagrass coverage increased between 1986–2001, coincident with historically improving nutrient trends. However, this increase leveled off and is now trending downward in Chincoteague Bay, suggesting that seagrass may have also passed a high point.[16,17] For more information, see Chapter 13—*Water Quality Responses to Nutrients* and Chapter 15—*Habitats of the Coastal Bays & Watershed*.

The large-scale changes in water quality trends are considered a 'warning shot across the bow' for the estuary and its watershed. Although management actions have occurred on land, it may take decades to see the results, especially in this system where groundwater is the dominant delivery mechanism and flushing times are so long (i.e., what enters the bay stays for a long time and continues to impact water quality). Changes in water quality will impact Chincoteague Bay's living resources (from algae to seagrass to shellfish and other fish), as well as those animals that depend on the bays for sustenance (ducks, ospreys, and otters).

Strong correlations have been shown between total nitrogen input into estuaries and total phytoplankton production.[2] Of specific interest are the impacts of

ADRIAN JONES

Wave energy exposes and erodes salt marshes in Chincoteague Bay.

JOANNA WOERNER

Fishing boats and the Chincoteague Channel bridge on Chincoteague Island.

changing nutrient loads on the abundance and quality of the algal community and whether these loads are related to the proliferation of HABS. HABS are those algae blooms that can be toxic to fish, shellfish, and/or humans, or which can indirectly disrupt ecosystems through production of high biomass and subsequent depletion of light, oxygen, and habitat.[6,18,20] Consequently, HABS can lead to severe environmental, economic, and public health consequences.

The HAB species that causes brown tides (*Aurecococcus anophagefferens*) preferentially uses dissolved organic nitrogen over nitrate (NO_3^-).[8] While fertilizer use throughout the world is increasing, the fraction of total fertilizer that is composed of organic material and manures is increasing at a greater rate.[21,24] For example, worldwide use of urea as a nitrogen fertilizer and feed additive has increased more than 50% in the past decade.[6] The Coastal Bays were documented as having some of the highest maximum concentrations of urea in Maryland.[7] Furthermore, nitrogen trends in Chincoteague Bay have been shown to be dominated by increasing dissolved organic nitrogen.[8]

Recommendations

- Implement the Coastal Bays Nutrient Reduction Strategy.
- Develop a monitoring strategy for groundwater.
- Investigate designating Chincoteague Bay as an Outstanding Natural Resource Water to prohibit future discharges.

Brown tides occur annually

Brown tides turn bay water to a characteristic coffee color. They are caused by a microscopic alga and were first documented in Maryland in 1998.[23,25] Analysis of historic pigment data has since confirmed its presence in Maryland since at least 1993.[23] Brown tide has been observed in all of the Maryland Coastal Bays and significant blooms (Category 3: >200,000 cells mL^{-1}) have occurred annually in Newport and Chincoteague Bays since 1999 when monitoring began. The Coastal Bays exhibit environmental conditions optimum for brown tide growth (i.e., temperature range of 20–25° C [68–77° F], high salinity, limited flushing, and high organic nutrients).[5] Blooms usually occur in late May to mid-June with peak concentrations lasting approximately two weeks.

Brown tide has had particularly detrimental effects on the Peconic Estuary ecosystem in New York. Eelgrass beds, which serve as spawning and nursery grounds for shellfish and finfish, have been adversely impacted by decreased light penetration, partly due to brown tide blooms. The Peconic Estuary bay scallop industry, once worth almost $2 million annually, was virtually eradicated to a dockside value of a few thousand dollars. Oysters, hard clams, and possibly blue mussels have also been impacted to varying degrees by brown tide, although long-term impacts on these shellfish are unknown. Although scientists have not been able to document specific impacts in Maryland, it is believed that brown tide blooms have limited scallops from re-establishing in the bays, reduced light to seagrasses, and decreased clam growth. For more information, see Chapter 13—*Water Quality Responses to Nutrients.*

Recommendations

- Reduce dissolved organic nitrogen responsible for brown tide blooms.
- Restore the natural resources affected by brown tide.

FEATURES OF CHINCOTEAGUE BAY & ITS WATERSHED

Bay islands are an essential habitat

Bay islands are being lost to erosion, sea level rise, and natural succession. Although many of these islands are man-made (created from dredge spoil in the 1930s), they are key habitat for some important living resources. For example, bay islands provide essential nesting habitat for numerous waterbird species, as well as spawning habitat for horseshoe crabs, especially as bay beaches on the mainland and Fenwick Island disappear or are significantly disturbed by human

JANE THOMAS

Aerial view of the Chincoteague Inlet in Virginia. Assateague Island is visible in the background.

activities. Natural vegetative succession or disturbance will change the suitability of islands as nesting habitat according to bird species nesting condition requirements (e.g., natural changes in plant communities over time eliminate key habitats, making the island uninhabitable for certain species). Creation of new islands has faced several obstacles in the past. Particularly important is the debate between essential fish habitat (seagrass) and essential bird habitat (bay islands). For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Recommendation

- Develop an action plan for bay island creation and preservation.

The Chincoteague Bay watershed is well protected

Due to strong agricultural zoning and a desire to protect the richness and beauty of Chincoteague Bay, Worcester County and the state of Maryland have protected 24% of the mainland Maryland watershed of the Coastal Bays' largest bay. When Assateague Island is included, this number increases to 38%. Most notable are the 2,324 contiguous protected hectares (5,743 acres) in the state's Rural Legacy Program that surrounds the 1,400-ha (3,500-acre) E.A. Vaughn Wildlife Management Area. Efforts have focused on large shoreline properties in the watershed which harbor dozens of rare and endangered plants and significant blocks of forest, gone from most of the northern Coastal Bays. With the highest wildlife diversity for both aquatic and terrestrial species, Chincoteague Bay will continue to be the focus of conservation dollars.

Wetlands in the Coastal Bays are protected in the Wetlands Reserve Program, in conservation easements, and in public (county, state, and federal) lands.

JANE THOMAS

The Chincoteague National Wildlife Refuge in Virginia is just one of many protected areas in Chincoteague Bay.

Forests and marshes blanket the bay side of Assateague Island.

The Chincoteague Bay subwatershed contains 10 of the 12 Non-Tidal Wetlands of Special State Concern in the Maryland Coastal Bays watershed. They are: Pawpaw Creek, Tanhouse Creek, Scotts Landing Pond, Scarboro Creek Woods, Pikes Creek, Stockton Powerlines, Riley Creek Swamp, Hancock Creek Swamp, Powell Creek, and Little Mill Run. These sites contain populations of rare, threatened, and endangered species or represent examples of unique wetland habitats. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed*.

Recommendations

- Forests:[4,14]
  - Establish a funding assistance program for reforestation and management to include private landowners. Encourage the planting of hardwoods for diversity.
  - Educate homeowners' associations on forest easement management and the ecological functions of forests. Promote native tree diversity and retain urban tree cover.
  - Increase landowner outreach efforts to promote a goal of 75% of forestland having forest stewardship plans over the next 10 years. Remove the disincentive to farmers who have a combination of forest and cropland who are penalized for having forest management plans (tax rates: $150/acre for those without farmland vs. $100/acre for those with farmland). Woodland should not be taxed at a higher rate.
  - Determine sites within the watershed that have rare, threatened, or endangered species and match these with groundwater recharge areas, wellhead protection sites, and sensitive areas with forest interior dwelling species in order to prioritize high priority conservation areas.
- Wetlands:
  - Management of the Non-Tidal Wetlands of Special State Concern requires active management to preserve their unique character. Management recommendations vary depending upon the site,

JANE THOMAS

An eroding marsh island in Chincoteague Bay.

but establishing a 30-m (100-ft) no-cut buffer from the edge of the wetland would benefit all of these wetlands.[15] Additional management measures, depending on the wetland, include minimizing human disturbance (such as trail construction), controlling woody plant succession and invasive species, and minimizing hydrologic alteration.[15]

- Several wetlands in the Chincoteague Bay subwatershed may qualify to be designated as Non-Tidal Wetlands of Special State Concern. They are: Pikes Creek Woods, Spence Pond, Truitt Landing, and Waterworks Creek.[13]
- Maryland Department of the Environment has worked to prioritize wetlands for preservation, restoration, and mitigation in the subwatersheds of the Coastal Bays, including assessing species and resources and identifying areas where the most benefit could be gained.[12,13] For more information on wetlands, see Chapter 3—*Management of the Coastal Bays & Watershed* and Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Forests & unaltered creeks & streams preserve Chincoteague Bay's wilderness

Along with the Newport Bay watershed to its north, the 31,550-ha (77,962-acre) Chincoteague Bay watershed remains the most heavily forested drainage basin in the Coastal Bays. Extensive pine monocultures harvested at 30–40-year intervals make its woods less diverse than those to the north and west. Nevertheless, more than half of the watershed's forests remain deciduous which has helped keep diversity high. The size and contiguous nature of the watershed's 6,760 ha (16,700 acres) of forest has rendered it one of the primary hubs for forest interior birds in the Coastal Bays watershed. Its connection to Newport Bay to the north and protected forests in the Pocomoke and Nassawango Rivers drainages to the west make the watershed's woods a key target for conservation. Through the Conservation Reserve Enhancement Program, watershed property owners have converted some 800 ha (2,000 acres) of farmland to forest over the past eight years and permanently protected 6,580 ha (16,250 acres) of the watershed.

Also unparalleled by any other watershed in the Coastal Bays are Chincoteague Bay's unaltered tidal creeks. Strong zoning laws and sparse development have left most of the watershed's creeks with undisturbed riparian habitat. Although high nutrient levels threaten many streams, the habitat quality and lack of disturbance on the creeks make for spectacular scenery. Many also hold nationally and even internationally rare plant species. However, extensively ditched streams have led to poor benthic and fish indices. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

The seldom-traveled and little-known secrets of creeks like Waterworks, Robins, Boxiron, Pawpaw, Tanhouse, Scarboro, and Pikes Creeks have rendered Chincoteague Bay a last bastion of true wilderness on the East Coast.

Wildlife diversity abounds

Wildlife diversity in Chincoteague Bay is spectacular. With ample forests, expansive marsh, and unbroken open space, the land surrounding Chincoteague Bay plays host to plant and animal species found nowhere else in the Coastal Bays watershed. The watershed's forests harbor over 30 endangered plants and its marshes provide homes for the rare saltmarsh sharp-tailed sparrow (*Ammodramus caudacutus*), breeding northern harriers (*Circus cyaneus*), gadwall (*Anas strepera*), black duck (*Anas rubripes*), black (*Laterallus jamaicensis*), king (*Rallus elegans*), and Virginia rails (*Rallus limicola*), barn owl (*Tyto alba*), and marsh wren (*Cistothorus palustris*). In winter, duck and goose diversity abounds and culminates in the Chincoteague National Wildlife Refuge at the bay's southern end. The bay's importance to migrating waterfowl is noted on an international level.

Chincoteague Bay also has great aquatic diversity, holding 3,133 ha (7,743 acres) of seagrass (about 73% of all the bay grass in the Coastal Bays). Seahorses, terrapin, and burrfish are among the residents. The combination of protected lands, seagrass abundance, and wildlife diversity have made Chincoteague Bay the last wildlife haven in the Coastal Bays.

Chincoteague Bay dubbed 'Last Chance Scenic Place'

In 2006, Scenic Maryland (*www.scenicmaryland.org*) released its Last Chance Scenic Places report which includes the coveted gem of the Coastal Bays—Chincoteague Bay. Their description is accurate, describing the remote bay and its watershed as "a wild, largely undeveloped region dotted with tiny islands, marshes, beaches, and hunting and fishing camps [offering] a wealth of scenic beauty and diverse habitats."

Scenic Maryland releases the annual report to draw attention to the state's most beautiful places which are also becoming the most imperiled. In Chincoteague Bay's Virginia portion, burgeoning development and permissive zoning threaten the very nature of the bay and its unspoiled vistas.

~

ACKNOWLEDGEMENTS

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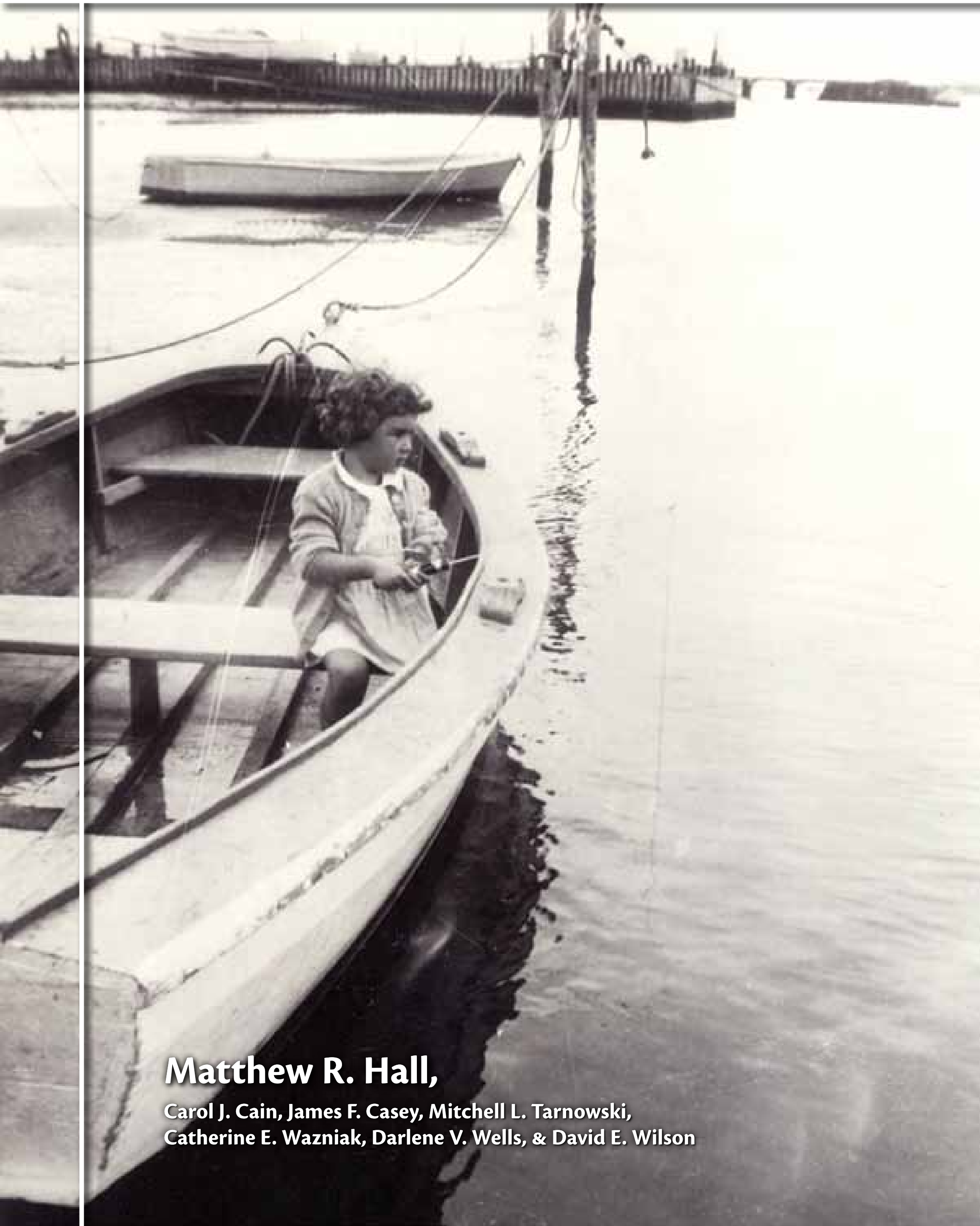
10. *History & the Future*



Matthew R. Hall,

Carol J. Cain, James F. Casey, Mitchell L. Tarnowski,
Catherine E. Wazniak, Darlene V. Wells, & David E. Wilson

TIMELINE

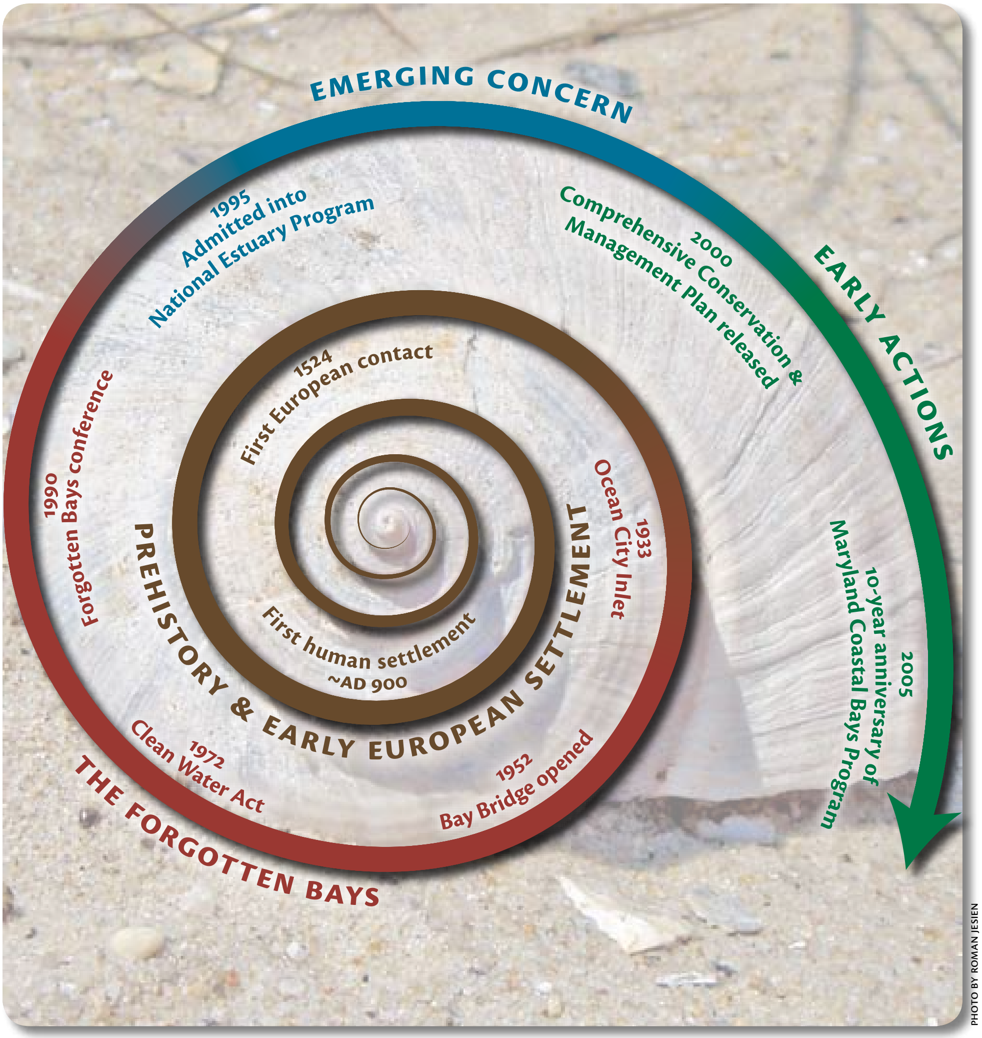


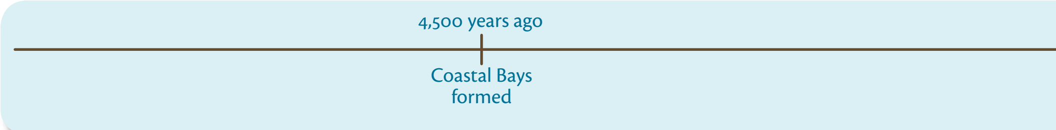
PHOTO BY ROMAN JESIEN

A timeline of major events and turning points in the history of Maryland's Coastal Bays.

PREHISTORY

The Coastal Bays were formed following the last Ice Age

Through multiple glaciations characteristic of the Pleistocene Epoch (1.8 million–10,000 years ago), the Delmarva peninsula took on its present-day shape.[42,47] The Coastal Bays were formed around 4,500 years ago when a rising sea flooded the area—a subsequent deceleration in sea level rise formed barrier islands (proto-Assateague and



Fenwick Islands).[2,54] The continued existence of these islands, and thus the Coastal Bays, is controlled by tides, climate, sediment texture, and shoreline transport of sediment.[14] For more information, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*

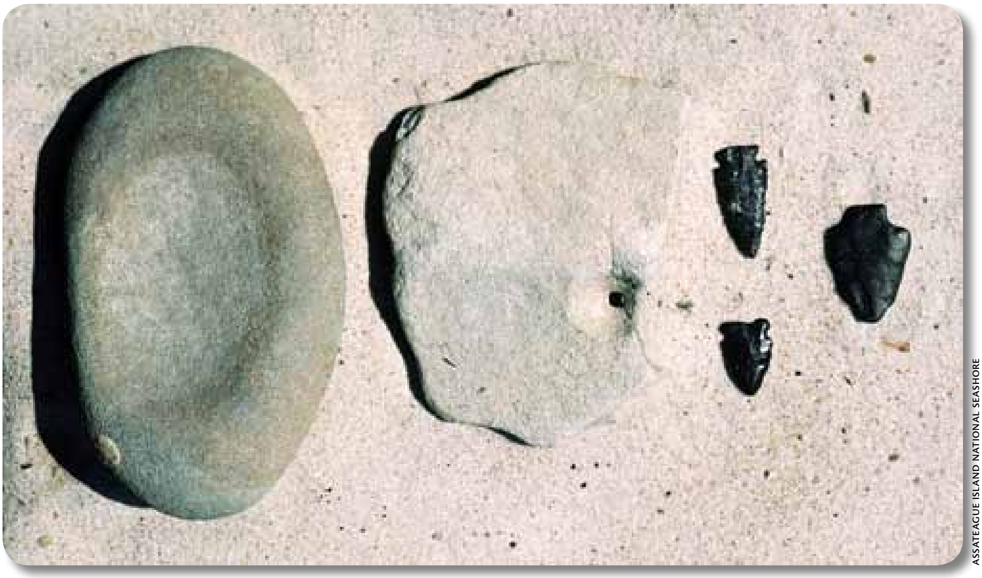
Archaeological evidence reveals a rich Native American history

The first Native Americans were thought to have entered the present Maryland Coastal Bays watershed around 10,000 years ago. These first human visitors are believed to have only used the region as an intermittent hunting ground, forming no permanent settlements. True settlement was not likely to have occurred until around AD 900 with the beginning of maize agriculture.[49]

These earliest settlers built small villages of low reed huts along the tributaries some distance from the bays.[44] They gathered nuts from oak–hickory and oak–pine forests, and tubers from marsh plants, known as tuckahoe. They fished and collected shellfish from the shallows. The major pre-European tribe, the Assateagues, lived in small villages from the cypress swamps in the south to present-day Ocean Pines.

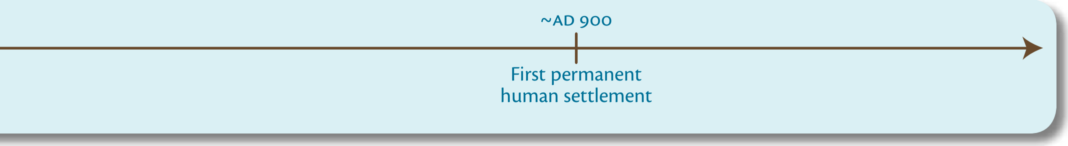
Archaeologists have found non-indigenous shells and copper pieces indicating established trade with far-away tribes. The Assateagues were known regionally for their dugout canoes, though they rarely ventured far from shore in them. Many Assateagues dispersed as a result of the Native American massacres in 1659–1960, while others were moved to reservations within the following decade.[44] A treaty signed in 1742 closed the reservations and most left the region, migrating as far north as Canada.[39]

Details of Native American culture are scant, though there are an abundance of archaeological sites that have yet to be studied and warrant protection.



ASSATEAGUE ISLAND NATIONAL SEASHORE

A grinding stone, stone ax, and obsidian projectile points found in the Coastal Bays. These Native American artifacts probably originated from the Rocky Mountains or Central America and were brought here through trade routes.



EARLY EUROPEAN HISTORY

Europeans first visited the Coastal Bays during the Age of Discovery

The first European contact with the Coastal Bays came from the crew of the explorer Giovanni da Verrazzano, who explored the region for France in 1524.[58] In 1649, Henry Norwood, one of a group of British castaways, was marooned on Assateague Island and wrote extensively of the land and peoples as they traveled, with the help of Native Americans, to Virginia.[44] These first European settlers were most likely farmers, hunters, and trappers, not unlike their Native American neighbors.[44]

ASSATEAGUE ISLAND NATIONAL SEASHORE

Giovanni da Verrazzano was the first European to explore the Coastal Bays.

Storms & shallow water led to frequent shipwrecks

Shallow waters and frequent storms of the coastal ocean caused many ships to founder from colonial times through the present day.[58] The Spanish Bar, a shoal located along Assateague Island near the Maryland–Virginia border in Chincoteague Bay, was named for a ship wrecked there while in transit to the Spanish Main in the 17th century. The *Virginia Merchant* went aground at Fenwick Island in 1648.

COURTESY OCEAN CITY LIFE-SAVING STATION MUSEUM, OCEAN CITY, MARYLAND. COLLECTION OF GEORGE AND SUZANNE HURLEY

Illustration of a colonial shipwreck site from *Scribner's Monthly* magazine.

Shipwrecks were so common in the 18th and 19th centuries that a cottage industry arose scavenging cargo and wood from them. In 1800, the Maryland General Assembly, concerned about this rise in opportunistic thievery, established an office of wreckmaster to oversee salvage operations along the coast. This office was merged with the U.S. Coast Guard in 1915.[44]

Pirates sought refuge in the hidden bays

Throughout the 17th, 18th, and early 19th centuries, pirates reportedly used the Coastal Bays as a refuge from pursuit and a cache for their plunder. Edward Teach and Jack Rackman, known as Blackbeard and Calico Jack respectively, were two of the most notorious pirates to seek safe harbor among the wild, dense, and uninhabited beaches of Assateague and Chincoteague Islands.[58]

So, too, did loyalist pirates, known as picaroons, and privateers hired by the British and French during the American Revolution.[50] Rings, medallions, and many period coins have been found along island beaches in the Coastal Bays, reminders of the days of high-seas plunder.

1524
Giovanni da Verrazzano explores Coastal Bays

1742
Worcester County established

ILLUSTRATION BY JOANN WHEELER

The pirate Blackbeard frequented the Coastal Bays.

African Americans played a major role in history & culture

Though most early black residents of the Coastal Bays region were slaves who worked lower shore plantations, many were free black settlers who owned land themselves.[68] Several early black settlers also established themselves as watermen, working the Coastal Bays for oysters, fish, and crabs. As the Civil War drew near, the number of escaped and freed slaves grew significantly. This conflicted with region's proximity to Virginia and its agriculture-based economy, leading to a bitter divide during the war. Segregation reigned into the mid-20th century.

Several historical sites remain as a testament to this period, including the Sturgis one-room school in Pocomoke City, the Henry Hotel in Ocean City, and the New Bethel Methodist Church in Germantown, east of Berlin, one of the oldest African American congregations.

The Coastal Bays watershed supported a diverse fauna

Just 400 years ago, black bears, bison, bobcat, cougars, elk, and timber wolves roamed what was then the wilds of eastern Worcester County, including Berlin and Ocean City.[44] Described as remote trapping lands by settlers in Virginia and Philadelphia, wildlife existed in harmony with the native peoples of the area who left only minor imprints on the land.

The extensive forests seen by Giovanni da Verrazzano provided the ground for what was then an intact, well-functioning ecosystem with top-line predators and a

ILLUSTRATION BY JERRY GERLITZKI

Slaves escaping the Eastern Shore during the Civil War.

© ISTOCKPHOTO.COM/ANITA ELDER

American bobcats were once found in the Coastal Bays.

1861–1865

Civil War

wide diversity of mammals, birds, reptiles, and amphibians. Although these forests have been greatly reduced, the Coastal Bays watershed still boasts the greatest diversity of birds and reptiles in the state. For more information, see Chapter 14—*Diversity of Life in the Coastal Bays.*

Assateague wild horses are descended from livestock of early settlers

The oft-told tale of shipwrecked Spanish horses swimming ashore to a life of freedom on Assateague Island may not be perfectly accurate. If true, these horses most likely joined the wild descendants of livestock left on the island by early settlers in the late 17th and 18th centuries.[44] Like many coastal islands, Assateague provided ideal free range and an opportunity to avoid mainland fencing laws and a tax system that was heavily weighted towards valuable possessions like horses.[58]

While adding to the unique character of Assateague, the horses are taking a toll on the island by over-grazing marsh and dune grasses, eating endangered plants, and disturbing breeding shorebirds. The National Park Service is using an innovative contraceptive vaccine to limit herd size and achieve a balance between protecting the horses and minimizing the ecological problems they create.[1]

Sika deer were introduced in the early 20th century

The small sika deer, an Asian elk, was released on Assateague Island in the early 1920s by a local Boy Scout troupe.[44] The Scouts acquired the deer from the Philadelphia area and brought them to Ocean City as an attraction to raise money. After the tourist season, the sika were turned loose on the island where

ALLISON TURNER, NATIONAL PARK SERVICE

The introduced sika deer compete with the native white-tailed deer for food.

ADRIAN JONES

Assateague horses are taking a toll on the delicate sandy ecosystem of the island.

1800s

Horses
introduced to
Assateague Island

1920s

Sika deer
introduced into
the Coastal Bays

they have since thrived. The Assateague sika deer may also have originated from James Island in Chesapeake Bay, where populations also survive.

Sika deer compete with native white-tailed deer for food, and are changing the character of Assateague's forests and shrub lands through their foraging habits.[45] An annual public hunting program is keeping the sika deer population in check, but may not be enough to adequately protect the island's other inhabitants. For more information, see Chapter 14—*Diversity of Life in the Coastal Bays* and Chapter 15—*Habitats of the Coastal Bays & Watershed.*

THE FORGOTTEN BAYS: PRE-CLEAN WATER ACT

Improvements in transportation brought more visitors & residents to the Coastal Bays

Following the Civil War, wealthy tourists and vacationers began traveling to the Coastal Bays area.[46] At first, they arrived at nearby Snow Hill by stagecoach. From there, liverymen would transport them to Public Landing for either accommodations there or to board a ferry to Green Run, site of Scott's Ocean House—the first hotel on Assateague Island.

COURTESY OCEAN CITY LIFE-SAVING STATION MUSEUM, OCEAN CITY, MARYLAND. COLLECTION OF THE OCEAN CITY MUSEUM SOCIETY

Railroad bridge across Sinepuxent Bay to Ocean City.

Likewise, Berlin was the crossroad to attractions in Ocean City on Fenwick Island. In 1876, a railroad bridge across Sinepuxent Bay to Ocean City was completed.[58] The train alone would bring over 3,000 visitors to the island each year, with many more continuing to arrive by stage (planks were laid over the tracks so

COURTESY OCEAN CITY LIFE-SAVING STATION MUSEUM, OCEAN CITY, MARYLAND. COLLECTION OF DORIS DENNIS

Frank Sacca's band entertains crowds on the boardwalk at Ocean City during the 1920s.

1876

Railroad bridge built to Ocean City

the stages could cross when no trains were expected).[55] About this time, the railroad reached the shores of lower Chincoteague Bay, opening up markets and accelerating oyster production.

Such multi-vehicle transportation continued until construction of the Bay Bridge was completed across Chesapeake Bay in 1952.[36] This event put the vacationer behind the wheel, and ushered in a new wave of development and recreational usage in the region.

Oceanic storms created many inlets, most of which were short-lived

No story of the Atlantic Coast would be complete without mention of the sometimes brutal hurricanes and nor'easters that batter the shores. While the Coastal Bays only rarely receive a direct hit from such storms, at least 11 inlets have been opened by surging tides since the mid-19th century.[59] Most were short-lived, remaining open for no more than a few years.

A hurricane in August 1933 did more damage to Ocean City than any hurricane before. The resulting storm surge created the current Ocean City Inlet. The opening of this inlet changed the very character of

COURTESY OCEAN CITY LIFE-SAVING STATION MUSEUM, OCEAN CITY, MARYLAND. COLLECTION OF J.D. QUILLIN, III

Damage to Ocean City from the 1962 nor'easter storm.

COURTESY OCEAN CITY LIFE-SAVING STATION MUSEUM, OCEAN CITY, MARYLAND. COLLECTION OF THE BALTIMORE SUN PAPERS

The newly-formed inlet at Ocean City, 1933.

1933 — Hurricane opens Ocean City Inlet

1962 — Ash Wednesday nor'easter storm

the bays. The water became saltier, and estuarine creatures such as crabs, clams, and flounder thrived.

The Ash Wednesday storm of 1962, a nor'easter, was devastating to Ocean City and Assateague Island. Two inlets formed three miles below Ocean City, but filled in within three years.[59] This storm provided impetus to stop planned development on Assateague Island and establish the park for public use.[24]

Larger populations necessitated improvements in waste management

With the coming of larger populations, the municipalities of the Coastal Bays were faced with greater waste management needs. In 1937, Ocean City opened its first sewage treatment plant discharging into the newly formed inlet. In 1969, the outflow was moved offshore.[56]

Berlin, Ocean Pines, Newark, and Assateague Island National Seashore all currently operate sewage treatment plants. Despite this, many residents of the Coastal Bays watershed retain on-site septic systems, with over 5,000 in Worcester County as a whole.[65] Continuing development in the Coastal Bays is increasing these nutrient inputs. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

The economy of the watershed is dependent to a large extent on agriculture. Since the mid-20th century, poultry has dominated, with Worcester County ranked 19th among all counties nationwide in broiler chicken production.[61] Effluent from two processing plants was historically regulated in the Coastal Bays watershed. However, these two poultry processing plants are now closed.[18,38]


DAVE WILSON

The Eastern oyster was once a lucrative fishery.

Oysters were once a lucrative harvest

The Eastern oyster (*Crassostrea virginica*) provided a lucrative industry to the Coastal Bays following the Civil War.[53] Mostly confined to the more saline waters of southern Chincoteague Bay, commercial tongers began culturing oysters, an innovative practice at the time.

The opening of the 1933 inlet triggered a scramble for lease bottom. Enthusiasm was short-lived, as the increased salinity instead fostered parasites and predators that reduced oysters to the small intertidal remnants still clinging to life today.[6] Despite this, commercial harvesting continued until 1983, mostly as a 'put-and-take' enterprise.

Agriculture arose as the dominant economic force in the watershed

The fertile soils of the Coastal Bays watershed have supported agriculture from pre-historic times through the

1965

Assateague Island National Seashore established present. Timber operations, mostly pine and cypress, may have been the first agricultural practices in colonial times.[28]

Crop farming (tobacco, corn, and wheat) soon followed and continues today. Crop farming this wet coastal plain required drainage and a sizable network of ditches was constructed over time. In fact, some of these ditches connect the Coastal Bays with Chesapeake Bay. In the early 20th century, truck farming of a variety of fruits (strawberries, peaches, tomatoes) came to the fore. Poultry production gradually took hold following World War II and continues today as the foremost agricultural industry in the watershed. Throughout, Coastal Bays farmers have shown adaptability in the face of ecological and economic change.

Non-agricultural economic growth also depended on natural resources

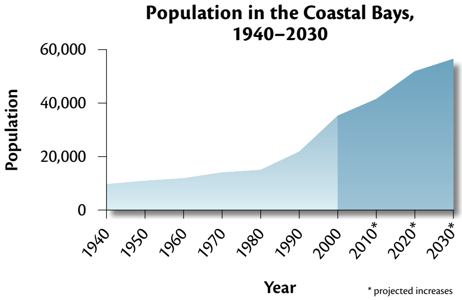
The economic viability of the Coastal Bays watershed has always depended on natural resources. For instance, Ocean City, once an isolated barrier island fishing village, became a resort destination soon after the first hotel opened there in 1869.[58] This transition in economic mainstay was contingent on the natural resources of abundant fish and accessible beach and bay recreational areas.

While recreation and tourism have become prominent economic forces,[48] many other industries have participated in the Coastal Bays' economic history. The opening and closing of inlets created and destroyed valuable shellfish operations from the late 19th to early 20th centuries, including the famous Chincoteague oyster.

Beginning with the establishment of the Ocean Pines development in 1968, real estate-related ventures have multiplied, mostly in the northern bays. Today, aside from agriculture, tourism and real estate provide the most to the economy, with the summer population swelling to nearly 40 times the resident population.[67]

Population growth was slow until the mid-20th century

Before European colonization, the permanent population of the Coastal Bays watershed was no more than 500 Native Americans.[17] The population remained small, mostly watermen and farmers, and rose gradually as advances in transportation increased the area's attractiveness as a getaway from nearby cities. In fact, three centuries were required to double the population from European settlement through 1940. In contrast, the population doubled again between 1940 and 1996, with most growth in the northern bays around Ocean City.[67]



The Coastal Bays' population has steadily increased, and is expected to increase by 60% by 2030.[17,63] Data is for the Maryland portion of the Coastal Bays watershed.

THE FORGOTTEN BAYS: POST-CLEAN WATER ACT

The Clean Water Act was passed in 1972

In 1972, the Federal Water Pollution and Control Act (shortened to the Clean Water Act) was signed into law. In waters with

1972

Clean Water Act

1976

Violation of water quality standards in tributaries.[27]
Areas of septic tank failure identified
in numerous towns in the Coastal Bays

point source discharges, comprehensive water quality data collection became a legal mandate. The Act also required states to inventory waterbodies not meeting water quality standards and to submit periodic water quality assessments to the U.S. Environmental Protection Agency (U.S. EPA). Considerable effort was initially put toward controlling point source discharges, and attention turned toward non-point sources only within the last decade.[16]

Current focus is on legally defensible information about impaired waterways in the form of Total Maximum Daily Loads (TMDLs). For an explanation of TMDLs, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Blue-green algal blooms occurred in St. Martin River in 1983

Detection of massive blue-green algal (cyanobacteria) blooms in St. Martin River during 1983 indicated severe degradation.[52] Such large blooms are considered an indicator of fecal contamination. Recent data indicates that blue-greens have decreased in St. Martin River, Trappe Creek, and Ayers Creek. However, bloom conditions ($>$10,000 cells mL^{-1}) still occur occasionally in Bishopville Prong.


WALT BUTLER

The cyanobacterium *Anabaena* sp. under the microscope.

Maryland banned phosphates in 1985

Excessive nutrient enrichment was recognized as a primary water quality concern in the United States during the 1960s. Phosphates from fertilizer and detergents was found to be the primary nutrient pollutant leading to increased algal growth in lakes and streams.[23] In response, states began passing resolutions that set limits to phosphate concentrations in detergents. Maryland established a state-wide ban on phosphates in detergents in 1985.[11] Since then, trends in phosphate concentrations have declined, but current data indicates that concentrations may again be rising. For more information, see Chapter 13—*Water Quality Responses to Nutrients.*

Seagrass recovery began in the 1980s

The Virginia Institute of Marine Science began monitoring seagrasses in the Coastal Bays in 1986.[41] By this time, seagrasses had already started to recover from the wasting


ADRIAN JONES

Eelgrass (*Zostera marina*) in Chincoteague Bay.

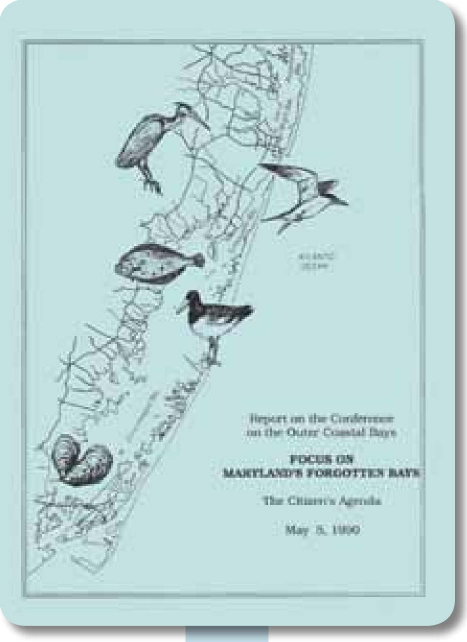
1983	1983	1985	1986
End of commercial oyster harvesting in the Coastal Bays	Massive blue-green algal bloom in St. Martin River	Phosphorus bans implemented in Maryland	Seagrass monitoring begins

disease that severely reduced acreage in the 1930s.[40] During the period 1986 through 1995, seagrasses increased 63%, from 2,305 to 3,758 ha (5,697 to 9,287 acres). Possible reasons for the increase include decreased disease pressure and improved water quality as a result of improvements to sewage treatment plants.

Although the increase was most pronounced in Chincoteague Bay, the presence of seagrass beds was also documented in Newport (1990), Assawoman (1991), and Isle of Wight (1992) Bays, showing a dramatic range expansion in the Coastal Bays during this period.[40]

The first citizens' conference on the environmental health of the Coastal Bays was held in 1981

In 1981, the first citizens' conference on the Coastal Bays was convened, focusing on aquatic resources. Citizen concern for the bays and lack of government agency attention over the following decade resulted in the 'Focus on Maryland's Forgotten Bays' conference, held May 5, 1990.[12] The conference was organized by several citizen groups, including the Committee to Preserve Assateague (now the Assateague Coastal Trust), the Worcester Environmental Trust, and the Sierra Club, to provide a forum for addressing concerns about water quality, wetland loss, and other impacts resulting from development pressures.



Report on the Conference
on the Outer Coastal Bays

FOCUS ON
MARYLAND'S FORGOTTEN BAYS

The Citizen's Agenda

May 5, 1990

The report from the Forgotten Bays conference.

The proceedings described the major impacts to the bays, including degraded water quality north of the Ocean City Inlet and in St. Martin River, declining fisheries, and loss of forest cover and wildlife habitat.

The conference called for citizen action to curb environmental impacts and drafted a resolution with 12 specific recommendations, including establishing the Coastal Bays as an estuary of national significance in the National Estuary Program. This was the first concerted effort to call for state and federal resources to evaluate and manage the Coastal Bays ecosystem.

Brown pelican populations expanded into Coastal Bays following DDT ban

Concurrent with the Clean Water Act, the pesticide DDT (dichloro-diphenyl-trichloroethane) was banned in 1972. DDT was used throughout the watershed as an agricultural insecticide. The chemical was found to weaken the shells of bird eggs, decreasing the probability that chicks would hatch. Top predator birds such as eagles, pelicans, and ospreys declined. After the ban, these species began to slowly gain in numbers. In 1987, the first recorded brown pelican nest in

1990 — Forgotten Bays conference

1991 — Formation of the State Water Quality Advisory Coastal Bays Subcommittee. Governor's Coastal Bays initiative began

Maryland was found in Chincoteague Bay.[7] In 15 years, this familiar shore bird had progressed from the brink of extinction to establishing nesting colonies in new territory. However, DDT's legacy may not be over, as the chemical continues to be found in the tissues of many birds and other animals.

Brown tide was first detected in 1993

Brown tides are caused by the excessive growth of a small, single-celled marine algae called *Aureococcus anophagefferens*. Blooms of the brown tide organism turn the water deep brown, making it unappealing to swimmers and fisherman alike. While not harmful to human health, the presence of brown tide is a problem for bay scallops and hard clams due to starvation, and seagrasses due to light-shading.[13]

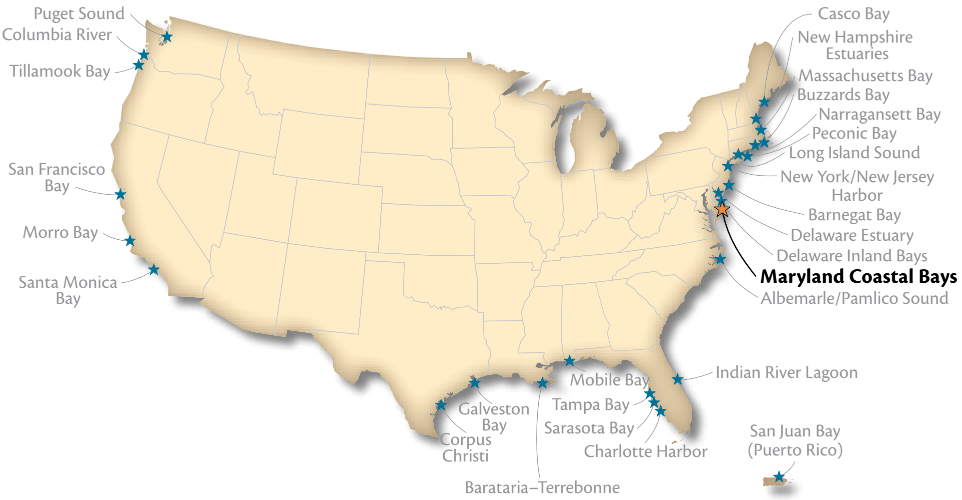
Brown tide was first identified in the United States in 1987 and first discovered in Maryland in 1998, but was possibly present as far back as 1993.[57] Routine monitoring since 1999 indicates that brown tide blooms are a common annual event in the Coastal Bays, peaking in May and June.[34] The bloom conditions observed are of concern, but it is currently unclear whether they are prolonged enough in duration to result in significant impacts to bivalves and seagrasses. Assessments of possible impacts to living resources are being explored. For more information, see Chapter 13—*Water Quality Responses to Nutrients.*

EMERGING CONCERN

The Maryland Coastal Bays were nominated to the National Estuary Program in 1995

The Maryland Coastal Bays were nominated to the U.S. EPA as an estuary of national significance due to the unique features of the bays, their recreational and commercial value, and the critical habitat

Location of the 28 National Estuary Programs



U.S. ENVIRONMENTAL PROTECTION AGENCY

Location of the 28 estuaries in the U.S. EPA's National Estuary Program.

1991–1992
New discharge permits issued to local municipalities and companies

1993
Brown tide first detected

1995
Nomination to the U.S. EPA's National Estuary Program

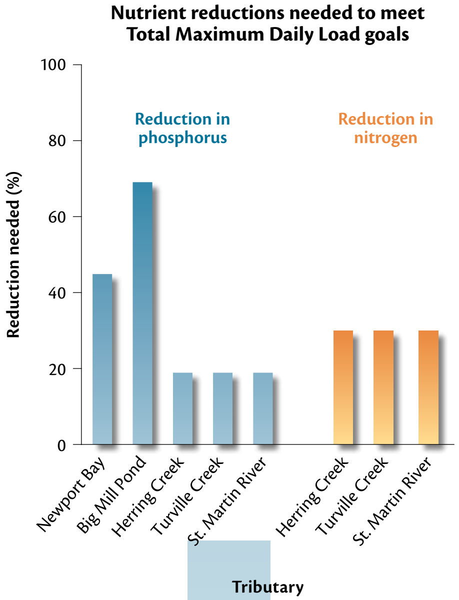
they provide to numerous species. The bays are important forage and nursery habitat for 115 fish species as well as the most significant area in Maryland for colonial waterbirds and many other bird species.[27]

Acceptance into the National Estuary Program allowed for the development of an intensive, multi-level management effort directed toward protecting and restoring the bays. Today, the Maryland Coastal Bays Program (MCBP) is a partnership among the towns of Ocean City and Berlin, the National Park Service, Worcester County, U.S. EPA, Maryland Departments of the Environment (MDE), Natural Resources (MD DNR), Agriculture, and Planning, and—most importantly—the citizens of the Coastal Bays watershed. These groups have come together to produce the first ever management plan for the Coastal Bays—the Comprehensive Conservation and Management Plan (CCMP).[26] MCBP is one of only 28 such programs nationwide.

The Coastal Bays were designated as 'impaired waters' in 1996

All five Coastal Bays—Assawoman, Isle of Wight (including St. Martin River), Sinepuxent, Newport, and Chincoteague Bays—were included on Maryland's impaired waters list in 1996. Since then, as mandated, the state and the U.S. EPA have created Total Maximum Daily Loads (TMDLS) for Newport Bay, Big Mill Pond in Chincoteague Bay subwatershed, and five tributaries to Isle of Wight Bay—Shingle Landing Prong, Bishopville Prong, St. Martin River, Herring Creek, and Turville Creek.[30]

Current nutrient TMDLS target nutrients to reduce high chlorophyll *a* concentrations (an indicator of algal blooms) and call for the maintenance of dissolved oxygen at levels where designated uses can be met. The TMDLS for the Coastal Bays were determined using a computer model that subtracted quantitative nutrient goals from estimated nutrient loads to determine the percent decrease required.[30]



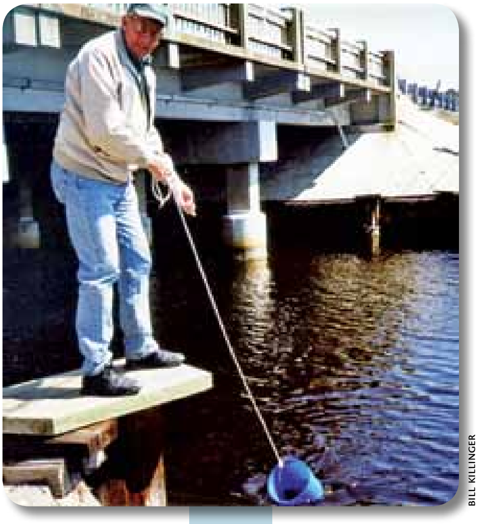
The nutrient reductions needed to meet the Total Maximum Daily Load goal for tributaries of the Coastal Bays.

Citizens became involved through volunteer monitoring in 1997

MCBP is dedicated to the preservation and improvement of the resources of the Coastal Bays. To help achieve this goal, a volunteer water quality monitoring effort was initiated by the MCBP Citizens' Advisory Committee and MCBP staff in 1997.[25] This program was organized and started sampling

1996

Coastal Bays included on
Maryland's impaired waters list



BILL KILLINGER

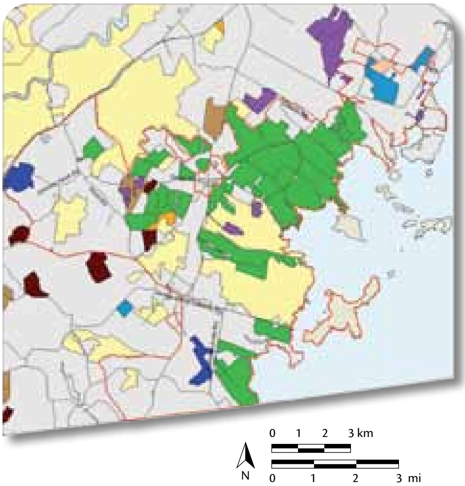
Coastal Bays volunteer Bill Killinger samples water in Ocean Pines.

prior to a comprehensive program being developed.

The volunteer program has since been integrated into a larger MCBP monitoring program. Data collected by this program adds to existing monitoring efforts by providing general long-term data in areas which are not routinely monitored, providing more frequent sampling (two times per month) to provide greater insight on the extent and duration of algal blooms, and providing observational information on living resources (such as fish kills and crab jubilees, both of which are caused by low oxygen concentrations in the water).

Rural Legacy Program introduced & community visioning workshops held

Started by the state of Maryland in 1997, the Rural Legacy Program allows counties to compete for funds to obtain permanent conservation easements from willing landowners in designated Rural Legacy Areas. The most successful in the state, the



- ☐ FY06 Coastal Bays Rural Legacy boundary
- 🟧 Forest Legacy easement
- 🟦 Forest Land Group
- 🟥 Maryland Agricultural Land Preservation Foundation District
- 🟫 Maryland Agricultural Land Preservation Foundation easement
- 🟪 Wetland Reserve Program easement
- 🟩 Rural Legacy easement
- 🟨 State-owned land
- 🟦 Maryland Environmental Trust easement
- 🟧 County-owned land

DATA COURTESY STATE OF MARYLAND AND WORCESTER COUNTY. MAP COURTESY WORCESTER COUNTY, MARYLAND

Map of the Coastal Bays Rural Legacy Area in the vicinity of Stockton and Girdletree, in the Chincoteague Bay subwatershed.

Coastal Bays Rural Legacy Area has placed some 2,500 ha (6,100 acres) in permanent conservation since 1998.[64] The Lower Shore Land Trust, the Conservation Fund, and Worcester County teamed up to run the county's program which continues today.

In 1998 and again in 2000, Worcester County residents took part in several community 'visioning' exercises which helped them decide and communicate how and where they wanted future growth in the Coastal Bays watershed and in other parts of Worcester County. Shown on the

1997

MCBP initiates volunteer monitoring program

1997

Rural Legacy Program begins

This map shows what more than 300 farmers, developers, environmentalists, and other citizens chose as their vision for Worcester County in 2050.

DATA AND MAP COURTESY MARYLAND COASTAL BAYS PROGRAM

map above is what more than 300 farmers, developers, environmentalists, and other citizens chose as their vision for the county in 2050.[66]

Potentially harmful algae *Pfiesteria* detected in Newport Bay in 1998

Pfiesteria is a single-celled aquatic organism that can bloom in large numbers under certain environmental conditions. There are two species of *Pfiesteria*—*P. piscicida* and *P. shumwayae*—both of which are potentially toxic to fish and people. *Pfiesteria* species have been shown to have a highly complex life cycle, with possibly more than 24 reported forms that live in either the bay sediment or water.[8]

Pfiesteria was first detected with targeted sampling in Maryland's Coastal Bays beginning in 1998.[35] Water and sediment surveys have been conducted in the Coastal Bays using molecular techniques to detect and identify these potentially harmful species. Rapid response efforts by MDE and MD DNR have examined fish kills and fish health events (distressed fish or fish with lesions) annually since 2000, occasionally detecting *Pfiesteria* species at the events. Bioassays, however, have all been negative for signs of toxicity. *No toxic* Pfiesteria *has ever been detected in Maryland's Coastal Bays*. The presence of *Pfiesteria* was predominantly in the Newport Bay system (Ayers, Trappe, Marshall, and Newport Creeks).

The federal government became involved with the U.S. Army Corps of Engineers Ocean City study in 1998

The feasibility of implementing a long-term sand management plan, improving navigation, and restoring habitat was investigated by the U.S. Army Corps of Engineers. This draft environmental impact study, completed in 1998, was the most extensive review of resources and conditions in the Coastal Bays to that date.[60]

The investigation of water resource problems led to the development of solution options to improve the ecosystem as a whole. These solutions included stabilization of the north end of Assateague Island, creation of a sand bypass system to maintain transport of sand around the Ocean City Inlet, dredging, and creation of marshes and bay islands. Currently, work is being undertaken to implement these suggested solutions.

Seagrass recovery continued during this period

Seagrasses increased by 93% in the Coastal Bays from 1995 through 2004 (from 9,287

1998
First community visioning exercise

1998
Pfiesteria detected in Coastal Bays

JANE THOMAS

Aerial view of the northern end of Assateague Island, the Ocean City Inlet, and southern Ocean City.

JANE THOMAS

Aerial view of Sinepuxent Bay, showing some of the extensive seagrass meadows behind Assateague Island.

1998

Ocean City
feasibility study

to 17,942 acres), believed to be an all-time high for this area.[31] Seagrass area leveled off and then suffered some losses in 2005. Recent goal development work indicates that less than 50% of the potential seagrass habitat may be occupied. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

EARLY ACTIONS

The Coastal Bays Comprehensive Conservation & Management Plan brought together many partners

In 1999, MCBP released their Comprehensive Conservation and Management Plan (CCMP), given the hopeful title 'Today's Treasures for Tomorrow.'[26] The CCMP details Action Plans in four areas: Water Quality, Fish and Wildlife; Recreation and Navigation; and Community and Economic Development. These Action Plans serve as blueprints for the public agencies responsible for protecting the area's natural resources and present a range of strategies that ensure economic stability through environmental recovery and protection.


DAVE WILSON

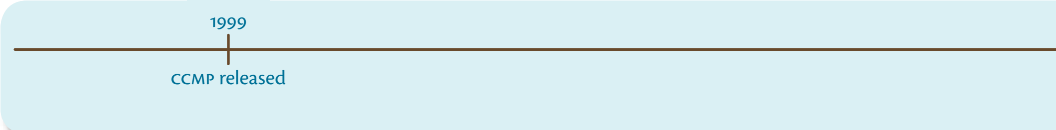
Environmental advocate and former Worcester County Commissioner Jeanne Lynch addresses the crowd at Macky's in Ocean City to mark the release of the CCMP in 1999.

Steps toward achieving the goals in the CCMP.

Because of the number and complexity of actions being undertaken in the CCMP, as well as the CCMP's emphasis on long-term solutions, implementation is characterized in three five-year phases. As of September 2004, the end of Phase One, 53% of the CCMP had been implemented, with a majority of actions showing substantial progress. Phases Two and Three are expected to realize more initiatives on the landscape of the watershed in addition to those actions affecting the water quality and wildlife within the bays. Visit *www.mdcoastalbays.org* for more information.

Coastal Bays-wide water quality monitoring instituted

In response to the requirements of the Clean Water Act, the state of Maryland currently collects water quality data through periodic sampling. An official monitoring program managed by MD DNR began in 2001, though many earlier state programs recorded water quality data.[32] In addition, the National Park Service at Assateague Island has collected data in the bays south of the Ocean City Inlet



Maryland Department of Natural Resources staff conducting monthly water quality monitoring in Chincoteague Bay.

since 1987, and MCBP instituted a volunteer monitoring program in 1997. All of these programs collect data monthly at fixed sampling stations.

Beginning in 2002, MD DNR deployed continuous water quality monitors in Bishopville Prong and Turville Creek. Another was installed at Public Landing in 2005. These automated monitors collect data every 15 minutes and connect to a website (*www.eyesonthebay.net*) for real-time viewing. MD DNR, in conjunction with the University of Maryland Center for Environmental Science (UMCES), collected intensive spatial data through the summer months of 2003 and 2004 using a DataFlow system (data viewable at the website listed above). In 2004, UMCES monitored for nitrogen sources on an intensive spatial scale as well.[22] For more information, see Chapter 13—*Water Quality Responses to Nutrients.*

The Coastal Bays became part of Maryland's Critical Area Program in 2002

In 1984, the Maryland General Assembly enacted the Chesapeake Bay Critical Area Protection Program. Under this law, the critical area was defined as any area within 305 m (1,000 ft) of tidal influence and the newly-established Critical Area Commission was charged with setting guidelines for development within these boundaries.[43] Then, as now, the three goals of the Critical Area Commission are the protection of water quality, conservation of habitat, and accommodation of future growth and development without adverse environmental impacts. At first, the Critical Area law only applied to the tidal Chesapeake Bay, but the Coastal Bays were added in 2002, increasing the state's critical area by some 12,000 ha (30,000 acres).

Historic & recent wetland loss was addressed with a restoration program

The Coastal Bays watershed has lost an estimated 22,000 ha (55,000 acres) of wetlands since European settlement.[3] Wetland losses and alteration have occurred from various activities. A network of ditches has drained many tidal and non-tidal wetlands.

Tidal wetlands have also been impacted by the construction of canals, bulkheads, or other hard shoreline stabilization projects. Direct conversion for agriculture and commercial and residential development has also resulted in extensive loss. Although slowed considerably by federal and state laws restricting development on wetlands, impacts still occur from human-induced changes in land use, sea level rise, and natural processes such as erosion.

2001	2002	2002	2003
MD DNR monitoring program begins	TMDLs approved for Big Mill Pond, Turville, Herring, and Manklin Creeks, and St. Martin River	Coastal Bays become part of Critical Area Program	TMDLs approved for Newport Creek, Newport Bay, and Kitts Branch

Recent state guidelines prioritize wetlands for protection and restoration under the CCMP goal of increasing wetland area by 4,000 ha (10,000 acres). As a start, the Natural Resources Conservation Service has created 4,000 ha (10,000 acres) of grass and tree buffers and restored 600 ha (1,500 acres) of wetlands in Chincoteague, Newport, and Sinepuxent Bays over the past 10 years.[9]

THE FUTURE

A federal program, implemented locally, seeks to identify restoration sites

The Watershed Restoration Action Strategy (WRAS) is a federally funded program which has created plans to improve water quality and wildlife habitat in the subwatersheds of the Coastal Bays.[63]

Begun in 2004 and administered by Worcester County in cooperation with MD DNR, the WRASS identify sites for restoration projects. Funding is available for land restoration activities which include wetlands, stream buffers, cover crops, flood control, wildlife habitat plantings, and shoreline protection.

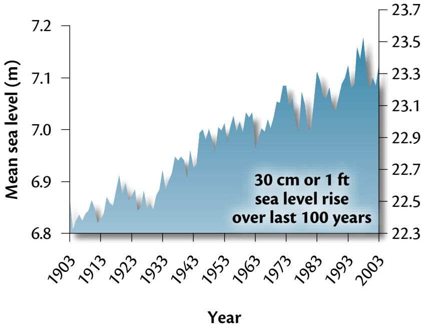
Funding and technical resources are made available through state and federal programs administered by a variety of agencies, including the Natural Resource Conservation Service, Maryland Department of Agriculture, and MD DNR.

Climate change could negatively impact the Coastal Bays

Climate change, though a global phenomenon, is projected to have a disproportionate effect on the Coastal Bays region. Current sea level rise is approximately one foot or 30 cm per century in Maryland, nearly double the average of coastlines worldwide, with current models predicting marked increases in these averages over the next century.[15,21,51]

Potential ecological effects of climate change on the Coastal Bays region include changes in species composition and migration patterns, alteration of habitat and water quality dynamics, and physical changes from sea level rise and altered weather patterns. Sub-tropical species currently abundant south of the Mid-Atlantic, such as brown shrimp (*Farfantepanaes* spp.), may benefit from warming conditions and colonize Mid-Atlantic estuaries (e.g., the nearby Chesapeake Bay).[62] Conversely, cold temperate species, such as striped bass and eelgrass, will likely decline. Shorter winters and warmer spring and autumn temperatures will likely result in earlier immigration and later emigration of many coastal species.[37,62] Algae dynamics could be altered, leading to increases in harmful algae blooms and longer periods of low dissolved oxygen exacerbated by higher temperatures.[37] Erosion of protective barrier islands and inundation of marshes

Sea level rise in Baltimore, Maryland, 1903–2003



DATA COURTESY PERMANENT SERVICE FOR MEAN SEA LEVEL

Annual mean sea level in Baltimore, Maryland, showing approximately one foot of sea level rise over the last 100 years.

2004

WRAS program begins

2004

Quantifiable Goals adopted and *State of the Bays* report released and wetlands will alter the very character of the ecosystem.[15] Climate change will also impact weather patterns, increasing the frequency and severity of coastal storms.[19,20] More frequent hurricanes and nor'easters will only serve to exacerbate and hasten the effects of a rising sea.[5] Shifts in growing seasons and rainfall averages could affect agriculture, the economic mainstay of the region for the past several centuries. Coupled with the expected rise in population, the effects of climate change will increase the probability of disaster.

Total Maximum Daily Load implementation will require both voluntary & regulatory actions

New water quality parameters set by MDE will help set meaningful nutrient reduction goals for those parts of the Coastal Bays requiring TMDLs.[10] To achieve the goals, a combination of voluntary commitments and regulatory procedures will be the rule. Low-cost loans, stormwater retrofit grants, stream restoration funding, agricultural programs, and help from all local, state, and federal partners in MCBP will aim to reduce nutrients. Many strategies in the CCMP will aid this effort.

Although rough estimates, calculations will include the sum total of combined efforts and calculate reductions as a percent of the area of each project divided by the total acreage of the targeted subwatershed. Septic upgrades, tree planting, and agricultural best management practices would also count as credits. Conversely, loss of forest and natural lands could count against nutrient reduction goals. The targets have a 10–15 year achievement goal.

Four factors provide assurance that TMDLs will be implemented in the Coastal Bays:

- National Pollutant Discharge Elimination System Permitting Program permits.
- Water Quality Improvement Act 1998, nutrient management plans.
- CCMP actions.
- Future monitoring and TMDL evaluations.

Protection of contiguous forest corridors is necessary for biodiversity preservation

The protection of contiguous forests is a critical element in keeping natural resources viable while accommodating population growth. Both the Worcester County Comprehensive Plan and the Coastal Bays CCMP note protection of large forest tracts as an important goal. The majority of wildlife species in the Coastal Bays depend on large, hardwood forests for their survival. A challenge over the coming decades will be to protect forest hubs and to connect them, allowing species migration between intact woodlands.[33]

The long-term survival of numerous forest-dependent bird species and more than 20 reptile and amphibian species will depend on the watershed's ability to retain both contiguous woodlands and large forested blocks. This translates into protecting the watershed's tracts of continuous forest as well as wooded corridors connecting them.

Projected population rise could further strain natural resources

Following the trend in coastal communities worldwide, the population of the Coastal Bays watershed is expected to rise steadily throughout the 21st century (see section earlier in this chapter).

2030

Resident population will
exceed 56,000 people

Though the watershed as a whole, and Ocean City in particular, is expected to remain a vacation destination—swelling the population by as much as 40 times during an average summer weekend—more permanent residents will move to the area.

An addition of over 20,000 permanent residents over the next decade is projected, increasing the total to just over 60,000. Approximately 12,000 more will make their homes in the Coastal Bays watershed by 2020.[67] More land will be required for incoming residents, and this change in land use, increase in impervious surfaces, increased nutrient loads, and increased impacts from recreational use will bring about additional stresses to the ecosystems comprising the watershed and bays downstream.

~

Meanings of some place names

Assateague	Place across
Chincoteague	A large stream
Sinepuxent	Shallow
Assawoman	Across stream

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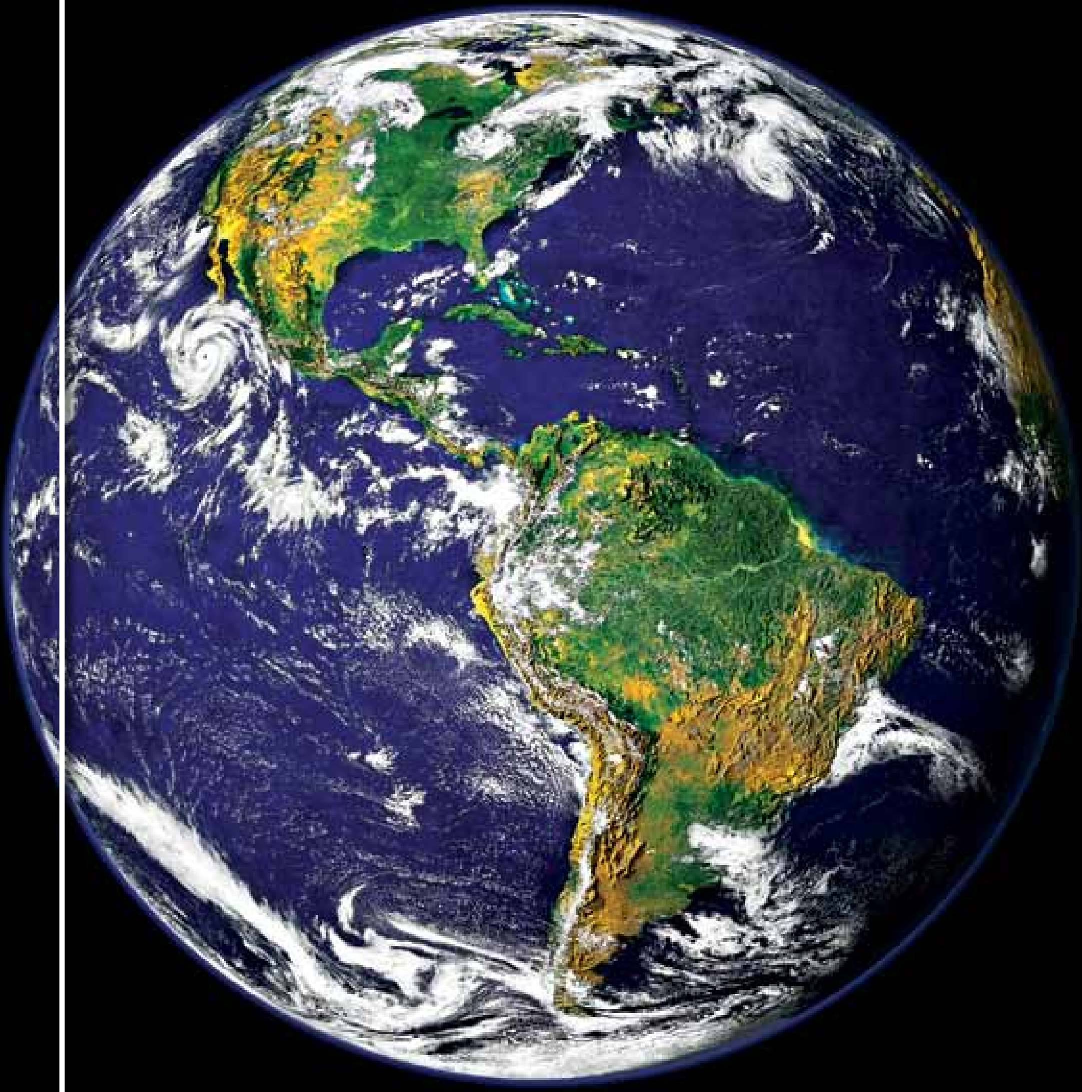
11. The Coastal Bays in Context



Suzanne B. Bricker,

William C. Dennison, Kenneth H. Dunton, João G. Ferreira, Matthew R. Hall, Jorge A. Herrera-Silveira, Ben J. Longstaff, Sara Morales-Ojeda, Christopher P. Onuf, Roberto Pastres, Jane E. Thomas, & Catherine E. Wazniak

COASTAL LAGOONS

Coastal lagoons are unique coastal features

Coastal lagoons are a significant feature of coastlines throughout the world, making up 13% of the world's coastline.[37] Lagoons are generally shallow—the depth of U.S. lagoons averages 1.6 m (5.2 ft). Lagoons are coastal waterbodies that are oriented parallel to the coast and separated from the ocean by a strip of low land such as a barrier island or sand spit. They usually have low freshwater inflow and, in most U.S. lagoons, tidal range is small, averaging 0.5 m (1.6 ft). The shallow nature of coastal lagoons means that water is generally well-mixed vertically by winds in comparison to other types of coastal waterbodies.

The area of water in coastal lagoons is generally small when compared to drowned river-valley estuaries, such as Chesapeake Bay, and the ratio of watershed area to lagoon area is small (median of 11), about half the average ratio of other types of estuaries (median of 28).[5] The small volume of water in coastal lagoons limits dilution, so they are particularly sensitive to any increase of nutrient inputs and tend to accumulate nutrients.

Most lagoons have relatively low freshwater inflow and exchange with the ocean is limited, occurring through only one or a few narrow inlets. This results in relatively long water residence times. Coastal lagoon inlets and barrier islands are dynamic in space and time, with sediment transport and storm events continuously changing their morphology. Lagoons with insignificant freshwater inflow and high evaporation can become hypersaline and, in these settings, stabilization or permanent opening of inlets may actually decrease average salinity. For more information on inlets and barrier islands, see Chapter 12—*Dynamic Systems at the Land–Sea Interface*.

Coastal waterways may be classified according to the forces that shaped them during their evolution—river flow, wave

JANE THOMAS

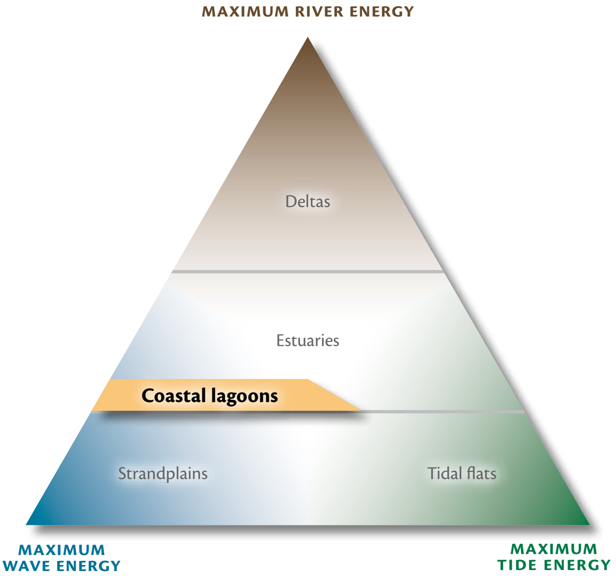
Coastal lagoons, such as the Maryland Coastal Bays, usually occur behind narrow barrier islands and are connected to the ocean through tidal inlets.

action, and tidal movement.[48] Coastal lagoons occur most commonly in wave-dominated systems, as they usually have minimal river input and are typically microtidal.

Coastal lagoons are very productive ecosystems, where life on the bottom (benthic) is closely linked to life in the water column (pelagic) and nutrients are efficiently recycled. Benthic microalgae and macroalgae can be important in lagoons where shallow waters allow light to penetrate to the bottom. Seagrass meadows, a typical benthic habitat within coastal lagoons—along with macroalgae and benthic microalgae—dominate primary production in lagoons. Retention of nutrients in the biomass of benthic primary producers during the growing season produces relatively high apparent water quality even when nutrient loading rates are high.[33] The predominance of benthic productivity makes lagoons very susceptible to eutrophication, when bloom-forming algae become prevalent, increasing turbidity and reducing light penetration which causes losses of benthic producers and release of nutrients into the water column. Long residence times and localized nutrient inputs in many lagoons provide opportunities for phytoplankton and slower-growing harmful algae species to bloom.[17]

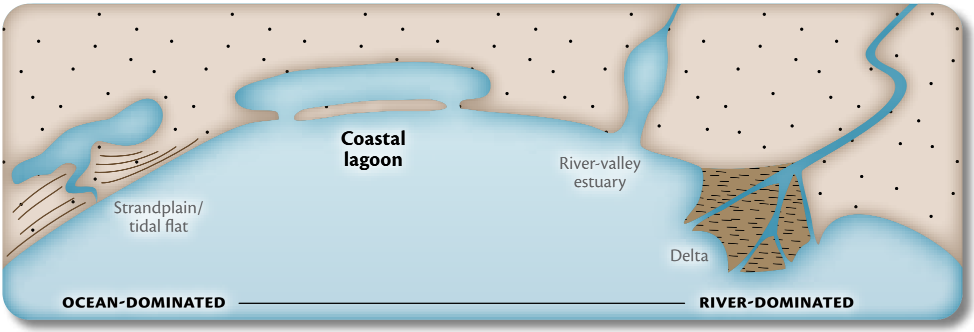
Lagoons are often fringed by wetlands such as salt marsh (temperate lagoons) or mangroves (tropical lagoons), which serve as habitat for a

Classification of estuaries & coastal waterways



Estuaries and coastal waterways can be classified according to the relative influence of rivers, waves, and tides.[48]

Types of coastal waterways



There is a continuum of coastal waterways, from strandplains/tidal flats and lagoons to estuaries and deltas[11,12] variety of organisms including wading birds, finfish, and shellfish. Living resources found in coastal lagoons include many filter feeders (oysters, clams, scallops, and mussels), finfish, and migratory birds. When intact, lagoons are highly productive. Some unpolluted lagoons yield greater numbers of fish per unit area than well-known fishing grounds such as the Peruvian upwelling.[37]

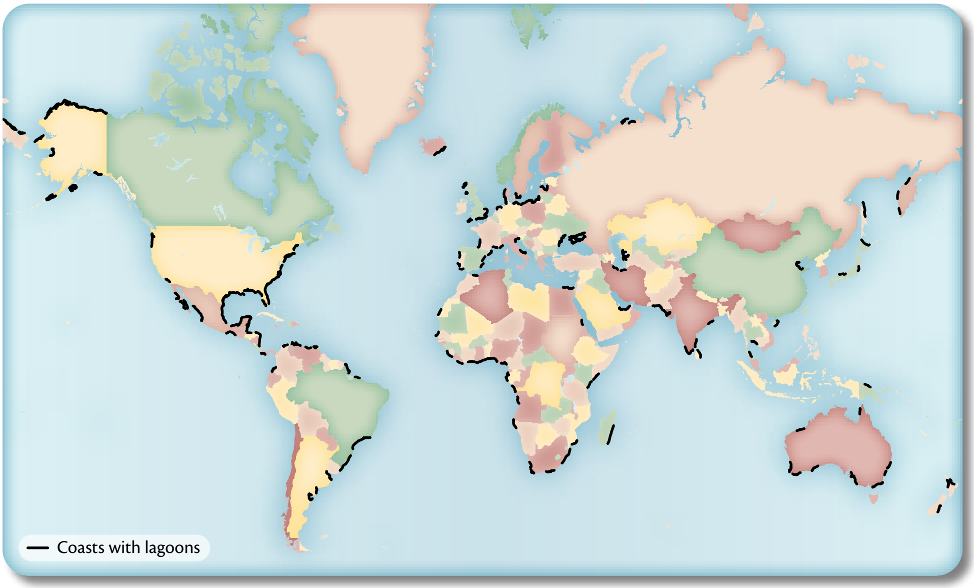
Sediments found in coastal lagoons are often muddier toward the mainland and sandier on the seaward side behind the barrier island or sand spit. For more information, see Chapter 13—*Water Quality Responses to Nutrients*, Chapter 14—*Diversity of Life in the Coastal Bays*, and Chapter 15—*Habitats of the Coastal Bays & Watershed*.

Threats to coastal lagoons include development, pollution, & shoreline hardening

Expanding coastal populations are putting pressure on coastal lagoons worldwide through increased wastewater inputs, increased development, and shoreline 'hardening,' including dead-end canals and rock walls. Atmospheric inputs of nutrients are also increasing, as are groundwater inputs, which can have a delayed effect of years to decades because of the lag times before groundwater reaches lagoon waters.

The dynamic nature of inlets and barrier islands and increasing coastal development often result in inlets being stabilized by structures such as jetties to prevent closure or migration. Stabilization of inlets changes circulation patterns and may impact the lagoon salinity regime. Lagoons are typically not well flushed because of restricted exchange with the ocean through inlets that are sometimes only open seasonally. Increasing the tidal exchange by stabilizing inlets can decrease residence time and thus decrease susceptibility to some types of algal blooms and other water quality problems. However, development on barrier islands may limit the formation of new inlets, maintaining

Global distribution of coastal lagoons



Coastal lagoons occur on all continents except Antarctica.[36]

the long residence times. Developed barrier islands often require sand replenishment to prevent their natural landward migration and to compensate for increased downdrift erosion caused by the stabilization of the inlet.

Coastal lagoons are expected to be strongly affected by climate change. The increase in frequency of storms that is predicted with global warming may intensify natural processes such as inlet formation, island overwash, and storm surges. In addition, lagoons are typically more highly influenced by wave mixing and meterological events than by tides. Sea level rise will also affect coastal lagoon watersheds because of their typically low elevations.

Globally, barrier island–lagoon systems make up 13% of the ocean's coastline. They occur on all continents except Antarctica (see map on facing page).

Although lagoons are sensitive ecosystems, they are increasingly impacted by development and human activities. Most lagoons have sandy beaches on the ocean side which attract heavy usage in summer. In many countries, lagoons are used for aquaculture because they have naturally high productivity. Lagoons provide picturesque locations and their watersheds suffer heavy pressures from development and tourism. Many have also been altered by engineered structures such as bridges and roads that foster runoff and erosion and alter circulation patterns, leading to sedimentation and eutrophication.

Studies worldwide show that many coastal lagoons have gone from highly productive fishing grounds and recreation areas to polluted ponds that no longer produce fish or shellfish. Because of this trend, there is a movement worldwide to develop management plans that will balance desired uses with the preservation and conservation of these sensitive ecosystems.

Eutrophication is a key threat

Eutrophication is a natural process in which nutrients such as nitrogen and phosphorus from the watershed, ocean, and atmosphere enter coastal waterbodies. Nutrients are essential for algal growth—which supports fisheries—but they become a problem when there is an oversupply that causes excessive growth of algae. The main sources of nutrients to coastal lagoons are wastewater inputs from septic tanks and combined sewer overflow, urban or suburban development and runoff, farming, tourist activities, and atmospheric deposition. One of the main features of lagoonal systems is their attraction as summer vacation destinations, leading to extreme seasonal changes in population. The population of Ocean City, Maryland in the northern Coastal Bays watershed increases to almost 40 times the resident population during the summer months—around 7,000 year-round residents compared with the average summer population of around 264,000.[39] The increase in watershed population puts intense nutrient pressures on these sensitive ecosystems at the most vulnerable time of the year—when temperatures are high and wind mixing is typically at a minimum.

Of great concern is the increase in nutrient inputs that is expected to

What is eutrophication?

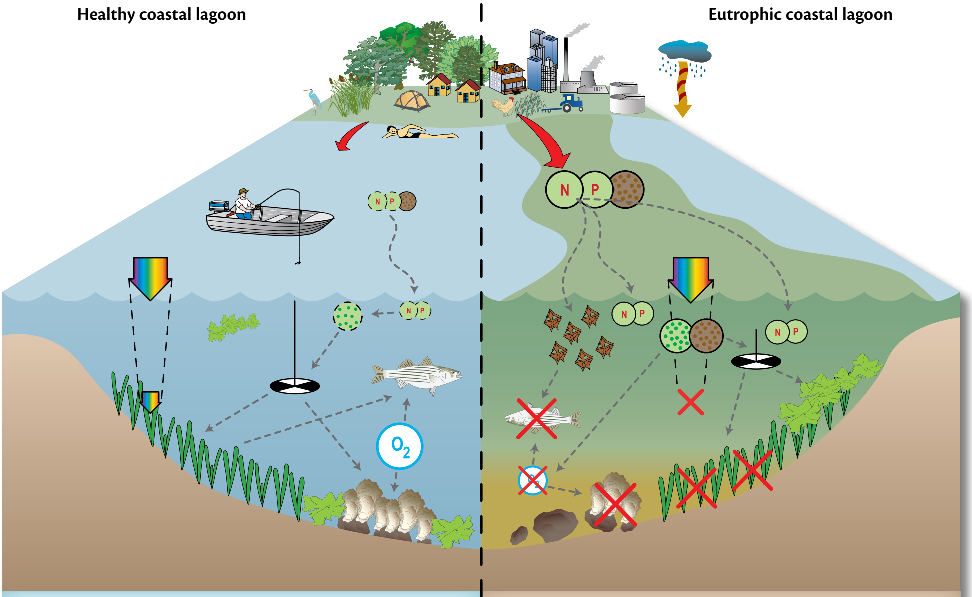
Eutrophication is the process by which the addition of nutrients (largely nitrogen and phosphorus) to waterbodies stimulates algal growth. Excessive nutrient inputs may lead to other serious problems such as low dissolved oxygen and loss of seagrasses.

In recent decades, human activities and population growth have greatly increased nutrient inputs to lagoonal systems, leading to degraded water quality and impairments of estuarine resources for human use.

continue as coastal populations increase. The U.S. coastal population increased by 27% between 1980 and 2003 and is expected to increase an additional 12% by 2020.[56] But in some lagoonal watersheds, past and future population increases may be even greater. For example, in the Barnegat Bay–Little Egg Harbor Estuary watershed in New Jersey, the population increased by 43% from 1980 to 2000,[25] and the coastal population in Maryland is expected to increase by 17% by 2020.

In addition to increases in total nutrient inputs, changes in the specific form of nutrients being delivered to waterbodies is also of concern. Increasing occurrences of brown tide in the Maryland Coastal Bays have been related to the increase in dissolved organic nitrogen, rather than inorganic nitrogen,[22,23] highlighting a need to focus on the component sources of nutrient inputs as well as the quantity of inputs. (Brown tide [*Aureococcus*

Healthy & eutrophic coastal lagoons



In healthy ecosystems, nutrient inputs—specifically nitrogen and phosphorus N P—occur at a rate that stimulates macroalgal and phytoplankton growth in balance with grazer biota. A low level of phytoplankton in the water column helps keep water clarity high, allowing light to penetrate deep enough to reach submerged aquatic vegetation. Low levels of phytoplankton and macroalgae result in dissolved oxygen O_2 levels suitable for healthy fish and shellfish, so that humans can enjoy the benefits that a healthy coastal environment provides.

In a eutrophic ecosystem, increased sediment and nutrient loads N P from farming, urban and suburban development, wastewater treatment plants, and industry, in combination with atmospheric nitrogen, help trigger both macroalgae and phytoplankton blooms, exceeding the capacity of grazer control. These blooms can result in decreased water clarity, decreased light penetration, decreased dissolved oxygen O_2, loss of submerged aquatic vegetation, increased nuisance/toxic algal blooms, and contamination or die-off of fish and shellfish.

anophagefferens] is a bloom-forming alga which can clog the feeding siphons of filter feeders such as clams, causing death.)

The physical characteristics of lagoonal ecosystems—low freshwater inflow, shallow depth, restricted tidal exchange, and large summer populations—combine to make these systems vulnerable to eutrophication. Typical problems observed in lagoons everywhere are high levels of chlorophyll *a* (an indicator of phytoplankton), occurrences of nuisance and toxic algal blooms, and high biomass of macroalgae (i.e., seaweed).

Lagoons usually do not have significant problems with depletion of dissolved oxygen because of wind mixing of the shallow water; however, they may experience diel oxygen cycles, where oxygen levels drop to hypoxic levels in the hours before sunrise.[1] The high levels of phytoplankton and macroalgae cause losses of seagrasses which are habitat for fish, crabs, and other commercially and recreationally harvested species.

For example, in Barnegat Bay–Little Egg Harbor Estuary, long-term annual occurrences of brown tide appear to have caused declines in hard clams (*Mercenaria mercenaria*) and seagrasses (eelgrass [*Zostera marina*] and widgeon grass [*Ruppia maritima*]).[25] Surveys showed a 67% decline of hard clams from 1985 to 2001, and a 62% loss of seagrass beds between the mid-1970s and 1999.[25] The loss of seagrass is particularly problematic since they dominate primary productivity and temporarily retain nutrients during the summer period, providing good water quality despite high nutrient inputs.[33] Progressive eutrophication impacts ecosystem structure and function with shifts from benthic to pelagic productivity causing negative effects on biotic communities, essential habitat, and recreational and commercial fisheries, which lead to reduced value of these lagoons.

In addition to traditional measures to stop watershed-based inputs from reaching lagoon waters, complementary measures from within lagoonal waters can be pursued. A recent review suggests that filter feeders, through aquaculture projects or restoration of native shellfish beds, can be a cost-effective complementary addition to coastal management strategies. The review showed that bivalve harvesting removes nutrients from coastal systems and that deposition of organic particles (i.e., feces, pseudofeces) into sediments also contributes to nitrogen removal.[44] This result is demonstrated by the low level of eutrophication impacts observed in the heavily populated, high-use Jiaozhou Bay lagoon in China. The low levels of eutrophication impacts are accounted for by the intensive aquaculture activity within the system.[57]

Additionally, mussel farming is currently promoted in Sweden as a solution to address coastal eutrophication, recognizing that reduction of phytoplankton biomass by bivalves reduces the risks of anoxic conditions in waterways that can occur when plankton blooms, triggered by excessive nutrient loading into coastal waters, die off and increase biological oxygen demand.[28]

JOANA DILAO

Coastal lagoons are particularly vulnerable to eutrophication, manifested here as excessive macroalgal growth in Ria Formosa, Portugal.


GEORGE BONIELLO

Summer brown tide bloom at Public Landing in Chincoteague Bay.

Further evidence of the benefit of aquaculture is shown in a model designed to balance aquaculture yield and profitability while minimizing nutrient-related environmental damage. The results show that farmers can potentially derive significant extra income through emissions trading since shellfish farms are nutrient sinks.[18]

One example of an effort to use this concept to improve coastal water quality is the Barnegat Bay Shellfish Restoration Program which raises seed clams to restock the system's clam population and raise awareness of the water quality benefits of filter-feeding populations (*www.reclamthebay.org*). Shellfish restoration or aquaculture projects may have greater benefit in smaller coastal waterbodies such as lagoonal systems, since a greater percentage of incoming nutrients can be removed in comparison to larger systems.[44]

Monitoring results and studies of coastal lagoons indicate that they are susceptible to nutrient-related problems. Even small inputs of nutrients can cause significant impacts, including excessive algal biomass and loss of fisheries, because of the long residence times of water. Because of their potential for highly productive fisheries and their use as vacation destinations, coastal lagoons should be afforded the best available management. This includes best management practices and sewage treatment to prevent nutrients from entering the waterbodies from the watershed, as well as complementary methods, such as aquaculture or re-establishment of native filter-feeding populations.

Eutrophication of coastal lagoons is evident at regional, national, & international scales

A recent analysis shows that eutrophication is a problem in estuaries and coastal waters in the U.S. and globally, with lagoons everywhere showing eutrophication impacts. The National Estuarine Eutrophication Assessment (NEEA) evaluated overall eutrophic condition of selected coastal systems throughout the U.S., Europe, Australia, and China using the NEEA/ASSETS (Assessment of Estuarine Trophic Status) method.[3,4,5,19] Each of the component ratings is determined using a matrix approach.

Overall eutrophic condition (OEC) is a combined assessment of five symptoms based on occurrence, spatial coverage, and frequency of problem occurrences. The rating is determined from a combination of the average scores for chlorophyll and macroalgae—primary symptoms indicating the start of eutrophication—and the worst score of the three more serious secondary symptoms (dissolved oxygen, seagrass loss, and nuisance/toxic algal blooms).

The 2007 NEEA study shows that more than half of all coastal ecosystems in the U.S. have moderate to high eutrophication (65%) but that proportionally more coastal lagoons in the U.S. are highly impacted (75%; see overall eutrophic condition results later in this chapter). Case studies highlight the similar impacts that are observed in lagoons elsewhere, such as

Primary symptoms	Description
Chlorophyll *a* (phytoplankton)	Chlorophyll *a* is a measure of the amount of phytoplankton (microscopic algae) growing in a waterbody. High concentrations can lead to low dissolved oxygen levels as a result of decomposition.
Macroalgal blooms	Macroalgae are large benthic algae commonly referred to as seaweed. Blooms can cause loss of submerged aquatic vegetation (seagrass) by blocking sunlight. Additionally, blooms may smother shellfish, corals, or other benthic organisms and habitat. The unsightly nature of some blooms may impact tourism due to the declining value of swimming, fishing, and boating.
Secondary symptoms	**Description**
Dissolved oxygen	Low dissolved oxygen is a symptom of eutrophication because it results from the decomposition of organic matter (from dense algal blooms). Dead algae sink to the bottom and bacterial decomposition of those cells consumes oxygen. Low dissolved oxygen can cause fish kills, habitat loss, and degraded aesthetic quality, resulting in the loss of tourism and recreational water use.
Seagrass loss	Loss of seagrass occurs when dense phytoplankton blooms caused by excess nutrient additions (and absence of grazers) decrease water clarity and light penetration. These phytoplankton may occur in the water column, or can grow directly on the seagrass blades, also blocking light. Turbidity caused by other factors (e.g., sediments resuspended by wave energy) similarly affects seagrass. The loss of seagrass can have negative effects on an estuary's function and may impact fisheries due to loss of critical nursery habitat.
Nuisance/toxic blooms	Blooms are thought to be caused by a change in the natural mixture of nutrients that occurs when nutrient inputs increase over a long period of time. *Nuisance blooms* involve algal growth that is so rapid or extensive that it influences water clarity, decreases oxygen levels (upon decomposition), clogs filter-feeder siphons, and crowds out other organisms. *Toxic blooms* involve large growths of toxin-producing algae that directly impact the health of organisms and may also contain toxins dangerous to humans. Many nuisance/toxic blooms occur naturally—some are circulated into estuaries from the ocean, where they may be maintained by land-based sources of nutrients.

Eutrophication symptoms included in the NEEA assessment.[5]

in the Lagoon of Venice, Italy, where eutrophic conditions were severe in the 1970s but have improved as a result of management measures since then. The case studies illustrate the various impacts of eutrophication and share information about successful management efforts that reduced observed problems.

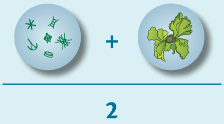
A desktop application of the method was developed recently as part of the SPEAR project (Sustainable Options for People, Catchment, and Aquatic Resources; *www.biaoqiang.org*).[20] It is now available for download in English, Chinese, Portuguese, and Spanish from *www.eutro.org/register*.

Calculating overall eutrophic condition

1. *Assign categories for primary and secondary symptoms.*
   The average of the primary symptoms is calculated to represent the estuary-wide primary symptom value. The highest of the secondary symptom values is chosen to represent the estuary-wide secondary symptom expression value and rating. The highest value is chosen because an average might obscure the severity of a symptom if the other two have very low values (a precautionary approach).

   Primary and secondary estuary-wide symptom expression values are determined in a two-step process:

A.



= **Estuary-wide primary symptom value**

B.

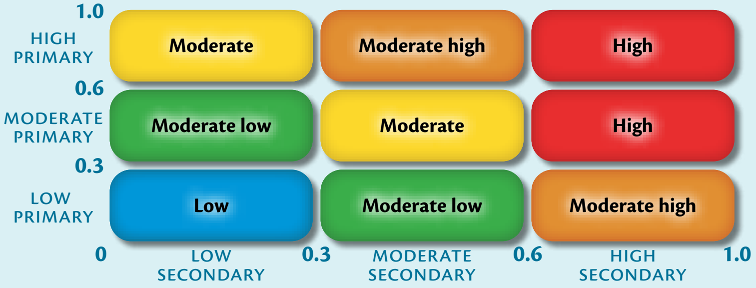
= **Estuary-wide secondary symptom value**

(Highest value is selected)

Estuary-wide symptom rating is determined:

Symptom expression value	Symptom rating
0.0–0.3	Low
0.3–0.6	Medium
0.6–1.0	High

2. *Determine overall eutrophic condition.*
   A matrix is used to combine the estuary-wide primary and secondary symptom values into an overall eutrophic condition rating according to the categories below. Thresholds between rating categories were agreed on by the scientific advisory committee and participants from the 1999 assessment.[3]



	LOW SECONDARY	MODERATE SECONDARY	HIGH SECONDARY
HIGH PRIMARY	Moderate	Moderate high	High
MODERATE PRIMARY	Moderate low	Moderate	High
LOW PRIMARY	Low	Moderate low	Moderate high

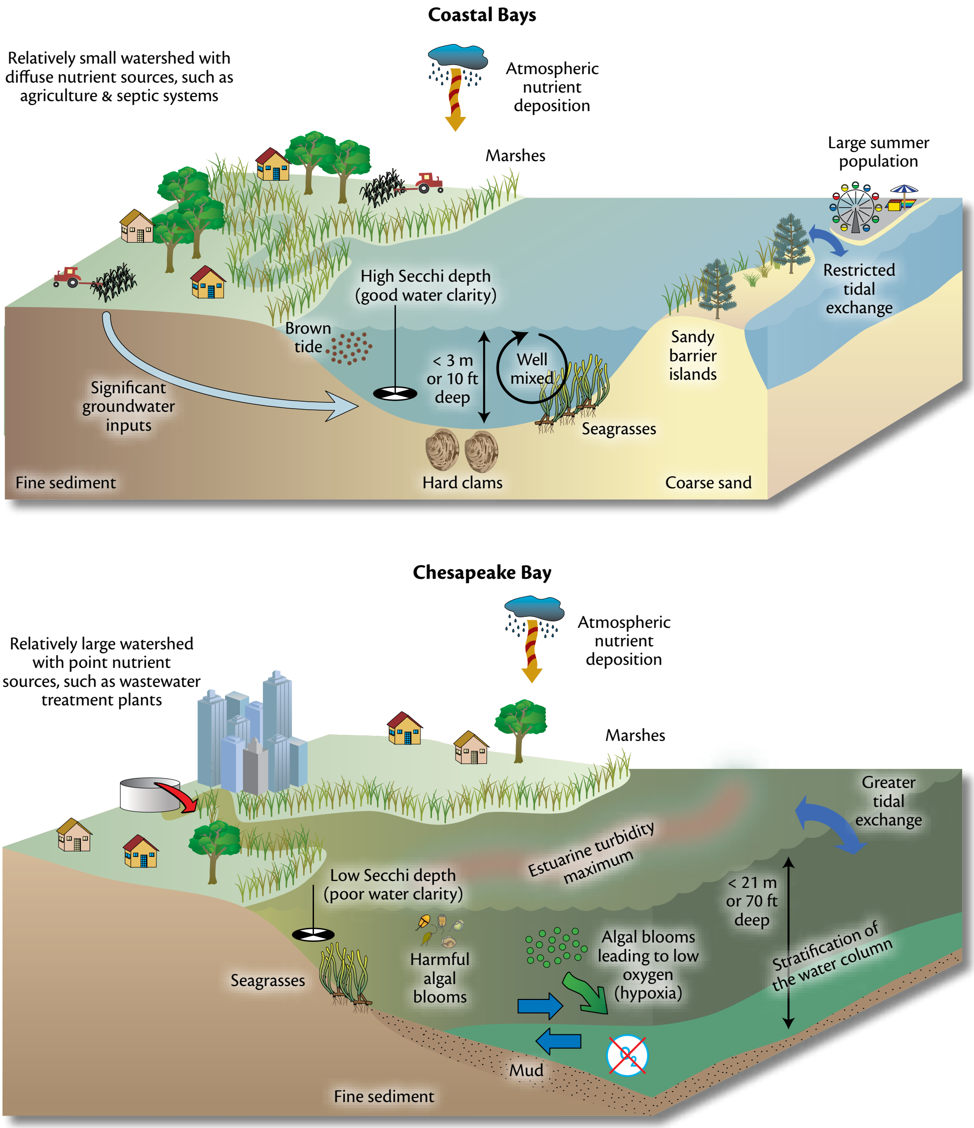
COASTAL LAGOONS IN THE UNITED STATES

Drowned river valleys are different from coastal lagoons

To illustrate the differences between drowned river-valley estuaries and coastal lagoons, descriptions of the Maryland Coastal Bays and the nearby Chesapeake Bay and tributaries are compared on the facing page. The characteristics of other types of estuarine systems may vary, especially in terms of susceptibility to impacts, but this comparison is intended to provide a basic overview.

Wind blowing across shallow coastal lagoons results in strong mixing of the water column, meaning oxygen levels usually remain high in open areas except during calm days in late summer. Dissolved oxygen is typically not a problem in lagoons due to the well-mixed water column, but many lagoons have problems with algal blooms (macroalgae, microalgae, and harmful algal blooms [HABs]), which can locally deplete oxygen.

The deeper Chesapeake Bay (averaging 21 m [70 ft]), has a large watershed (171,944 km^2 [66,388 mi^2]), high inputs of turbid river water, heavy nutrient load, and a large opening to the ocean which promotes greater tidal exchange in the lower bay. These features provide the potential for water-column stratification



Coastal lagoons are different from drowned river-valley estuaries such as Chesapeake Bay. These differences often make coastal lagoons more vulnerable to eutrophication.

(layers of water of different salinity or temperature) that can lead to low oxygen levels, particularly with high nutrient levels.

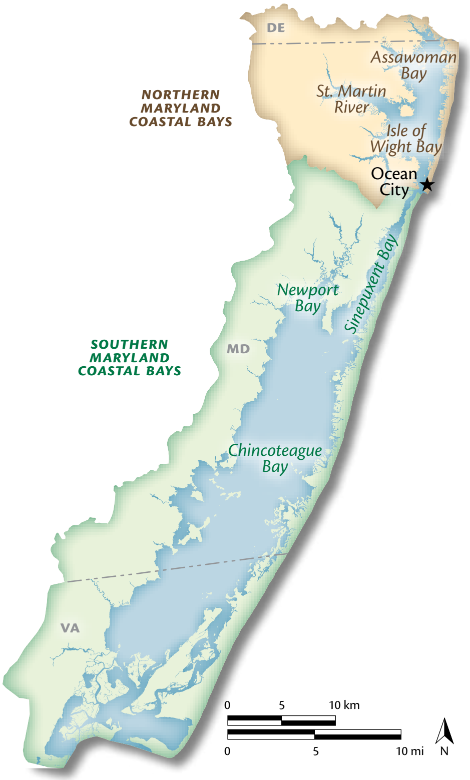
The Chesapeake Bay watershed includes large population centers, such as Baltimore and Washington, D.C., with notable point-source sewage discharges. The population is less variable seasonally; however, population density is greater—Chesapeake Bay has 83 people km^{-2} (215 people mi^{-2}), compared to the resident density in the Coastal Bays watershed of 27 people km^{-2} (70 people mi^{-2}). The larger Chesapeake Bay watershed means that much more agricultural area is present, as well as extensive heavy industry with associated contaminant discharges.

The shallow nature of lagoons limits dilution which, together with long residence times, seasonal population pressures, and benthic-dominated primary productivity, makes the Coastal Bays more sensitive to nutrient inputs than Chesapeake Bay. The problems that develop include algal blooms (microalgae and macroalgae) which cloud the water column, causing losses of seagrasses and other benthic primary producers, and occurrences of HABS. There are also recent indications of dissolved oxygen issues. By comparison, the larger, deeper Chesapeake Bay has had high-level impacts for several decades, including well-established problems with low dissolved oxygen in the deep channels and seagrass loss along the shallow flanks, in addition to increasing problems with algal blooms and HABS. While nutrients are the primary pollutant problem in the Coastal Bays, problems in Chesapeake Bay include additional contaminants due to the larger population and more diverse land use within the watershed.

Eutrophication was assessed in the Maryland Coastal Bays

Overall eutrophic conditions in the Maryland Coastal Bays were determined from primary (increased chl *a* and macroalgae) and secondary (dissolved oxygen problems, seagrass loss, and occurrence of nuisance/toxic blooms) symptoms, using the most recent available data (see table on page 190). Water quality data was collected monthly (by Maryland Department of Natural Resources and Assateague Island National Seashore water quality monitoring program) at 60 lagoon sites (26 in the northern Coastal Bays and 34 in the southern Coastal Bays) during 2004 and data concerning the spatial distribution of macroalgae was collected in 2003 and seagrasses in 2004.[32,53]

Northern & southern Maryland Coastal Bays



Location of the northern and southern Maryland Coastal Bays and watersheds.

Northern Maryland Coastal Bays (Assawoman & Isle of Wight Bays & St. Martin River)

Primary symptoms in the northern Maryland Coastal Bays indicated

JANE THOMAS

The Ocean City Inlet forms the boundary between the northern and southern Maryland Coastal Bays.

eutrophication impacts, with hypereutrophic chlorophyll *a* concentrations and some areas with harmful concentrations of macroalgae. Chlorophyll *a* was *High* (90th percentile value was 91.95 µg L^{-1} in the mixed zone and 22.8 µg L^{-1} in the seawater zone), and macroalgal biomass was *Moderate*, resulting in an overall *Moderate* primary symptom expression. *Low* incidences of secondary symptoms (10th-percentile dissolved oxygen value was 3.5 mg L^{-1} in the mixed zone and 4.8 mg L^{-1} in the seawater zone) resulted in *Low* secondary symptom expression.

Although several species of harmful and toxic algae are known to occur in the northern Maryland Coastal Bays, including the potentially toxic dinoflagellates *Prorocentrum minimum* and *Chattonella cf. verruculosa*, and the toxic *Pfiesteria piscicida*, there is no evidence of toxic episodes in the Maryland Coastal Bays.[47] A nuisance species that has increased in abundance since it was first identified in this system in 1999 is brown tide, which bloomed at low concentrations in the northern Maryland Coastal Bays during 2004, coincident with decreased rainfall during that year. *High* primary symptom expression and *Low* secondary symptom expression resulted in *Moderate* overall eutrophic condition for the northern Maryland Coastal Bays, and the rating has not changed since the early 1990s.[3]

JOANNA WOERNER

The northern Maryland Coastal Bays are influenced by large developed areas, including Ocean City and Fenwick Island.

Southern Maryland Coastal Bays (Sinepuxent, Newport, & Chincoteague Bays)

Primary conditions in the southern Maryland Coastal Bays were similar to those in the northern bays with *High* chlorophyll *a* (90th percentile was 33 µg L^{-1}) and *Moderate* macroalgal abundances, resulting in *High* primary symptom expression. There were *Low* incidences of dissolved oxygen problems

JANE THOMAS

The southern Maryland Coastal Bays benefit from the Assateague Island National Seashore.

(10th percentile value was 5.2 mg L^{-1}) and seagrass coverage increased in the early 2000s.[30,31] However, there were *High* nuisance/toxic blooms—intense annual blooms of brown tide at Category 3 levels (the highest of three categories; > 200,000 cells L^{-1}), which are known to seriously impact mussels, scallops, hard clams, seagrasses, and copepods.[21,52] This resulted in a *High* secondary symptom rating.

High primary symptom expression and *High* secondary symptom expression resulted in *High* overall eutrophic condition for the southern Maryland Coastal Bays, indicating significant eutrophication problems. In this system, conditions have worsened since the early 1990s when the overall eutrophic condition was *Moderate low*,[3] because of increasing frequency of brown tide events and high chlorophyll *a*.[54]

Maryland's Coastal Bays share characteristics with other Mid-Atlantic coastal lagoons

The lagoons of the Mid-Atlantic (i.e., Cape Cod, Massachusetts south to the Maryland Coastal Bays) are of particular interest because they are located in one of the most densely populated regions of the country and are therefore subject to more intense pressures than lagoons in other regions. The six lagoon systems in this region are Great South Bay, Barnegat Bay–Little Egg Harbor Estuary, New Jersey Inland Bays, Delaware Inland Bays, northern Maryland Coastal Bays, and southern Maryland Coastal Bays. Residence times vary from 21–100 days (averaging about 50 days), highest tidal height is 1 m (3.3 ft), and all lagoons are less than 2 m (6.6 ft) deep on average (see table on page 190). There are only low-level impacts of dissolved oxygen depletion in all of these systems, a result of their characteristically shallow nature that allows for wind mixing. However, some lagoons (e.g., Maryland Coastal Bays) have recently shown signs of oxygen depletion in the late summer, even to the point where crab jubilees have been observed—when the waters that are home to crabs become so depleted of oxygen that the crabs crawl up on land in search of oxygen to breathe.

Mid-Atlantic coastal lagoons have moderate to high levels of macroalgae, (primarily *Enteromorpha* and *Ulva*), which are known to smother seagrasses and bivalves,[2,14] and can cause low dissolved oxygen events. In some shallow lagoonal systems, additional nutrients will result in increased macroalgal abundance rather than high concentrations of chlorophyll *a*.[37] However, in these Mid-Atlantic lagoons, chlorophyll *a* impacts are moderate to high in all except the New Jersey Inland Bays. Macroalgal impacts in the New Jersey Inland Bays have worsened since the early 1990s.

A symptom of eutrophication typical of lagoons is the occurrence of nuisance or toxic algal blooms, due in part to long water residence times. Many HABS are slow-growing and thus may not be able to bloom in systems with shorter residence times. Three of these lagoons have high level nuisance/toxic bloom impacts—Great South Bay, Barnegat Bay–Little Egg Harbor Estuary, and the southern Maryland Coastal Bays. However, the other three—the New Jersey Inland Bays, Delaware Inland Bays, and the northern Maryland Coastal Bays—are rated as low, meaning that there are some nuisance and/or toxic bloom occurrences in all of these lagoons. In Barnegat Bay–Little

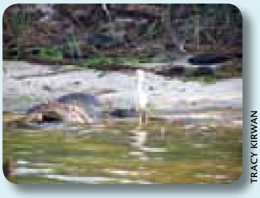
Barnegat Bay–Little Egg Harbor Estuary

Small tidal range, low tributary inflow, and limited ocean exchange with high nutrient inputs led to *High* eutrophic conditions. Chlorophyll *a* concentrations were high with blooms of brown tide and other harmful algal blooms, there was seagrass loss, and fisheries were highly reduced.

SCOTT HAAG

New Jersey Inland Bays

The high susceptibility of these bays is due to moderate dilution and low flushing. Chlorophyll *a* concentrations were low but brown tide blooms were a problem. Macroalgae blooms caused significant die-off of seagrass but there were no dissolved oxygen problems. Eutrophic conditions were *High*.



TRACY KIRWAN

Mid-Atlantic coastal lagoons overall eutrophic condition, 2004

Delaware Inland Bays

Low freshwater input and small tidal range led to *Moderate* eutrophic conditions. Severe hypoxia was observed in parts of the bays and seagrass was limited by excessive macroalgal growth. Chlorophyll *a* concentrations were moderate and some nuisance/toxic blooms occurred.

CHRIS BASON

Great South Bay

Moderate dilution and low flushing led to high levels of chlorophyll *a* and macroalgae, although oxygen depletion was not a problem. Some nuisance/toxic and brown tide blooms occurred in this system. Overall eutrophic conditions were *Moderate high*.

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Northern Maryland Coastal Bays

Shallow depth, small tidal range, and small freshwater inflow combined with high summer population led to *Moderate* eutrophic conditions. Chlorophyll *a* concentrations were very high and macroalgal abundances were moderate but there were no problems with nuisance/toxic blooms, low dissolved oxygen, or seagrass loss.

Southern Maryland Coastal Bays

Low flushing and dilution capabilities led to *High* eutrophic conditions which have worsened in the past decade. Chlorophyll *a* concentrations were high and nuisance/toxic blooms, especially brown tide, were observed. Dissolved oxygen was not a problem.

Coastal lagoon	Watershed area (km^2)	Pop'n (× 1,000)	Lagoon area (km^2)	People per km^2 of lagoon	Avg. depth (m)	Tide height (m)	Avg. salinity (ppt)	Exchange time (days)
Great South Bay	1,733	2,084	383	5,441	1.10	0.57	16	199
Barnegat Bay–Little Egg Harbor Estuary	1,730	520	280	2,211	1.5	0.75	20	74
New Jersey Inland Bays	3,431	330	278	1,188	1.11	1.00	28	27
Delaware Inland Bays	560	27	72	374	1.39	0.53	26	61
MD Coastal Bays	**770**	**21**	**389**	**54**	**1.93**	**0.59**	**29**	**42**
—Northern	**283**	**15**	**54**	**281**	**1.92**	**0.67**	**28**	**21**
—Southern	**487**	**6**	**335**	**17**	**1.94**	**0.50**	**29**	**63**

NATIONAL ESTUARINE EUTROPHICATION ASSESSMENT DATABASE

Characteristics of the Mid-Atlantic coastal lagoons, early 2000s. Long exchange times in the Maryland Coastal Bays are balanced by some of the lowest population densities (per area of lagoon) of all the lagoons, although summer populations may increase to nearly 40 times the resident year-round population.[6,29,43,46,54]

Egg Harbor Estuary, nuisance/toxic blooms have been reported for more than a decade.[5,25] In the southern Maryland Coastal Bays, data show that these blooms have become worse during the past decade.[5,23,49]

Brown tide bloom events have been recorded in Barnegat Bay–Little Egg Harbor Estuary in 1995, 1997, and 1999–2002, with bloom cell concentrations exceeding two million cells L^{-1} in 2000.[25,40] Brown tide has also been observed in Great South Bay, where brown tide was first observed and identified in 1985.[9] In the 1999 NEEA, the rating for nuisance/toxic blooms for the southern Maryland Coastal Bays was "no problem," [3,49] meaning that there has been significant worsening of bloom conditions since then, while conditions have remained at moderate levels in Great South Bay and at high levels in Barnegat Bay–Little Egg Harbor Estuary during the same time period.

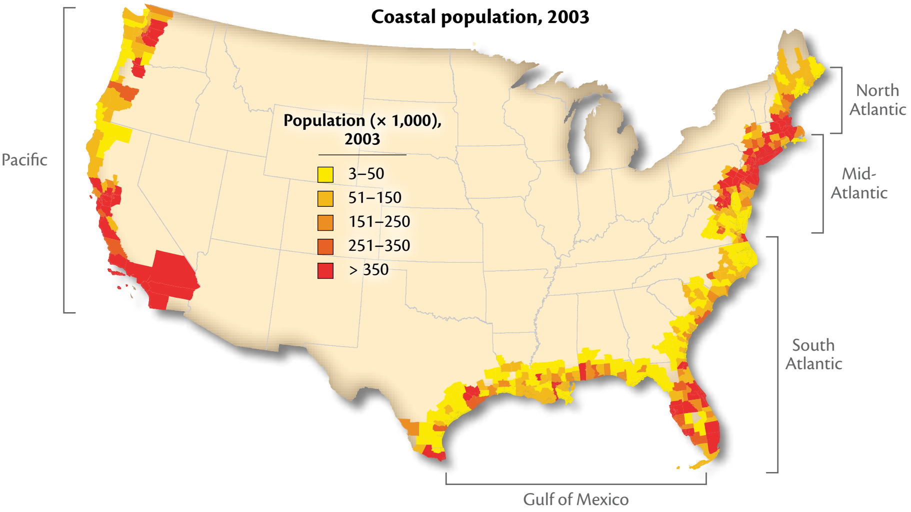
In both Barnegat Bay–Little Egg Harbor Estuary and the southern Maryland Coastal Bays, several toxic and non-toxic HAB species have been observed but the most noted HAB is brown tide.[22,23,25,40,47,49] In both lagoonal systems, blooms commonly occur at Category 3 levels ($>$ 200,000 cells mL^{-1})—concentrations which may cause severe impacts on mortality of shellfish and reductions in seagrasses.[21,49] There is also evidence that the frequency, duration, and intensity of blooms has increased in the past decade in the southern Maryland Coastal Bays.[49] Although troubling, these increases are consistent with observed population increases in coastal watersheds. The population in the southern Maryland Coastal Bays watershed doubled and has increased more than 40% in the Barnegat Bay—Little Egg Harbor Estuary watershed between 1980 and 2000.[25,54]

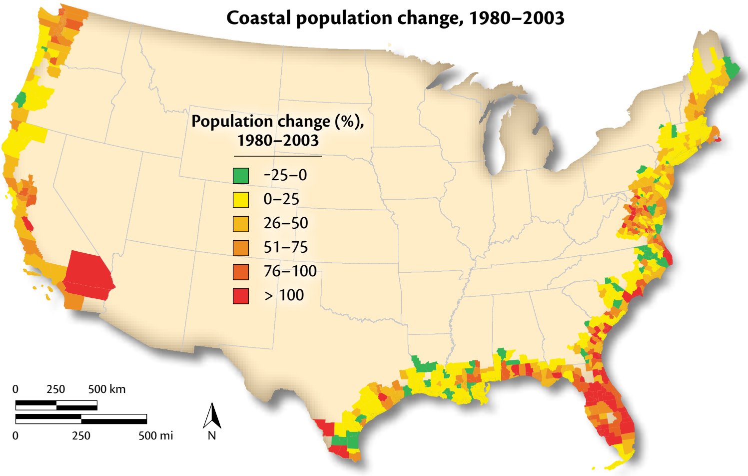
Nutrient loads have also increased with measured dissolved organic nitrogen concentrations doubling in the southern Maryland Coastal Bays.[23] Recent results have shown that brown tide favors organic nitrogen, increases of which have contributed to the proliferation of brown tides in the southern Maryland Coastal Bays.[23] This highlights that the composition of nutrients, in addition to the amounts entering a lagoon are important factors influencing the species that are able to grow and bloom and suggests that management measures must be attentive to the forms of nutrients that are being targeted for reduction.

Different regions have differing pressures & susceptibility

Over half of the nation's population lives on the coastal fringe of the contiguous United States, an area only one-fifth of the land area.[50] This large population has significantly increased the amount of nutrients entering the nation's coastal waterways, including coastal lagoons.

Population density within the coastal fringe varies greatly between regions. Some areas are under intense pressure, such as the North and Mid-Atlantic and Florida coasts, where very high densities occur, while other areas have relatively low population densities such as parts of the South Atlantic and Gulf of Mexico coasts. Coastal populations are increasing rapidly, with the majority of regions recording





Coastal areas in the contiguous United States already support high human populations (top), and population growth continues to add pressure to coastal estuarine systems (bottom).[35] There are 30 coastal states in the United States containing a total of 673 coastal counties, boroughs, parishes, or county equivalents. NOAA's Special Projects office defines a county as coastal if one of the following criteria is met: (1) at a minimum, 15% of the county's total land area is located within a coastal watershed or (2) a portion of or an entire county accounts for at least 15% of a coastal cataloging unit. For the purposes of this book, coastal states and counties are grouped into five regions: North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico, and Pacific.[10]

at least a 25–50% increase between 1980 and 2003,[35] although some areas, such as Florida, experienced increases over 100%. The coastal population increase is also projected to continue for at least the next decade.[34]

Differing climate conditions, freshwater inflow, number of tides per day, and oceanic exchange all contribute to the susceptibility of coastal lagoons to eutrophication. For example, the lagoons along the Gulf of Mexico coast are more vulnerable than those on the temperate Mid-Atlantic coast because of the warmer climate and longer growing season.

The North Atlantic region (Maine to Cape Cod, Massachusetts) of New England has a rocky shoreline and wave-cut cliffs in the north, while to the south there are cobble, gravel, and sand beaches with extensive marshes. There are no lagoons in this region, due in part to the large tidal range in the Gulf of Maine.

The Mid-Atlantic region (Cape Cod south to the Maryland Coastal Bays) is characterized by sandy beaches, numerous barrier islands, and extensive salt marshes. Water depths are shallower in this region (averaging 4.7 m [15.5 ft]). Tidal flushing (averaging 0.8 m [2.6 ft]) is dominant in northern ecosystems, while freshwater inflow is more important in the southern part of the region. This is the most densely populated of all regions with an average of 156 people km^{-2} (404 people mi^{-2}).

The South Atlantic region (Maryland Coastal Bays south to Florida) is comprised of extensive barrier island–lagoon–salt marsh systems. Depths are shallow (averaging 3 m [9.8 ft]) and tides are variable, averaging 0.6 m (1.9 ft) in North Carolina systems, 1.8 m (5.9 ft) in South Carolina and Georgia ecosystems, and 0.5 m (1.6 ft) in Florida. Circulation is dominated by wind and seasonal freshwater inflow in the north, and by freshwater inflow and tides in the south. The warmer climate and low water exchange makes these ecosystems, especially the lagoons, susceptible to development of nutrient-related problems.

The Gulf of Mexico (Florida west to Texas) has the most lagoons of any region but also has open bays and tidal marsh–delta complexes. This region has the lowest tidal ranges (averaging 0.4 m [1.3 ft]) and the shallowest depths (averaging 1.9 m [6.2 ft]) of all regions. Freshwater inflow is highly variable with seasonal rains dominant in the western lagoons. Circulation patterns are mostly wind-driven and coastal waters are warmest of all regions due to the subtropical climate. Long water residence times and extended high temperatures make these the most susceptible ecosystems of all the regions.

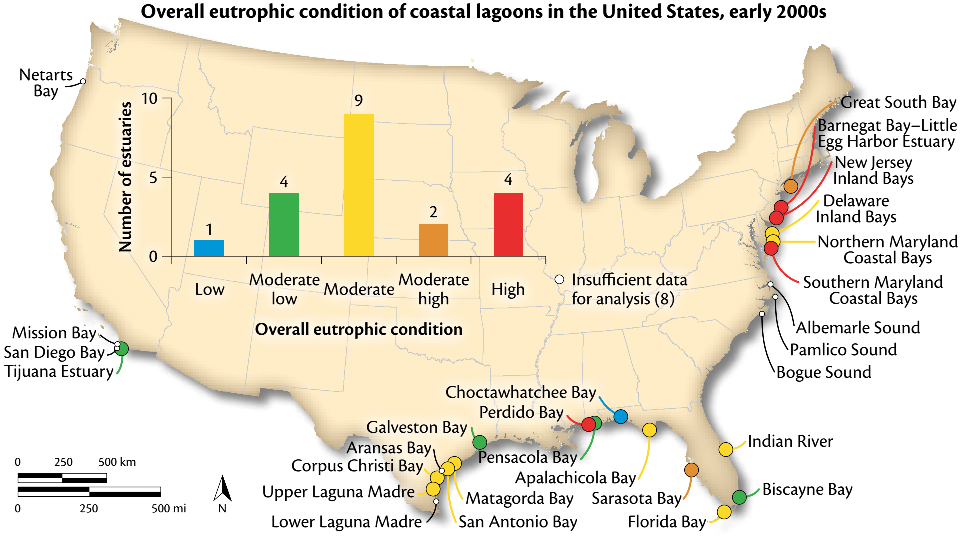
The Pacific coast region (Washington, Oregon, and California) is highly variable with rocky shores, sandy beaches, and river outlets, with a few lagoonal systems in the south where population density is highest. Circulation is dominated by seasonal freshwater inflow to the south and freshwater inflow and tides to the north. Water depths (averaging 14.4 m [47.2 ft]) and tidal heights (averaging 1.5 m [4.9 ft]) are highly variable along this coastline. Susceptibility is also variable, with higher susceptibility in the south due to longer residence times, warmer climate, and location of large population centers.

All U.S. coastal lagoons show signs of eutrophication

In the United States, there are coastal lagoons distributed along the Atlantic, Gulf of Mexico, and Pacific coastlines. They are variable in size—the 28 lagoons included in NOAA's NEEA range from 1 km^2 (0.4 mi^2) of water area to almost 5,000 km^2 (1,930 mi^2), averaging 709 km^2 (274 mi^2).[3,5] However, they are more similar in most other physical characteristics. Most are very shallow (averaging 1.6 m [5.2 ft]) with a small tidal range (averaging 0.54 m [1.8 ft]).

There are moderate to high levels of eutrophication observed in 15 of 20 of the

Overall eutrophic condition of coastal lagoons in the United States, early 2000s



Overall eutrophic condition for United States coastal lagoons shows that most lagoons are rated as *Moderate*. However, many of the lagoons that are rated as *Moderate high* or *High* are located in the Mid-Atlantic region.[5]

NEEA lagoons (for eight lagoons, data were inadequate for assessment). All but one (Indian River Lagoon, Florida) of the most impacted lagoons are located along the Gulf of Mexico and Mid-Atlantic coasts.

Upper Laguna Madre—Ecosystem transition occurred with the initiation of brown tides

Upper Laguna Madre, along the southeast Texas coast, has an area of 591 km^2 (228 mi^2), average depth of 0.3 m (1 ft), and is microtidal with a tidal range of 0.15 m (0.5 ft). Seasonally and meteorologically influenced changes in water level are more important than lunar tides in driving water exchange in this lagoon. Annually, evaporation is approximately twice precipitation, and no permanent streams discharge into the lagoon. As a result, the waters of the lagoon are hypersaline during the summer (annual average salinity >37 ppt). Seagrass meadows cover approximately two-thirds of the bottom. The surrounding watershed includes a National Park, a National Wildlife Refuge, and very large cattle ranches. The extreme northern end of the watershed is becoming increasingly urbanized.

Upper Laguna Madre was known for its clear water until a phytoplankton bloom (*Aureoumbra lagunensis*) developed in the spring of 1990 and persisted long enough to earn its own name—Texas brown tide.[55] The first episode lasted until October 1996, with a few brief blooms since then, including one as recently as August 2007. Although not acutely toxic to most biota, the bloom reduced light reaching the bottom long enough to eliminate 12 km^2 (4.6 mi^2) of seagrass from deeper areas of the lagoon, and little recovery has occurred since. The concern is that a

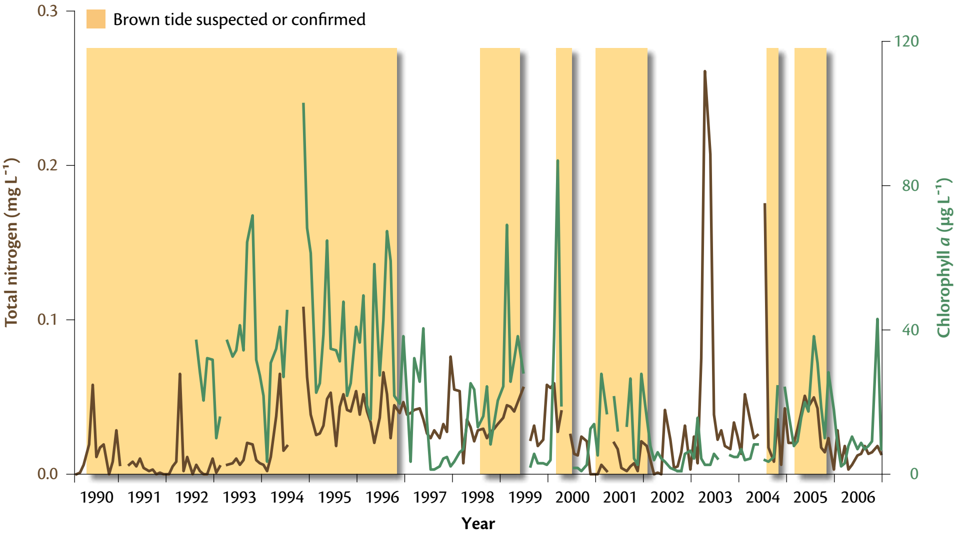

KEN DUNTON

Seagrasses in Upper Laguna Madre have been negatively affected by the Texas brown tide.

Location of Upper Laguna Madre

Location of Upper Laguna Madre on the Gulf of Mexico coast of Texas.

Brown tide, nitrogen, & chlorophyll in Laguna Madre, 1990–2006



Nitrogen, chlorophyll *a*, and brown tide occurrence in Laguna Madre between 1990–2006. Note: prior to April 1994, total dissolved nitrogen only included measurements of nitrate (NO_3) and nitrite (NO_2).

historically clear-water system has been converted abruptly to one that supports algal blooms much of the time without an obvious cause.

A retrospective analysis of the algal bloom established that the 1990 bloom initiated in Baffin Bay, a tributary of Upper Laguna Madre.[15,55] The initiation of the bloom is suspected to be linked to a variety of unusual circumstances preceding the bloom, including a long drought culminating in high salinities and a hard freeze coinciding with extremely low water. The high salinity eliminated most species of phytoplankton and grazers, but high salinity is tolerated by *A. lagunensis*, which was able to bloom. Despite being a relatively slow-growing organism that cannot assimilate nitrate, the bloom achieved densities exceeding one million cells mL^{-1}, which was attributed to a lack of grazing pressure and availability of ammonium released from decaying fish and invertebrates killed by the hard freeze. Other factors that contributed to the long persistence of the bloom include the unpalatability of *A. lagunensis* cells (i.e., a feeding-depressant effect on most grazers), the low flushing rate, and a nutrient subsidy from the gradual die-back of seagrasses. Although this *ad hoc* reconstruction accounts for the dynamics and controls of the first brown tide episode reasonably well, it is less satisfactory in accounting for the resurgence of the brown tide in subsequent episodes. Evidently, the blooms can be sustained at low levels of nitrogen and may be kick-started from dormant cells in the sediments.

This system was characterized by *Moderate* symptom expressions for chlorophyll *a* and nuisance/toxic blooms, resulting in a *Moderate* overall eutrophic condition.

COASTAL LAGOONS AROUND THE WORLD

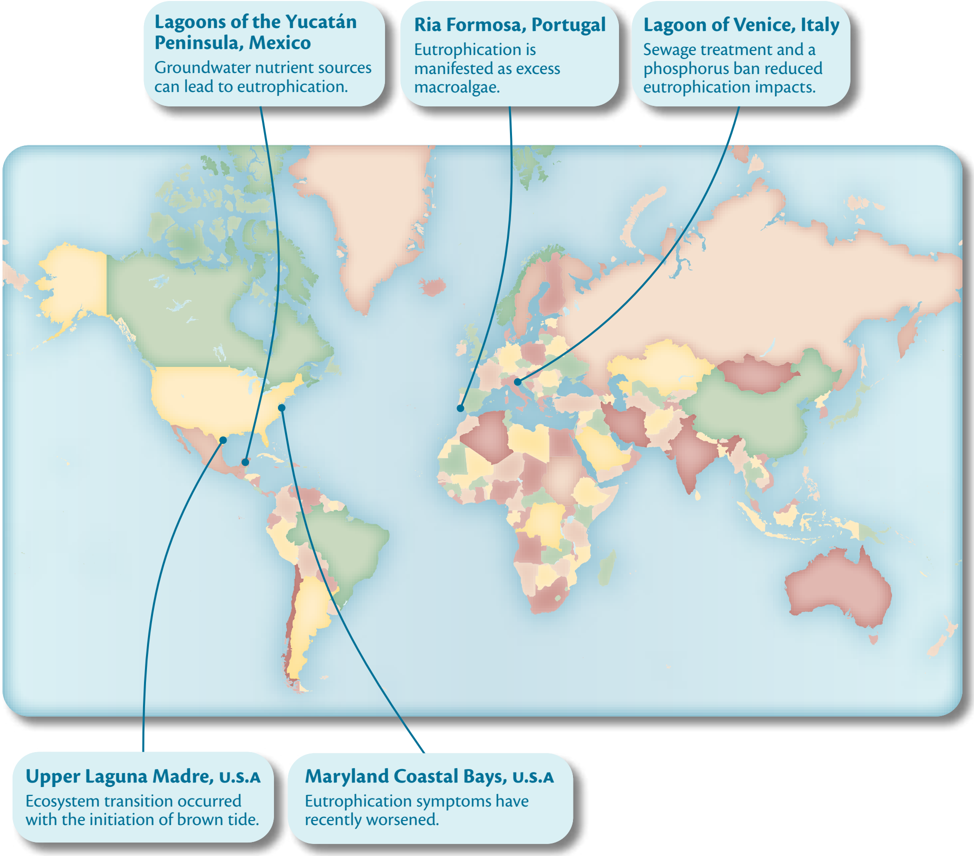
Similar symptoms & progression of eutrophication are seen globally

Research and monitoring in the past decade have revealed that eutrophication impacts have been observed in estuaries and coastal waterbodies around the world. In most cases, the progression of symptoms and the symptoms themselves are similar, often beginning with high chlorophyll *a* or macroalgae. Low dissolved oxygen, seagrass loss, and occurrences of harmful algal blooms are also observed. Though not all symptoms are observed in all estuaries and different

DATA COURTESY MARC IMHOFF (NASA/GSFC) AND CHRISTOPHER ELVIDGE (NOAA/NGDC). IMAGE BY CRAIG MAYHEW (NASA/GSFC) AND ROBERT SIMMON (NASA/GSFC)

This night view of the city lights of Earth shows the global extent of human population pressures in the coastal zone.

Case studies of coastal lagoons globally



Lagoons of the Yucatán Peninsula, Mexico
Groundwater nutrient sources can lead to eutrophication.

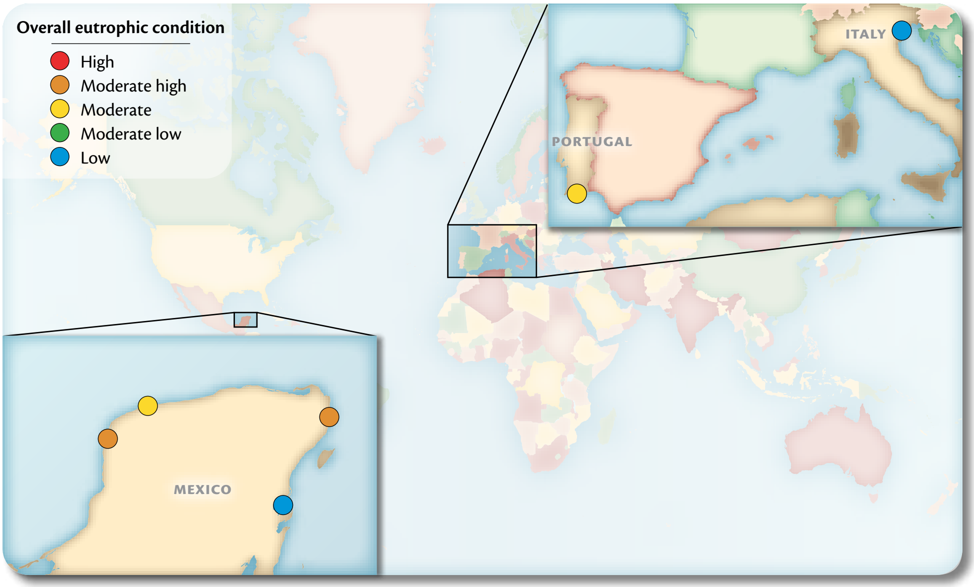
Ria Formosa, Portugal
Eutrophication is manifested as excess macroalgae.

Lagoon of Venice, Italy
Sewage treatment and a phosphorus ban reduced eutrophication impacts.

Upper Laguna Madre, U.S.A
Ecosystem transition occurred with the initiation of brown tide.

Maryland Coastal Bays, U.S.A
Eutrophication symptoms have recently worsened.

Global case studies—overall eutrophic condition



combinations of symptoms occur, there are commonalities, particularly in coastal ecosystems of the same geomorphological type. For example, macroalgal problems are observed in coastal lagoons more than in fjords or drowned river valleys, which seem to have more dissolved oxygen problems than are observed in coastal lagoons.

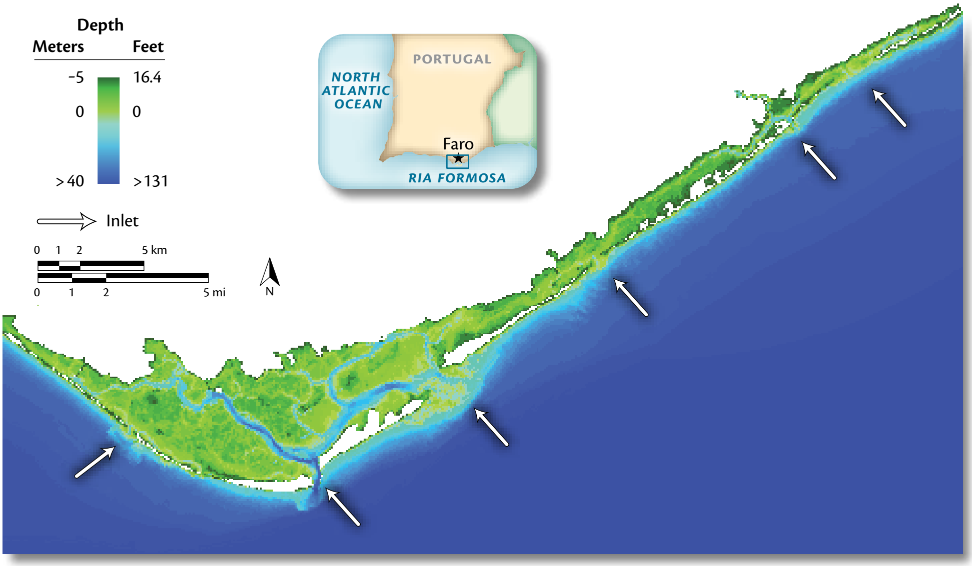
The case studies that follow are intended to highlight the different expressions of eutrophication that occur in different lagoon systems around the world. The case studies include Ria Formosa (Portugal), Lagoon of Venice (Italy), and lagoons of the Yucatán Peninsula (Mexico), in addition to those already presented—Upper Laguna Madre (Texas) and the northern and southern Maryland Coastal Bays. The Lagoon of Venice study also illustrates how the application of carefully planned management measures has relieved eutrophication. The success of these management measures should be used to encourage and promote management elsewhere to prevent future degradation and relieve impacts in lagoons elsewhere.

Ria Formosa, Portugal—Eutrophication is manifested as excess macroalgae

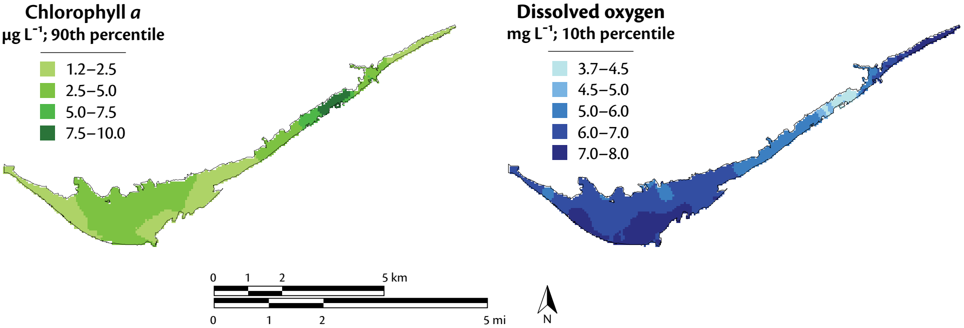
Ria Formosa is a shallow (averaging 1.5 m [5 ft]), small (49 km^2 [19 mi^2]) lagoon located in a sheltered coastal area in southern Portugal, southwestern Europe. It is a hypersaline barrier island–lagoon system connected to the ocean by six inlets—five natural and one artificial. The semi-diurnal tidal exchange (average tidal height of 2 m [6.6 ft]) is significantly greater than the residual volume, and freshwater inputs are negligible, leading to high average salinities (36 ppt). The lagoon has several channels and an extensive intertidal area covered by sand, muddy sand flats, and salt marshes.

The main sources of nutrients are point source discharges from a population of 150,000 inhabitants. Ria Formosa supports a wide range of uses, including tourism, extraction of salt and sand, fisheries, and aquaculture. Clam

Location & bathymetry of Ria Formosa, Portugal



Ria Formosa general view, showing bathymetry and inlets. Depths are referenced to a tidal datum (negative values are intertidal). The eastern end of the lagoon was not included as it is a distinct hydrographic area.



Interpolated surfaces for chlorophyll *a* (left) and dissolved oxygen (right) in Ria Formosa.

(*Ruditapes decussatus*) aquaculture provides a yield of 8,000 metric tonnes (8,800 U.S. tons) total fresh weight per year.

Pelagic primary production within the lagoon is strongly limited by rapid water turnover.[26,27,51] The combination of nutrient peaks, shallow water, large intertidal area, and short water residence time (approximately one day) results in benthic eutrophication symptoms such as intense macroalgal blooms.[7,13] The maximum values of macroalgal biomass observed in Ria Formosa reach about 2 kg dry weight m^{-2} (0.41 lb ft^{-2}).

Species	Spring	Summer
Ulva lactuca	1,350	100
Enteromorpha ramulosa	700	200
Gracilaria verrucosa	140	18
Fucus spiralis	335	75
Total macroalgae biomass	**2,525**	**393**

Maximum biomass (g dry weight m^{-2}) of macroalgae in the Faro–Olhão area in 1993. Note: values taken from graphical information.[16]

The 90th percentile value for chlorophyll *a* (5 µg L^{-1}) resulted in a rating of *Low*. The macroalgal component of the model showed that parts of the system are impaired, particularly in the western end, due to excessive blooms of *Enteromorpha*, which locally cause oxygen problems and increased mortality of benthic bivalves. The combination of *Low* chlorophyll and *High* macroalgal symptoms gave a *High* primary symptom rating. Dissolved oxygen was generally above the 5 mg L^{-1} threshold, indicating no oxygen problems, and there were no significant problems with losses of seagrasses or occurrences of nuisance or toxic blooms. The secondary symptom rating for Ria Formosa was *Low*, which, combined with the *High* primary symptom rating, gave a *Moderate* overall eutrophic condition.


JOANA DILAO & TIM CARRUTHERS

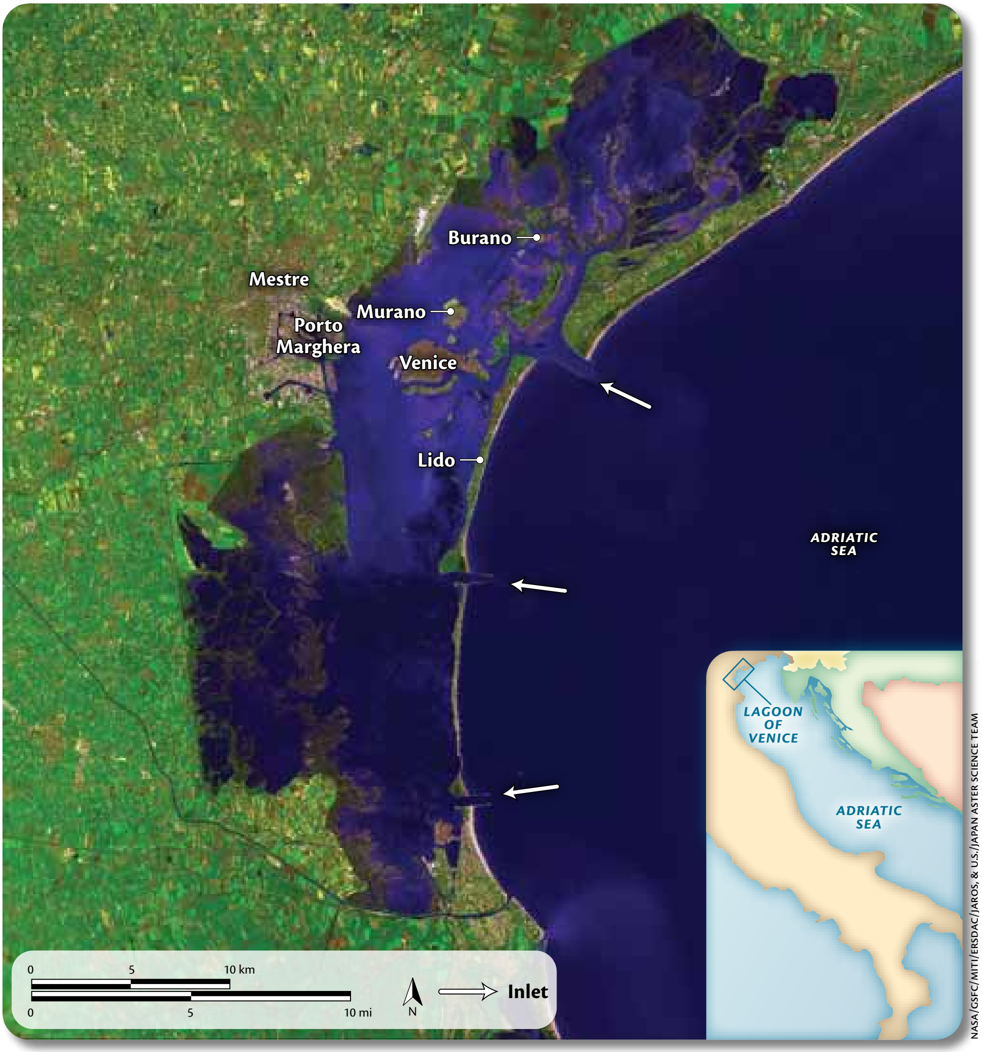
Ria Formosa has extensive intertidal areas (left), which support hard clam populations (middle). Eutrophication symptoms are manifested as excessive macroalgal growth, such as this *Enteromorpha* and *Ulva* bloom (right).

Lagoon of Venice, Italy—Sewage treatment & a phosphorus ban reduced eutrophication impacts

The Lagoon of Venice is one of the largest lagoon systems in Europe, with a total surface of 550 km² (212 mi²), of which 360 km² (139 mi²) are open to tidal exchanges. The lagoon is located along the northeast coast of the Adriatic Sea in Italy. It is a shallow water basin (averaging 1.5 m [5 ft]), connected to the sea by three inlets. The semi-diurnal tide (average tidal height of 1.9 m [6.2 ft]) drives exchanges of water volumes which are, on average, equivalent to the volume of the entire lagoon and comparable to the yearly freshwater inputs. The average annual salinity is >25 ppt.

Seven main tributaries and several minor canals carry the wastewater of this densely populated drainage basin, which hosts agricultural and industrial activities, into the lagoon. Other relevant nutrient

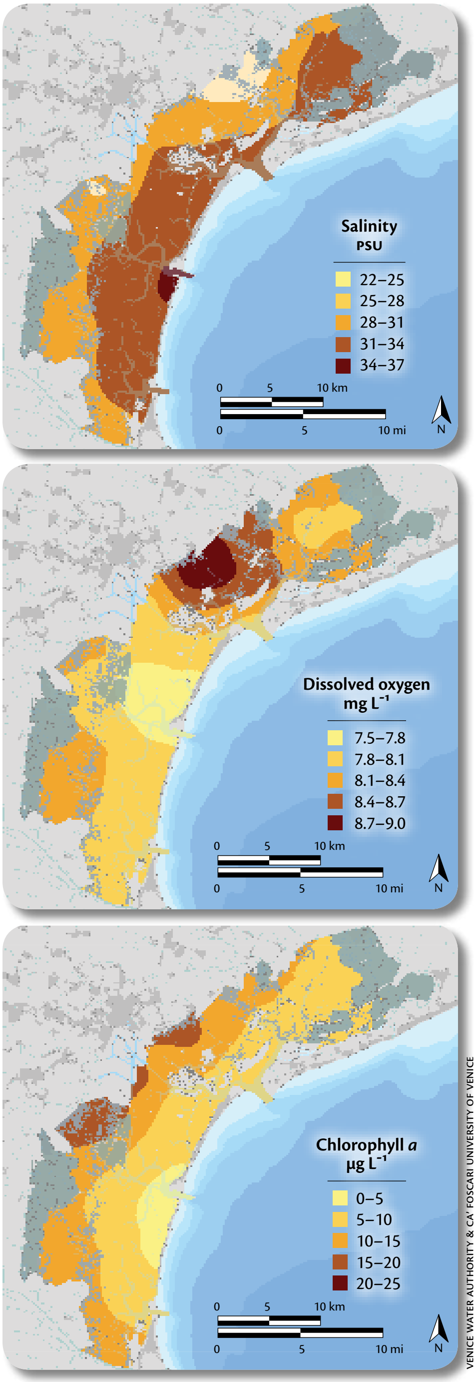
Location of the Lagoon of Venice



NASA/GSFC/MITI/ERSDAC/JAROS, & U.S./JAPAN ASTER SCIENCE TEAM

The Lagoon of Venice is located along the northeast coast of the Adriatic Sea.

Salinity, dissolved oxygen, & chlorophyll in the Lagoon of Venice, 2001–2003



VENICE WATER AUTHORITY & CA' FOSCARI UNIVERSITY OF VENICE

Interpolated surfaces for the salinity (top), dissolved oxygen (middle), and chlorophyll *a* (bottom) average concentrations.

and pollutant sources are the chemical industrial area of Porto Marghera, located on the edge of the lagoon in front of the city of Venice, the city of Venice itself, and other small islands (Murano, Burano, Lido, and others).

The uncontrolled discharges of nutrients during the 1960s and 1970s contributed to hypereutrophic conditions, which were evident during the 1980s when the density of macroalgae (*Ulva rigida*) reached values as high as 20 kg m^{-2} (4.1 lb per ft^{-2}) of fresh weight in large areas of the central part of the lagoon. In order to reduce the loads of nitrogen and phosphorus, wastewater treatment plants were built and phosphorus was banned from detergents in the 1980s. These actions, together with other restoration activities (e.g., planting of buffer strips to prevent nutrient inputs from runoff) aimed at lowering the unpleasant effects of acute eutrophication, led to a marked decrease in the concentration of soluble reactive phosphorus. During the last 15 years, macroalgae biomass has markedly decreased, while seagrass meadows (mainly *Zostera marina* and *Cymodocea nodosa*) have progressively recolonized large areas in the central and southern part of the lagoon.

The most recent available data were used to calculate eutrophic condition, including nutrient input measurements collected in 1999,[8] water quality data collected monthly at 30 lagoon sites during 2001–2003,[42] and seagrass spatial distribution data from 2002.[45] The 90th percentile value for chlorophyll *a* (24.4 µg L^{-1}) was high but spatial coverage was low, resulting in a *Low* rating. Macroalgae biomass was also *Low*, resulting in a *Low* primary symptom rating. The dissolved oxygen 10th percentile (6 mg L^{-1}) indicated *Low* problems with oxygen. The biomass level of macroalgae did not represent a problem for the lagoon, and recent increases in the spatial coverage of seagrasses also indicated no problems. As

STEFANO CIAVATTA & ILARIA BEISO

Venice's waterways are a large part of the city's charm (left). The church of Santa Maria della Salute is at the entrance of the Grand Canal (middle). Rising sea level often results in *acqua alta*, or high water—a regular occurrence in Piazza San Marco (right).

a result, the secondary symptom rating was *Low*, which, combined with the *Low* primary symptom rating, gave a *Low* overall eutrophic condition classification.

Even though the watershed population of the lagoon is likely to increase in the near future, the construction of new wastewater treatment plants, decommissioning of factories in the industrial area, and other interventions aimed at controlling nitrogen and phosphorus loads have already been planned and should result in decreased future nutrient loads.

A future challenge for the Lagoon of Venice will be the storm surge flood gates currently being constructed at each inlet. Relative sea level rise has made Venice highly susceptible to flooding. The reduced exchange with the Adriatic Sea will make the lagoon more susceptible to eutrophication symptoms. These flood gates will effectively shut the lagoon off from the Adriatic Sea during periods of high water level to reduce flooding in the city of Venice.

Yucatán Peninsula, Mexico—Groundwater nutrient sources can lead to eutrophication

Coastal lagoons are distributed along the Gulf of Mexico and Caribbean coastlines of the Yucatán Peninsula, a 400,000 km^2 (150,000 mi^2) flat, limestone terrace located in southeast Mexico, with 1,250 km (780 mi) of shoreline. These lagoons provide a variety of socioeconomic services such as fisheries, port facilities, and low- and high-density recreational activities that support important urban areas such as Progreso and Cancún. The ecological and socioeconomic importance of these ecosystems and perceived threats to coastal water quality resulted in their inclusion in ECOPEY (Ecosistemas Costeros de la Peninsula de Yucatán [Coastal Ecosystems of the Yucatán Peninsula]), a long-term ecosystem research and management program of the Mex-LTER program (*www.mexlter.org.mx*) that began in 1994.

The coastal lagoons of the Yucatán are variable in size—the 11 lagoons range from 3 km^2 (1.2 mi^2) to almost 1,500 km^2 (580 mi^2) of water area. The physical characteristics are consistent with lagoons elsewhere. They are very shallow (averaging 1.2 m [3.9 ft]), with a small tidal range (averaging 0.65 m [2.1 ft]), surrounded by mangrove vegetation, and covered with seagrasses. Many have limited connectivity to the ocean and the most important source of freshwater is through groundwater discharges (nine million m^{-3} yr^{-1} km^{-1} of coastline [11 million yd^{-3} yr^{-1} mi^{-1} of coastline]), which is characteristic of this area of karstic limestone where rivers are almost absent. Restricted tidal exchange and variable groundwater discharge lead to water residence times from weeks to years. As a result of variable freshwater inputs, the salinity of individual lagoons varies from oligohaline (low salinity;

inner zone of Celestún and Ascensión) to mesohaline (moderately brackish; middle zone of Celestún), euhaline (ocean-strength salinity; Chelem and Bojórquez), and hypersaline (more saline than ocean water; inner zones of Chelem). Circulation is dominated by wind–tides and seasonal freshwater inflow, and is also influenced by changes in land use of the surrounding watersheds and from circulation pattern modification.

The ecological functioning of the coastal lagoons of the Yucatán Peninsula is strongly influenced by local and regional forcing functions such as the Yucatán coastal current, Cabo Catoche upwelling, and runoff, as well as by pulse events such as hurricanes, groundwater discharge, and cold fronts. The main sources of nutrients to Yucatán coastal waters are from manure, fertilizer, and sewage. Tourism is a major feature of this area (there were about eight million visitors in 2000 to Cancún, Playa del Carmen, and Cozumel).[41] There are four million Yucatán residents, more than half of whom live within the coastal zone, and future increases are expected. The extent of past growth is evident from the total load of nitrogen and phosphorus to Yucatán coastal waters, which has approximately doubled during each of the past two decades (see table, above). However, the primary source of nutrients is from agricultural activities, most notably pig farms which sell primarily to the U.S. market. Manure accounted for

Nutrient loads	1980	1990	2000
Nitrogen	79,100	169,200	309,400
Phosphorus	24,800	64,100	115,600

Estimated loads (metric tonnes yr^{-1}) from Yucatán State in 1980, 1990, and 2000.[24]

Location of the Yucatán Peninsula coastal lagoons

Location of coastal lagoons of the Yucatán Peninsula.

40–50% of the total nitrogen loads and 75–80% of phosphorus loads during the last two decades.

Preliminary results show that on account of high nutrient inputs and long residence times, more than half of the Yucatán coastal lagoons show signs of eutrophication. Under natural conditions, nitrate and silicate concentrations are high in areas with groundwater influence, while phosphate concentrations are typically low. However, in places such as the Yucatán Peninsula, the disposal of wastewater through septic tanks (90%) causes significant increases in ammonium, nitrate, and phosphate concentrations in groundwater, which discharges into and impacts the lagoons. Observed problems include dinoflagellate blooms and high chlorophyll *a* concentrations that discolor the water to the extent that tourism has declined. The spatial coverage of seagrasses (mostly *Halodule wrightii* and *Thalassia testudinum*) has decreased in some lagoons (e.g., Celestún and Chelem Lagoons) and the species composition has changed in others (e.g., Nichupté–Bojórquez). Sediment and nutrient exports to the coastal sea have expanded eutrophic influences beyond lagoonal waters.

A more detailed analysis of eutrophic conditions was done for four coastal lagoons from Yucatán Peninsula (Chelem, Celestún, Nichupté–Bojórquez, and Ascensión Lagoons).

Celestún Lagoon—Groundwater impacts even protected lagoons

Celestún Lagoon comprises an area of 28 km^2 (10.8 mi^2), with a average depth of 1.2 m (3.9 ft). It is an estuarine lagoon (averaging 22 ppt), vertically homogeneous in the main body and stratified in the tidal channel, and is microtidal with a tidal range of around 0.6 m (2 ft). This lagoon is highly susceptible to development of eutrophication problems due to moderately long water residence times (20 days) in the inner zone and the high nitrate inputs (5.7 mg L^{-1} [80 μM]) from groundwater springs that are polluted with waste from pig farms located in the watershed. The lagoon is part of a Biosphere Reserve, where human density is low, and the lagoon supports such activities as tourism, fishing, and salt extraction.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Celestún Lagoon shows few signs of eutrophication.

High chlorophyll *a* and macroalgae resulted in a *High* primary symptom expression. *Low* dissolved oxygen problems combined with *Moderate* seagrass loss and *Low* nuisance and toxic blooms resulted in *Moderate* secondary symptom expression. These symptom expression ratings resulted in *Moderate high* overall eutrophic condition.

Chelem Lagoon— Highly impacted lagoons are eutrophic

Chelem Lagoon has an area of 14 km^2 (5.4 mi^2) and average depth of 0.8 m


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Chelem Lagoon shows many eutrophication symptoms.

(2.6 ft). It is a euhaline system (averaging 35 ppt) and is vertically homogeneous and microtidal with a tidal range of 0.6 m (2 ft). This lagoon is highly susceptible to eutrophication processes due to long water residence times (50 days) and the fact that the watershed is characterized by the highest human population density of the north coast of the Yucatán Peninsula. Additionally, this lagoon receives groundwater nutrient inputs from a polluted aquifer. The most important human activities are tourism, fishing, and urban development.

Moderate chlorophyll *a* and macroalgae resulted in *Moderate* primary symptom expression. *Low* incidences of dissolved oxygen problems combined with *Moderate* seagrass loss and nuisance/toxic blooms resulted in *Moderate* secondary symptom expression. These symptom expression ratings resulted in *Moderate* overall eutrophic condition.

Nichupté–Bojórquez—Small nutrient loads into susceptible lagoons can lead to eutrophication

Nichupté–Bojórquez is a lagoon system comprising an area of 50 km^2 (19.3 mi^2) with an average depth of 0.8 m (2.6 ft). It is a polyhaline lagoon (16–36 ppt) and is vertically homogeneous and microtidal with a tidal range of 0.3 m (1 ft). Long water residence times (100–400 days) make this lagoon highly susceptible to the eutrophication process due to intense Cancún tourism and development within the watershed. Although there are seagrasses covering the lagoon bottom, the leaves are covered with epiphytes which is strong evidence of eutrophic impact.

Moderate chlorophyll *a* and *High* macroalgae resulted in *High* primary symptom expression. *Moderate* dissolved oxygen problems combined with *Moderate* seagrass loss and *Low* nuisance and toxic blooms resulted in *Moderate* secondary symptom expression. These symptom

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Nichupté Lagoon, with the adjacent tourist center of Cancún, shows eutrophication signs.

expression ratings resulted in *Moderate high* overall eutrophic condition. This suggests that even small nutrient loads into lagoons with long residence times can have significant impacts.

Bahía de la Ascensión—Protected lagoons are less eutrophic

Bahía de la Ascensión, located inside the Biosphere Reserve Sian Ka'an, comprises an area of 740 km^2 (286 mi^2), with an average depth of 2.5 m (8.2 ft) and estuarine salinity (3–33 ppt). This lagoon is vertically homogeneous and microtidal with a tidal range of 0.5 m (1.6 ft). This system has moderate susceptibility to eutrophication due to long residence times (100 days), despite high exchange with the ocean through a wide inlet. The human population density in the surrounding watershed is very low and the main activities are ecotourism and fishing.


SARA MORALES-OJEDA

Bahía de la Ascensión has low overall eutrophic condition, likely a result of low population density.

Low chlorophyll *a* and *Moderate* macroalgae resulted in *Low* primary symptom expression. *Low* occurrences of dissolved oxygen problems, seagrass loss, and nuisance and toxic blooms resulted in *Low* secondary symptom expression. These symptom expression ratings resulted in *Low* overall eutrophic condition, likely the result of low population density and thus low associated nutrient loads.

Lagoons are unique coastal features that are found along coastlines all over the world, parallel to the coast but separated from the ocean by a barrier island or sand spit. They are usually shallow and well mixed with restricted connectivity to ocean waters and often have limited freshwater inflow. They support very productive fisheries and their attraction as summer destinations results in seasonal watershed population increases of many times the resident population.

Natural characteristics, particularly the long water residence times, make these systems sensitive to nutrient inputs from human-related activities

Coastal lagoon	**Surface area (km^2)**	**Avg. depth (m)**	**Salinity range (ppt)[1]**	**Avg. residence time (days)**	**Chl *a* conc.[2] Annual avg. bloom conc.[3] (µg L^{-1})**
Celestún	28	1.2	5–39	20	6 30
Chelem	14	0.8	20–44	50	4 20
Nichupté	48	2.0	16–36	100	1 10
Bojórquez	2.5	1.5	23–34	400	0.8 10
Bahía de la Ascensión	740	2.5	3–33	100	0.5 5

Characteristics of the Yucatán coastal lagoons discussed in this chapter. All these lagoons have groundwater as the primary freshwater source.

1. Minimum–maximum salinity range.
2. Chlorophyll *a* concentrations (annual average).
3. Annual bloom chlorophyll *a* concentrations (annual average).

Lagoon	**Overall eutrophic condition**	Primary symptoms		Secondary symptoms		
		Chlorophyll *a*	Macroalgae	Dissolved oxygen	Nuisance/ toxic blooms	Seagrass loss
Great South Bay	🟠	🔴	🔴	🔵	🟡	⚪
Barnegat Bay	🔴	🔴	🔴	🔵	🔴	🟢
New Jersey Inland Bays	🔴	🔵	🔴	🔵	🔵	🔴
Delaware Inland Bays	🟡	🟡	🔴	🔵	🔵	🔵
Northern MD Coastal Bays	🟡	🔴	🟡	🔵	🔵	🔵
Southern MD Coastal Bays	🔴	🔴	🟡	🔵	🔴	🔵
Indian River	🟡	🔵	🟡	🔵	🟡	🔵
Biscayne Bay	🟢	🔵	🔵	🟡	🔵	🔵
Florida Bay	🟡	🔴	⚪	🔵	⚪	⚪
Sarasota Bay	🟠	🔴	🔴	🔵	🟡	🔵
Apalachicola Bay	🟡	🟡	🔵	🔵	🟡	🔵
Choctawhatchee Bay	🔵	🔵	⚪	🔵	⚪	⚪
Pensacola Bay	🟢	🟡	⚪	🔵	⚪	⚪
Perdido Bay	🔴	🔵	🟡	🔴	🔵	🔵
Galveston Bay	🟢	🔴	🔵	🔵	🔵	🔵
Matagorda Bay	🟡	🔴	🔵	🔵	🔵	🔵
San Antonio Bay	🟡	🔴	⚪	🔵	⚪	⚪
Corpus Christi Bay	🟡	🔴	🔴	⚪	🔵	⚪
Upper Laguna Madre	🟡	🟡	⚪	⚪	🟡	⚪
Tijuana Estuary	🟢	🟡	🟡	🔵	🔵	🔵
Ria Formosa	🟡	🔵	🔴	🔵	🔵	🔵
Lagoon of Venice	🔵	🔵	🔵	🔵	🔵	🔵
Celesún Lagoon	🟠	🔴	🔴	🔵	🔵	🟡
Chelem Lagoon	🟡	🟡	🟡	🔵	🟡	🟡
Nichupté–Bojórquez Lagoon	🟠	🟡	🔴	🟡	🔵	🟡
Bahía de la Ascensión	🔵	🔵	🟡	🔵	🔵	🔵

Overall eutrophic condition

- 🔴 High
- 🟠 Moderate high
- 🟡 Moderate
- 🟢 Moderate low
- 🔵 Low

Primary & secondary symptom expression

- 🔴 High
- 🟡 Moderate
- 🔵 Low
- ⚪ Unknown

This table summarizes the early-2000s overall eutrophic condition, including primary and secondary symptoms, for the 20 coastal lagoons in the United States with sufficient data for analysis, and the global case studies considered in this chapter.

and modifications of the watershed. The symptoms and progression of eutrophication is similar among lagoons globally, as are the impacts to water quality and human uses. While relatively unimpacted lagoons are known to support fisheries that rival those of known fishing areas (e.g., Georges Bank and the Peruvian Upwelling), productivity in lagoons around the globe has declined as a result of nutrient increases that have caused excessive macroalgal blooms, occurrences of nuisance and toxic algal blooms, losses of seagrasses, and there is some evidence that dissolved oxygen is an emerging problem in some lagoons despite the well-mixed water column.

Measures to protect lagoons from further degradation include limiting nutrient inputs through traditional management strategies such as sewage treatment and agricultural best management practices. Traditional measures may be complemented by alternative measures within the waterbody such as the restoration of shellfish beds or implementation of aquaculture projects.

* * *

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12. Dynamic Systems at the Land–Sea Interface

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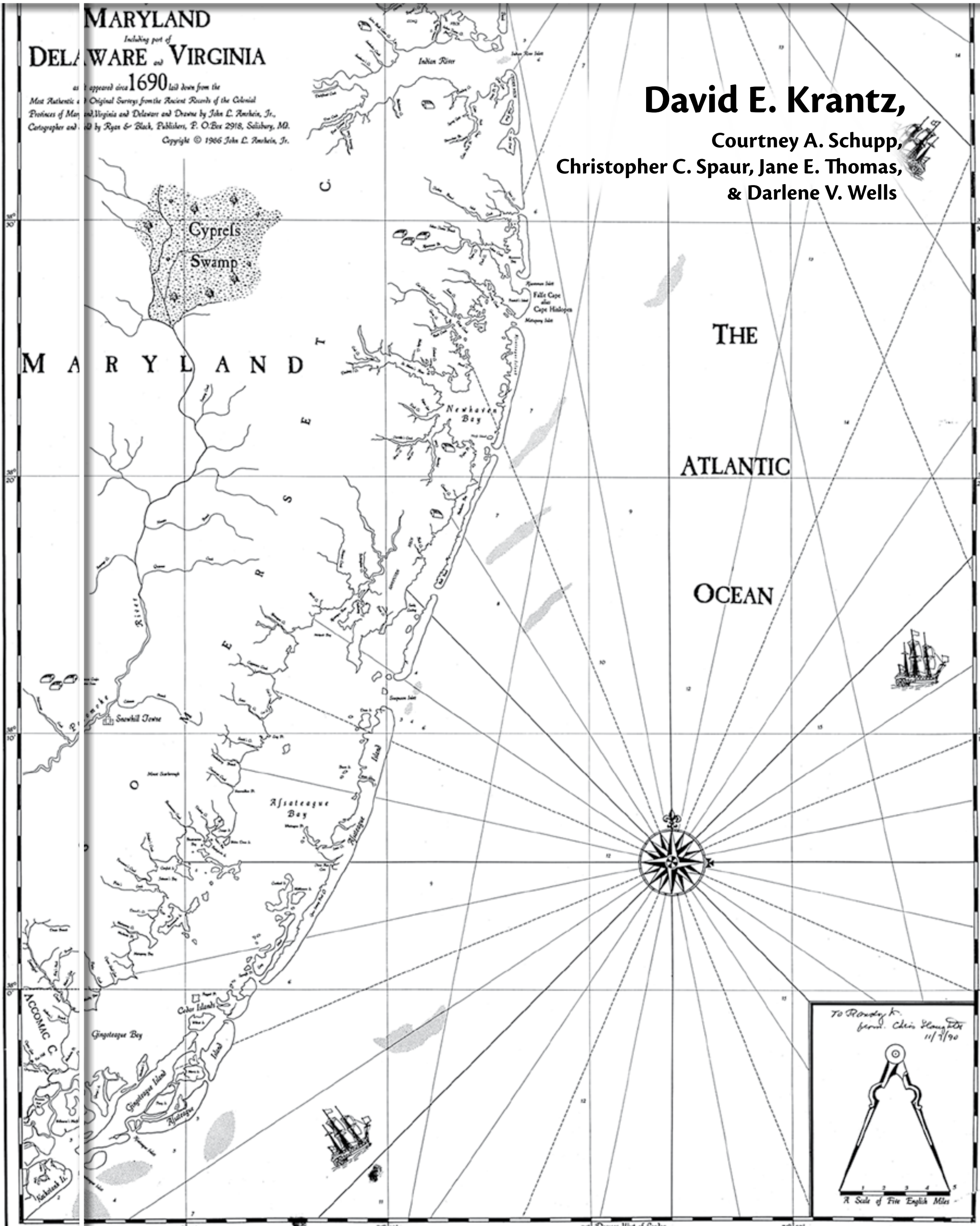
Courtney A. Schupp,
Christopher C. Spaur, Jane E. Thomas,
& Darlene V. Wells

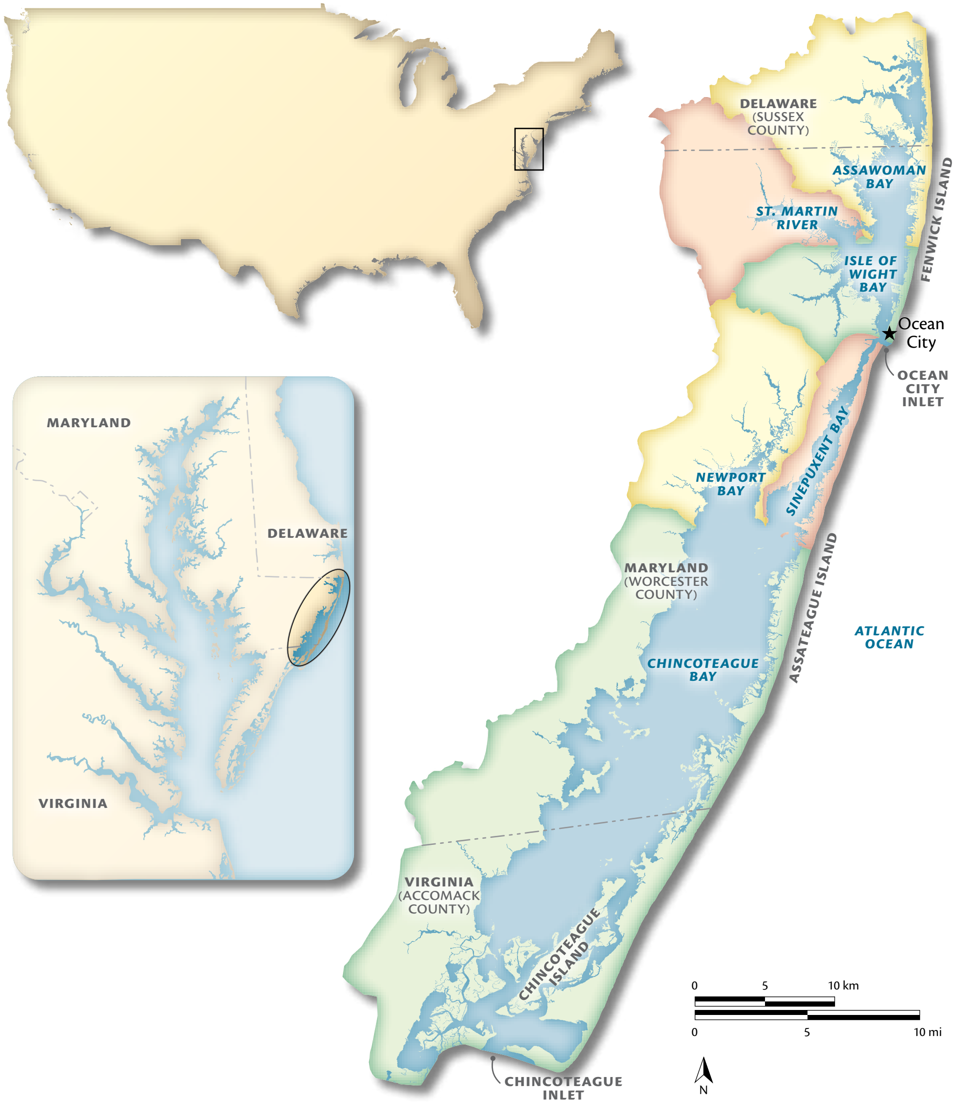


THE PHYSICAL SETTING OF THE COASTAL BAYS

The Coastal Bays are on the Atlantic Coastal Plain

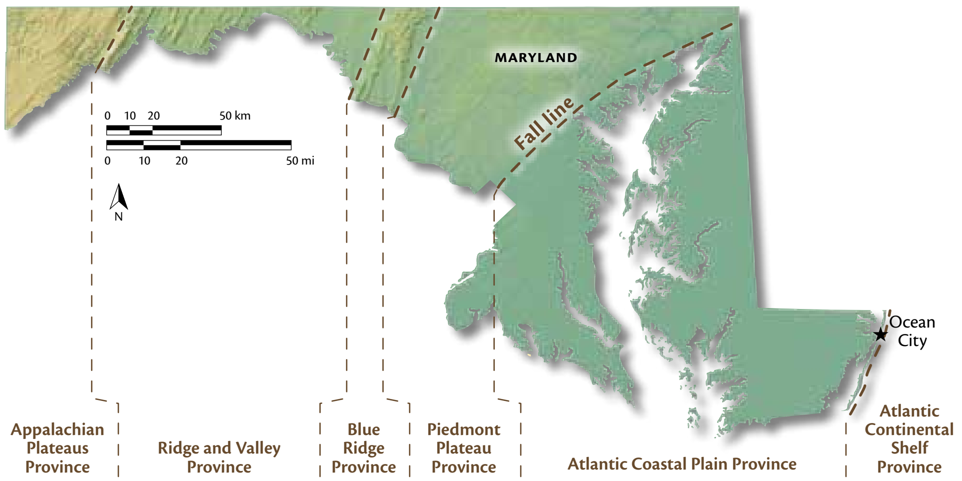
The Maryland Coastal Bays are coastal lagoons that lie east of the mainland of Worcester County, Maryland, adjacent to the Atlantic Ocean and behind the barrier islands of Fenwick Island (Ocean City) and Assateague Island. Stretching from the Maryland–Delaware state line south into Virginia, the bays include Assawoman, Isle of Wight, Sinepuxent, Newport, and Chincoteague Bays. The bays and their Maryland watershed encompass 453 km^2 (175 mi^2) in a narrow strip east of the Pocomoke River watershed. This coastal zone is critical

Location of Maryland's Coastal Bays



The Maryland Coastal Bays are located on the Mid-Atlantic coast of the United States.

Physiographic provinces of Maryland

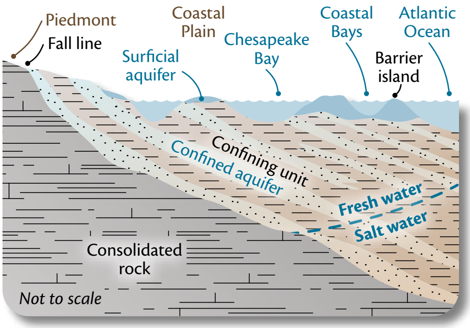


Six regional physiographic provinces run through Maryland, each with a distinct landscape character and geologic history. The Fall Line coincides with a break in slope of the rivers, and marks the boundary between the Piedmont Plateau and Atlantic Coastal Plain provinces. The Coastal Bays lie along the eastern edge of the Coastal Plain.

habitat for migratory shorebirds and waterfowl, many important commercial and recreational finfish and shellfish species, and numerous rare and threatened plant and animal species. For more information on the Coastal Bays' living resources, see Chapter 14—*Diversity of Life in the Coastal Bays*.

The Coastal Bays and their watersheds are located along the Atlantic coast of the Delmarva Peninsula on the eastern edge of the Atlantic Coastal Plain province. The Coastal Plain is characterized by a low and flat landscape underlain by unconsolidated or only partially consolidated sediments such as gravel, sand, silt, and clay. (*Unconsolidated* sediments are those near the land surface that have not been cemented together or compacted by deep burial.) If viewed in cross section, the layers of sediment that underlie the Coastal Plain would appear to be wedge shaped, thinnest in the west and expanding to almost 2.4 km (1.5 mi) thick at the Atlantic coastline.

Cross section of the Atlantic Coastal Plain

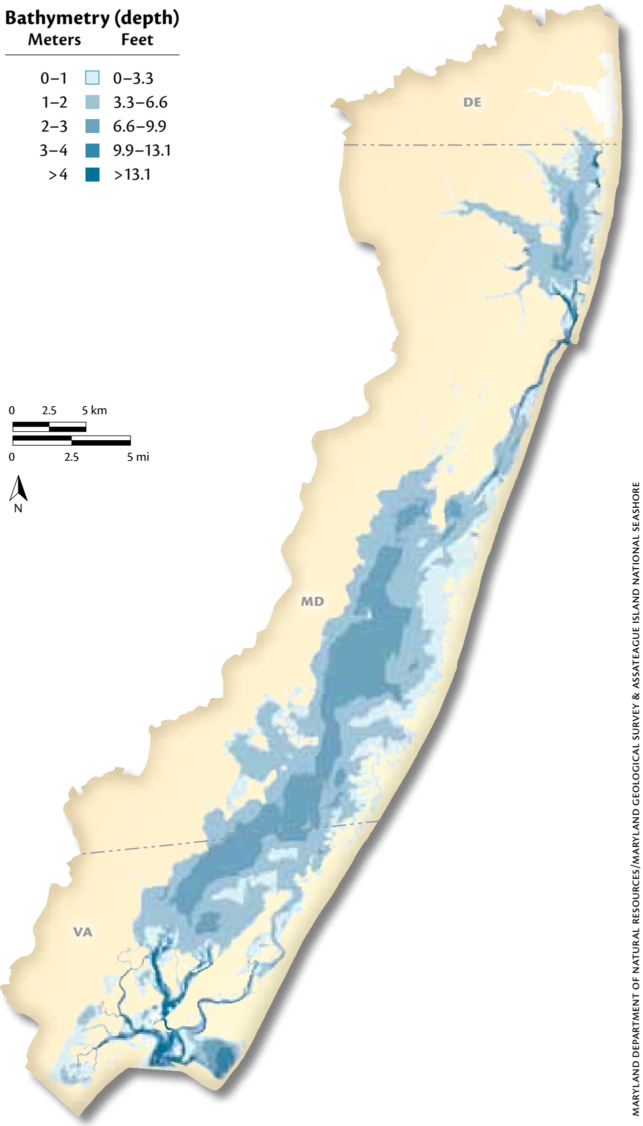


Conceptual cross section of the Atlantic Coastal Plain aquifer system in southern Maryland.[40] The cross section runs approximately northwest to southeast.

The Coastal Bays are shallow & flushed by two inlets

The Coastal Bays are shallow, averaging 1–1.2 m (3.3–3.9 ft) deep, except in the navigation channels and inlets. A sandy subtidal flat less than 1 m (3.3 ft) deep created by storm overwash extends as much as 2 km (1.2 mi) westward into the bays from the barrier islands. Wind blowing across the shallow open waters of the bays results in mixing of the water column, meaning that dissolved oxygen levels usually remain high in open-water areas. Surface water input from streams to the Coastal Bays is relatively low because of small contributing watersheds (approximately twice the size of the lagoons themselves) and common sandy soils that allow rapid infiltration of rainwater. Consequently, groundwater is an important source of freshwater inflow to the bays.

Tidal exchange with the Atlantic Ocean is limited to two inlets—the Ocean City Inlet in Maryland and Chincoteague Inlet in Virginia, south of Chincoteague Island. Flushing rates, or water residence times, have been estimated from as short as nine days for Isle of Wight Bay, to as long as 63 days for Chincoteague Bay.[23,37]



Bathymetry (depth) of the Coastal Bays in Maryland (2000–2003) and Virginia (2007).

MARYLAND DEPARTMENT OF NATURAL RESOURCES/MARYLAND GEOLOGICAL SURVEY & ASSATEAGUE ISLAND NATIONAL SEASHORE

PROCESSES SHAPING THE COASTAL BAYS

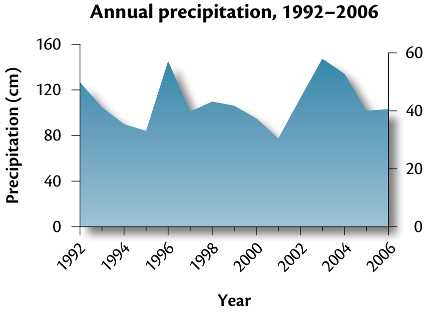
The Coastal Bays are products of modern processes & geologic history

The present Coastal Bays have evolved over approximately the last 5,000 years behind the barrier islands in response to slow, gradual sea level rise. However, in a dynamic coastal environment, the physical factors that sculpt the protecting barrier islands and control the hydrologic characteristics of the bays vary over time scales from twice-daily high and low tides and the two-week cycle of spring and neap tides, up to decadal and centennial changes in the frequency and intensity of coastal storms and wave climate. The greatest changes to the coastal system occur during a few intense storm events that last only a few days but may alter the shape and function of the islands and bays for the next several decades.

Coastal storms have a large impact

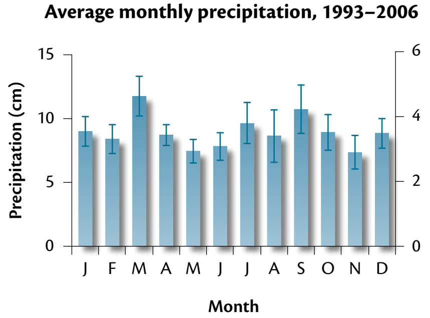
Meteorological events such as coastal storms exert considerable influence on circulation, sediments, and water chemistry within the Coastal Bays. The most significant weather effects are brought about by transient cyclonic (low-pressure) or anti-cyclonic (high-pressure) systems. Anti-cyclonic systems, characterized by high barometric pressure and clockwise, outward circulation, usually produce fair, clear weather in Maryland. Cyclonic systems, or low barometric-pressure cells, are the storms. These are more defined, with greater energy and intensity than the anti-cyclonic systems.

Weather fronts generally move through the region from the west; however, coastal storms have the greatest impact on the Coastal Bays, and the strongest winds from these storms usually blow from the east and northeast. A typical path for extratropical storms—those that form outside of the tropics—is to develop as a low off Cape Hatteras, North Carolina, and then intensify and track northward



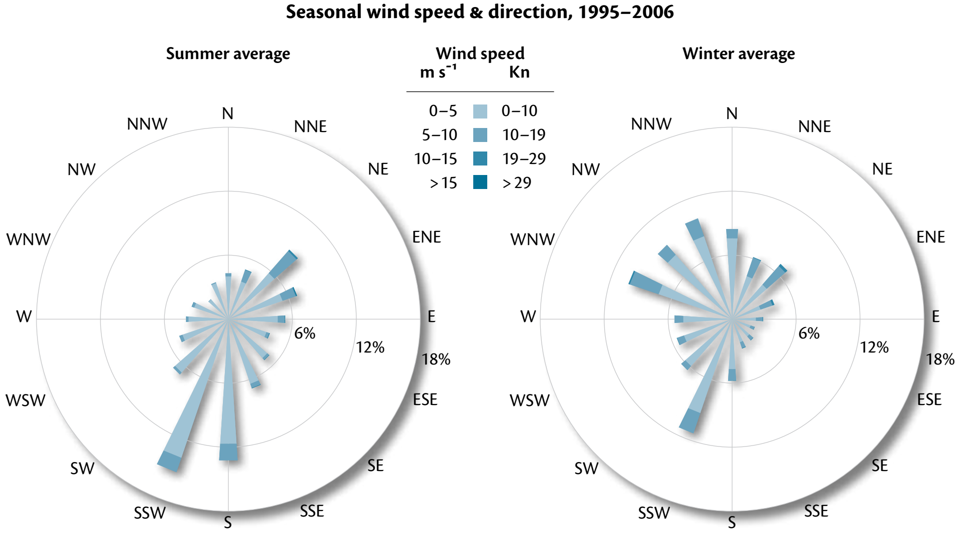
BUREAU OF LAND MANAGEMENT/ASSATEAGUE ISLAND NATIONAL SEASHORE, REMOTE AUTOMATED WEATHER STATION ASTM2

Precipitation in the Coastal Bays watershed varies year by year but averages around 43 in per year. These data are from the weather station approximately halfway along Assateague Island.



NATIONAL WEATHER SERVICE

Monthly average (and standard error) of precipitation for the Maryland coast for the period 1993–2006.

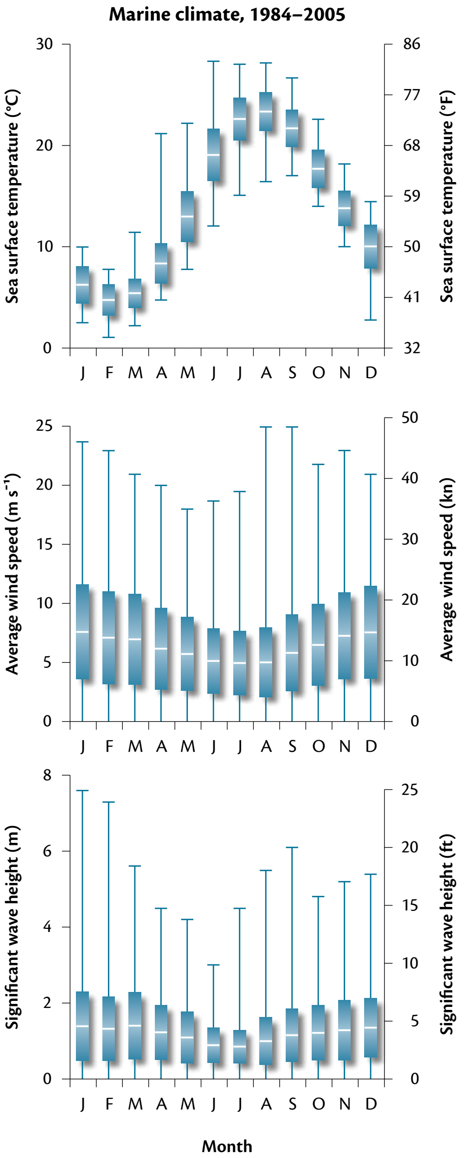


BUREAU OF LAND MANAGEMENT/ASSATEAGUE ISLAND NATIONAL SEASHORE, REMOTE AUTOMATED WEATHER STATION ASTM2

Summer winds are generally out of the southern sector, while in winter, the prevailing winds are from the west. Data are from Assateague Island. For summer, the average was taken from June 21–September 21. For winter, the average was taken from December 21–March 21.

parallel to the Mid-Atlantic coast. Tropical storms such as hurricanes most commonly approach the region from the south or southwest.

In the summer, mild to moderate prevailing winds driven by the Bermuda High usually blow from the south and southeast, producing gentle waves along the ocean coast and in the Coastal Bays. The most intense summer cold fronts sweeping through the area produce lines of thunderstorms with strong circulation generally from the southwest. Strong southwesterly winds blowing up the axis of Chincoteague Bay can create substantial waves (> 1.2 m or 4 ft, in many cases) that thoroughly mix the water column. In the fall, passing cold fronts often will be followed by several days of stiff northerly to northwesterly winds generated by the trailing high-pressure system.



Marine climate for the Atlantic Ocean off the Maryland coast. Data show the median value, first and third quartiles, and lowest and highest values.[32]

Over the past century, the most powerful storms to impact the Maryland coast have been the nor'easter storms. These extratropical storms occur most frequently in late fall (October–November) and early spring (February–March), and generally approach from the south. As the storm moves north along the coast with winds circulating counterclockwise, it produces the highest winds and most damaging waves from the northeast—hence their name, 'nor'easters.'

The wind and wave climate along the Maryland coast has a distinct seasonality. The highest average wind speeds, corresponding to the largest significant wave heights, typically occur in the fall, winter, and early spring. (The *significant wave height* is the average height of the largest one-third of the waves in a particular sea state. These waves contain the majority of the wave energy.) Winds and waves abate, and shift to a more southerly direction, from mid-May through mid-August.

Summaries of two long-term records from instrumented stations off the Maryland coast show that winds of gale force or higher impact the region about one-half of one percent of the time, which is equivalent to two to four storms per year. Offshore waves during these events may rise to greater than 4 m (13 ft) up to nearly 7.5 m (25 ft).[32] However, as waves approach shore and move into shallower

Wind speed (knots)	Beaufort scale name	Percentage of observations offshore[1]
0	Calm	1.0
1–3	Light air	5.3
4–6	Light breeze	14.0
7–10	Gentle breeze	25.2
11–15	Moderate breeze	25.4
16–20	Fresh breeze	17.9
21–24	Strong breeze	6.8
25–33	Near gale	4.2
34–47	Gale to strong gale	0.3
> 48	Storm	< 0.1
> 64	Hurricane	≪ 0.1

Annual distribution of wind speed, Atlantic coast of Maryland.

1. NOAA data buoy 44009, 30 km (18.5 mi) east of Fenwick Island at the DE–MD state line in 28 m (92 ft) of water; period of record 1984–2005.

water, friction with the bottom releases energy and reduces wave height. The beach at Ocean City is hit with waves above 3.5 m (11.5 ft) height about once every 10 years, and extreme waves greater than 4.5 m (15 ft) once every 50 years.[47]

The two storms with the greatest impact on the Maryland coast during the 20th century were a hurricane in 1933 and a nor'easter in 1962. The slow-moving Ash Wednesday nor'easter, as it is known, pounded the entire Mid-Atlantic coast from March 6–8, 1962. This storm coincided with an extra-high spring tide, produced a storm surge of 2.7 m (9 ft) above mean low water, and lasted through five successive high tides. Sustained gale-force winds of 72 km hr^{-1} (45 mi hr^{-1}) with gusts of 105 km hr^{-1} (65 mi hr^{-1}) were reported by the Coast Guard Station in Ocean City. This single storm extensively damaged coastal communities from Long Island, New York, through Virginia, and completely reshaped the barrier islands of the Delmarva coast.[45]

Almost every property in Ocean City suffered some type of damage, from accumulation of sand and debris to total destruction of buildings. Flooding occurred from both the ocean and bay sides and the elevated water level allowed waves to wash over large sections of the barrier islands. Both Fenwick and Assateague Islands were breached in numerous places. Since 1962, Ocean City has not experienced any storms that have approached the intensity and duration of the Ash Wednesday storm.

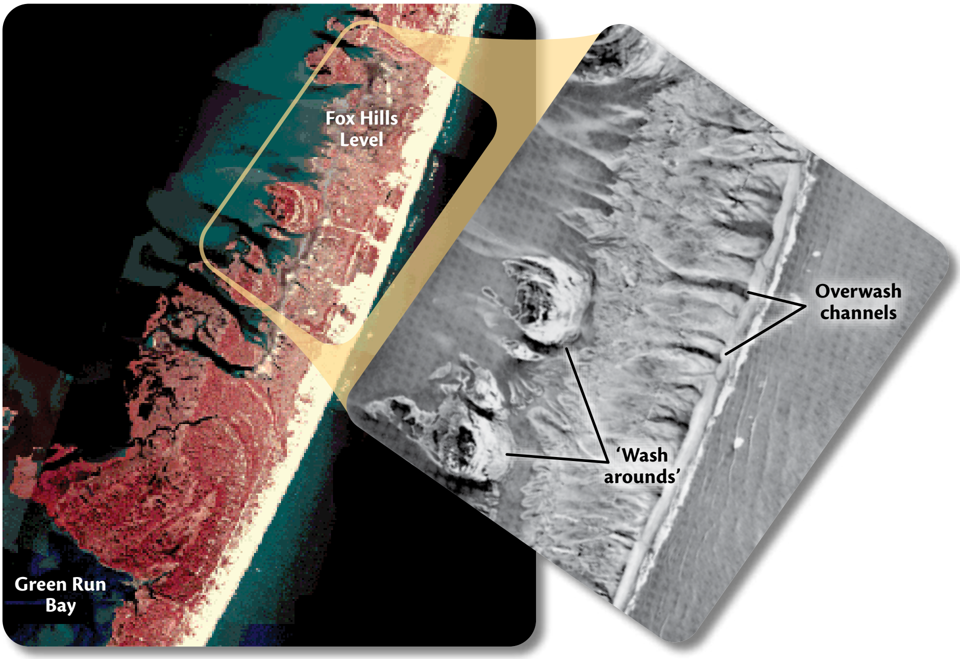
Unlike extratropical storms, which form in the mid-latitudes during the

Range of wave height (m)	Range of wave height (ft)	Percentage of observations offshore[1]	Percentage of observations nearshore[2]	Recurrence interval (years) for nearshore[3]
0.0–0.4	0.0–1.3	5.2	31	
0.5–1.4	1.5–4.6	69.5	61	1
1.5–2.4	4.9–7.9	20.0	7.1	2
2.5–3.4	8.2–11.2	3.8	0.9	3–7
3.5–4.4	11.4–14.4	1.1	< 0.1	10–25
4.5–5.4	14.7–17.7	0.2	≪ 0.1	50 or greater
5.5–6.4	17.9–21.0	0.1	—	
6.5–7.4	21.2–24.3	0.1	—	

Annual distribution of wave height along the Atlantic coast of Maryland.

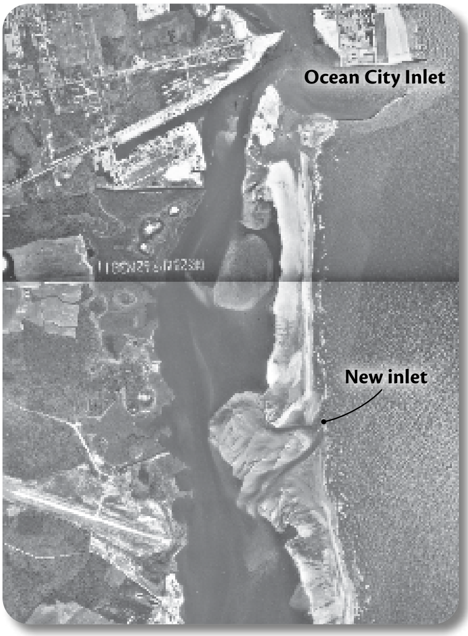
1. NOAA data buoy 44009, 30 km (18.5 mi) east of Fenwick Island at the DE–MD state line in 28 m (92 ft) of water, period of record 1984–2005.
2. U.S. Army Corps of Engineers wave gauge MD002, approximately 1 km (0.6 mi) off Ocean City, Maryland, in 9 m (30 ft) of water; period of record 1993–2001.
3. Calculated by U.S. Army Corps of Engineers, refer to *http://sandbar.wes.army.mil*, station MD002.

Overwash channels & ‘wash arounds’ created during the 1962 storm



Aerial photo of Assateague Island, showing the overwash channels and ‘wash arounds’ created by the 1962 nor’easter storm. Photo mosaic at left from Assateague Island National Seashore; aerial photo on right modified.[12]

Inlet formed after 1962 storm



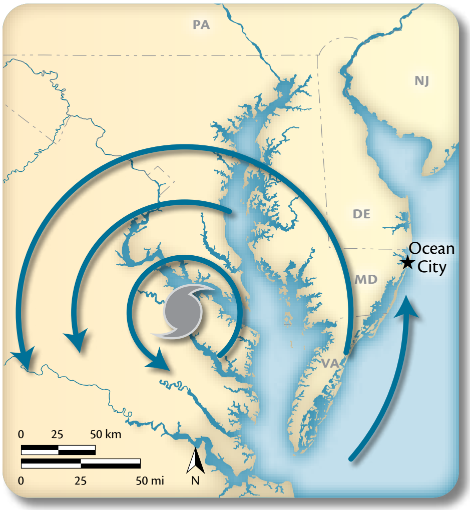
NATIONAL OCEAN SERVICE, NOAA

April 28, 1962. Visible here is the inlet breaching northern Assateague Island that was created by the nor’easter of March 1962.

winter months, hurricanes are cyclonic depressions that originate in the tropical latitudes during the months of July through November. Before reaching the Maryland coast, hurricanes usually lose much of their power and are downgraded to tropical storms or tropical depressions.

Although hurricanes are more severe than nor’easters, they occur less frequently. Studies have shown that during the mid-to-late 20th century, hurricanes crossed the coast (i.e., the storm eye made landfall) between Barnegat, New Jersey, and the southern tip of Assateague Island less frequently than any other area along the U.S. Atlantic coast.[12] Even though the Maryland coast has suffered few direct hits from hurricanes, even near-misses create large waves and storm surge that drive seawater through the inlets and over the barrier islands into the Coastal Bays.

The hurricane of 1933—which made landfall across the Virginia coast just south of the Chesapeake Bay mouth and moved through Maryland west of Chesapeake Bay—caused the greatest damage to the Maryland coast recorded up to that time. Although of shorter duration than the 1962 nor'easter, the 1933 hurricane was much more intense. Winds during the 1933 hurricane were reported to be 160 km hr^{-1} (100 mi hr^{-1}) with nearshore waves 6 m (20 ft) high. During the storm, Fenwick Island was breached, forming the current Ocean City Inlet, which was stabilized with jetties soon after the storm and maintained since then by the U.S. Army Corps of Engineers. The stable inlet at Ocean City fundamentally altered the Coastal Bays ecosystem, especially for Isle of Wight and Assawoman Bays and St. Martin River, which previously were fresher but poorly flushed.


Storms that track west of the Coastal Bays

Storms that track west of the Coastal Bays can produce a storm surge by pushing water into the Coastal Bays, due to the counter-clockwise rotation of the storm.

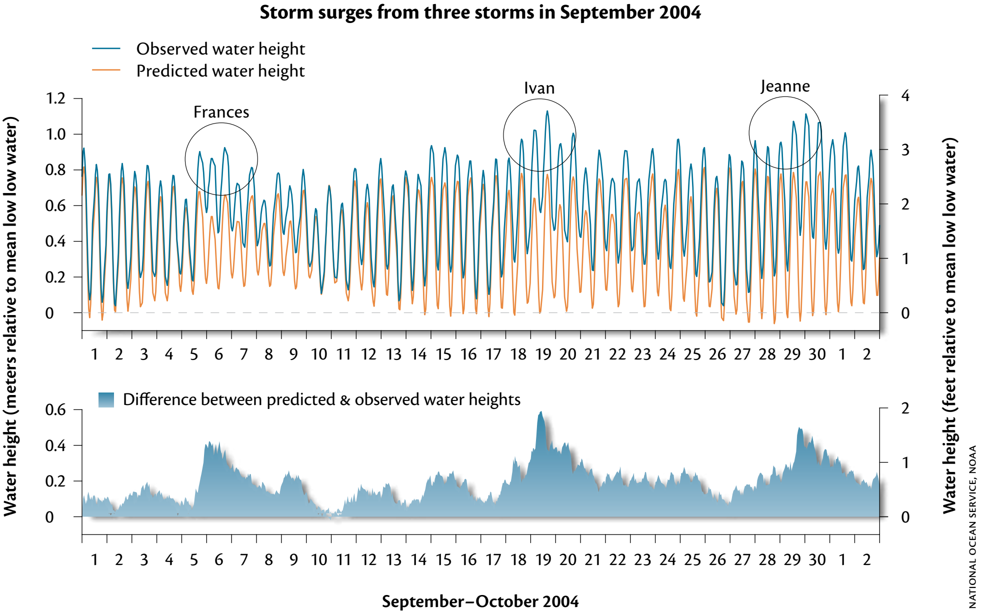
Meteorological events cause storm surge

Storm surge—also called a storm tide or hurricane tide—is the rise in water level in the ocean and bays above normal level due to the piling up of water against the coast by the strong winds accompanying a hurricane or intense storm. Reduced atmospheric pressure, particularly the extreme low associated with the center of a hurricane, contributes to the surge. The magnitude of the surge depends on several factors: the size, intensity, and the track and speed of the storm; the shape of the coastline; nearshore topography; and the astronomical tide stage. A storm surge is potentially catastrophic, especially if landfall coincides with high tide and is accompanied by extremely high wind-driven waves. Worldwide, most hurricane deaths are caused by the storm surge.

Storm surge height is typically measured as the sea level height observed during the storm above the normal sea level height. Storm surges of 3–4 m (10–13 ft) are common for moderate, Category 1 or 2 hurricanes. Recent extreme storm surges include a 6-m (20-ft) surge during Hurricane Hugo striking South Carolina in 1989, and the devastating 8-m (26-ft) surge generated by Hurricane Katrina along sections of the Louisiana and Mississippi coast in 2005.

The strongest winds of a hurricane are typically in the northwest quadrant, and a storm moving from southeast to northwest can push a large wall of water (the storm surge) ahead of it. The most damaging hurricane that could impact the Maryland coast would approach slowly from the southeast, creating the maximum surge and striking the coast almost at a right angle. Most Atlantic hurricanes over the last decade stayed out to sea, passing the Maryland coast, or made landfall in North Carolina or Virginia and tracked west of the Coastal Bays.

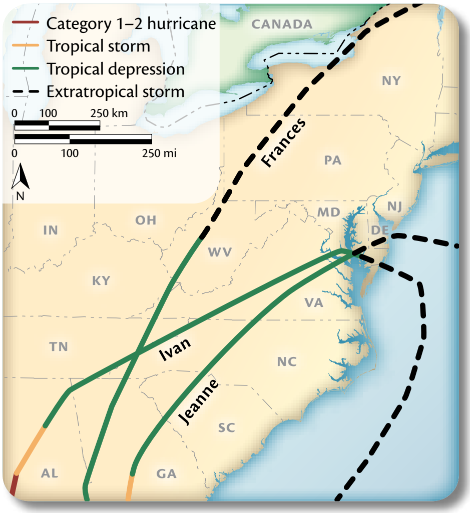
In September 2004, tropical storm remnants of three hurricanes (Frances, Ivan, and Jeanne) all tracked west of the Coastal Bays, but still caused widespread flooding from storm surge. Due to the counter-clockwise circulation of hurricanes, even when they travel west of the bays, strong southerly winds along the Atlantic coast push seawater through the inlets into the bays.



NATIONAL OCEAN SERVICE, NOAA

Storm surge from three storms that affected the Coastal Bays during September 2004. Data are from NOAA tide gauge station #857-0283, located in Isle of Wight Bay at the Ocean City Inlet.

Storm tracks of three 2004 hurricanes

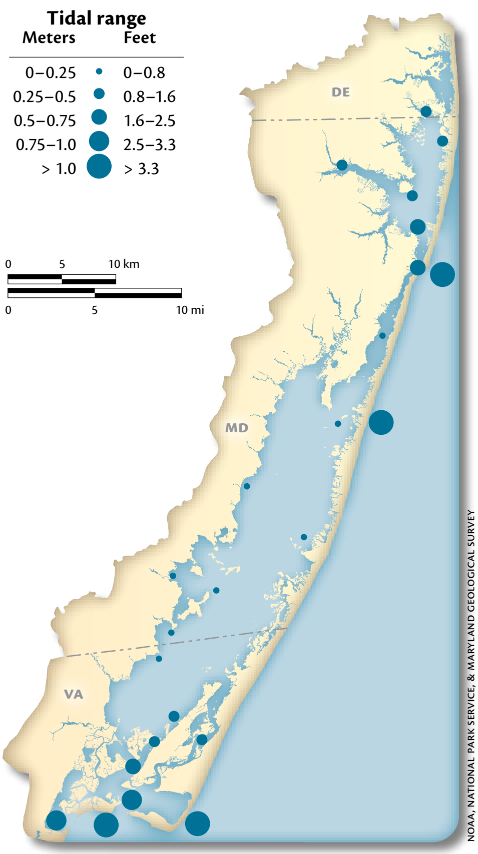


Storm tracks of the three storms—Frances, Ivan, and Jeanne–that tracked west of the Coastal Bays in September 2004.

Wind events influence the Coastal Bays more than astronomical tides

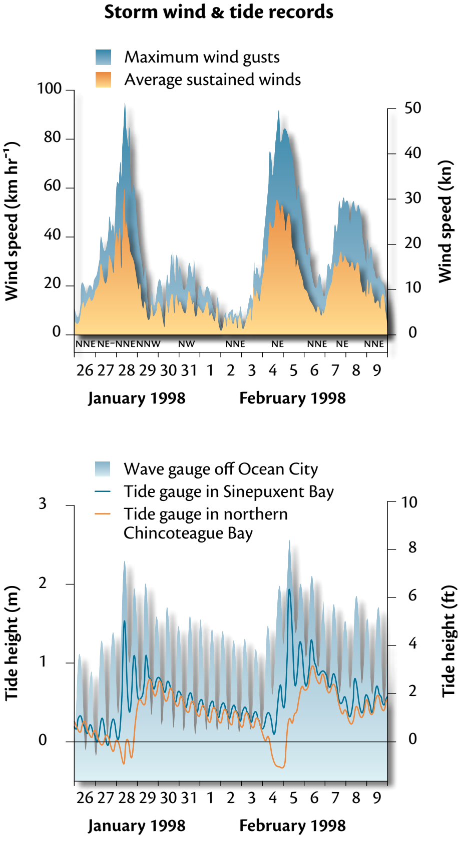
The Maryland coast is classified as microtidal, with a tidal range in the ocean less than 1.5 m (4.9 ft). (*Tidal range* is the elevation difference between high tide and low tide.) The tidal range near the two inlets is a little more than 1 m (3.4 ft), and diminishes rapidly with distance from the inlets. The range drops to 45 cm (17.7 in) in Assawoman Bay, and 12 cm (4.7 in) in central Chincoteague Bay. Because the Coastal Bays are shallow with a very small tidal range, tidal currents are relatively weak except near the inlets, and wind events influence the bays more than the astronomical tides.

When strong winds blow persistently for a day or more over the open water of the bays, the wind stress, or friction of the wind with the water surface, both creates waves and transports the water downwind. Besides the direction, duration, and intensity of the wind, the *fetch*—or the distance over open water that the wind blows—controls the response of water level in the bays. For example, the long axis of the connected Chincoteague and Sinepuxent Bays trending southwest to northeast is nearly 50 km (31 mi) long, but Chincoteague Bay is only 6–8 km (3.6–4.2 mi) wide in most areas. Consequently, wind blowing from the



NOAA, NATIONAL PARK SERVICE, & MARYLAND GEOLOGICAL SURVEY

Tidal range in the Coastal Bays and the adjacent Atlantic Ocean. The Coastal Bays are microtidal.



REMOTE AUTOMATED WEATHER STATION

NOAA, NATIONAL PARK SERVICE, & U.S. ARMY CORPS OF ENGINEERS

Wind and water levels in the Coastal Bays during two nor'easter storms in the winter of 1998.[39]

northeast gains a lot of traction and will push the water in the bay to the south—similarly, southwesterly winds pile up water in northern Chincoteague Bay.

The effect of storm winds on bay water is seen in the wind and water-level records from two nor'easters in 1998. During the first day of each storm, the water level in the ocean and measured at Ocean City Inlet rose above the predicted tidal height by as much as 1.5 m (4.9 ft). However, at the same time, the water level in northern Chincoteague Bay dropped dramatically, as the bay water was transported to the south, and did not rise until the storm passed and the northeasterly winds weakened. Although there are no tide-gauge data from the southern part of Chincoteague Bay for these events, the water levels most likely rose by at least 0.5 m (1.6 ft) during the peaks of the storms.

These wind events enhance the otherwise sluggish exchange of water between the Coastal Bays and the coastal Atlantic Ocean as a large volume of ocean water is driven through the inlets into the bays during the storm, and bay water exits to the ocean as the storm recedes. Wave action in the bays produces opposing effects on water chemistry—air bubbles in white caps and breaking waves oxygenate the water column, but at the same time anoxic sediments are stirred up from the bay floor, releasing chemically reduced compounds as well as nutrients such as ammonium and phosphate.

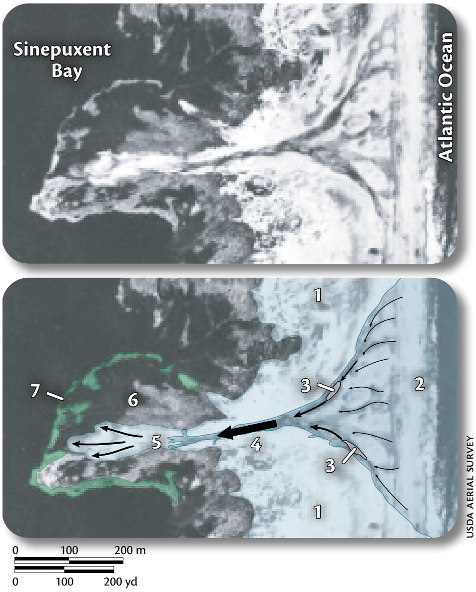
Winds between 20 and 33 knots—stronger than a fresh breeze but below gale force—occur about 11% of the time along the Maryland coast and may be associated with the passage of weather fronts or low-pressure systems. Typically, these moderately strong winds, especially if sustained for more than six hours from a constant direction, are capable of producing whitecaps and churning up fine sediments from the bay floor over most of the Coastal Bays; however, there have been few systematic studies of these processes in the Coastal Bays. The high turbidity from these wind events may persist for one to two days after the winds abate. When accompanied by elevated water levels, these more-frequent, moderately strong wind events also contribute to the erosion of tidal marshes by wave attack along the outer edge of the marsh and undercutting of the root mat.

Barrier islands protect the Coastal Bays

Assateague and Fenwick Islands protect the Coastal Bays and mainland Maryland from major storms and some of the impacts of sea level rise. The barrier islands absorb much of the energy of waves and currents produced by storms before they reach the bays and mainland. However, in extreme storms, the combination of elevated water level and large waves in the ocean result in the overwash of sections of the barrier island. Low-lying areas of the islands are particularly susceptible and may be breached to form a new tidal inlet. A view of central Assateague Island following the 1962 storm shows the after-effects of 1–2 m (3.3–6.6 ft) of seawater driven by waves flowing across Fox Hills Level. Nearly 45 years later, the channels, storm ridges, and 'wash-arounds' created by that event are still visible on the island.

During major storms, large quantities of sand from the beach and shoreface (the innermost shelf) are transported over the island and deposited on the back-barrier flat and in the bays. Overwash may be extensive, as seen after the 1962 storm, or more localized in overwash fans. Wind blowing across the emergent back-barrier overwash flats before plant cover is re-established may rework the sand to create low dunes on this otherwise remarkably flat surface. Over time, the overwash process builds up the height of the island and creates the shallow platform for tidal marshes and subtidal flats along the eastern edge of the Coastal Bays.

Overwash system on Assateague Island



USDA AERIAL SURVEY

1. Extent of overwash from most recent storm.
2. Catchment area for channelized overwash.
3. Deeply scoured section of overwash channel.
4. Convergence of overwash flow.
5. Distributary flow and deposition to form fan.
6. Washover fan from previous storms.
7. Reworking of washover sands by waves.

An individual overwash system on northern Assateague Island created by a coastal storm.

On time scales of hundreds to thousands of years with gradual sea level rise, overwash and the opening and closing of inlets allow the barrier islands to roll over and migrate landward. Development on Fenwick Island and construction of artificial dunes has effectively prevented overwash and sand deposition on the bay side of the island since the mid-1970s.

The Fenwick Island beach has been maintained by the state and U.S. Army

Corps of Engineers since the late 1980s through beach nourishment measures. Sand dredged from offshore shoals in the Atlantic Ocean now provides the source of sand for longshore transport along Fenwick Island. About 610,000 m^3 (800,000 yd^3) are placed on Fenwick Island from these sources every four years.[48]

GEOLOGY & HYDROLOGY OF THE COASTAL ZONE

Sand moves along the coast

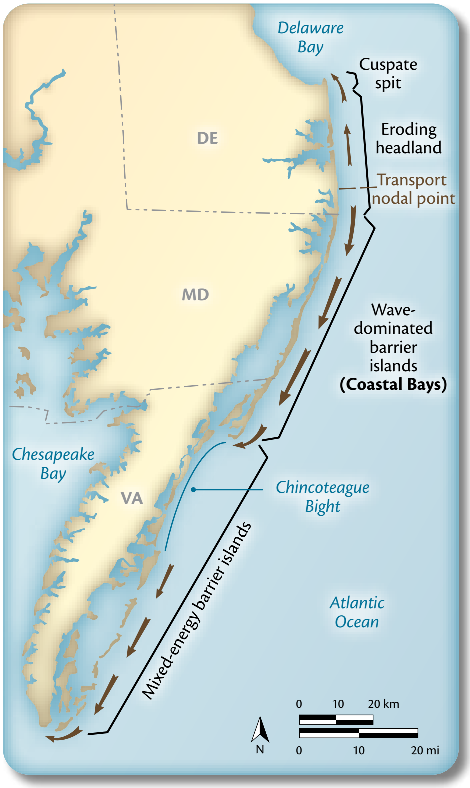
The regional transport of sand along the coast affects the overall morphology of the barrier islands, and local variations create hot spots of erosion. Wave action moves sand grains along the beach in the swash zone (area of surf run-up) and, more importantly, drives currents flowing parallel to the beach that carry sand grains. The annual net transport of sand is a balance between energetic flow to the south generated by nor'easter storms during the winter, and less vigorous but more constant flow to the north produced by southeasterly waves during the summer.

During average years with moderate storms, sand in the upper shoreface (the inner shelf near the beach) is transported in a natural cycle. Vigorous waves during storms (primarily in winter) move sand offshore to form bars, and fair-weather summer waves push sand back onshore to widen the beach. For the Maryland coast, 6–6.5 m (20–21 ft) seems to be the depth limit for this offshore–onshore transport of sand.[41] However, during major storms, bottom sediments over most of the shelf are set in motion as large, long-wavelength waves churn the water column. During these storms, the zone of longshore sand transport may extend offshore 1–2 km (0.6–1.2 mi) into water as deep as 20 m (66 ft).

The Mid-Atlantic coast may be subdivided into several *coastal compartments* that are bounded by the mouths of major estuaries and have similar geomorphic character:[15] Long Island, New Jersey, the Delmarva Peninsula, and the Virginia–North Carolina coast from Cape Henry to Cape Lookout. For the entire Mid-Atlantic coast, the net longshore transport of sand is to the south or southwest. In the northern section of each coastal compartment, the net transport reverses in response to gradients in wave energy and shoreline orientation downdrift of the estuary mouth.

The dividing point between zones of northerly and southerly transport is known as a *nodal point*. Within each zone, local reversals of transport direction occur near inlets and with major changes in shoreline orientation. The nodal point along the Delmarva coast lies between South Bethany, Delaware, and the Delaware–Maryland state line.[8]

Delmarva coastal compartments



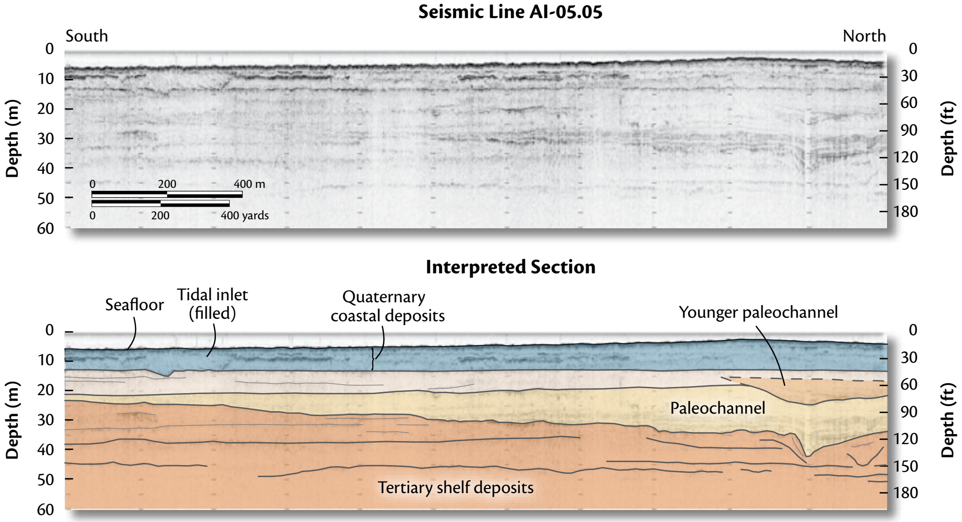
The Atlantic coast of Delmarva (Delaware–Maryland–Virginia) may be subdivided into four coastal compartments, each with a characteristic morphology related to sediment transport (brown arrows) and wave and tide energy.[15,34]

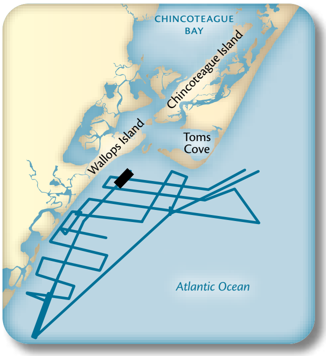
For the Delmarva coast south of the Delaware–Maryland state line, net longshore transport is to the south and is estimated to be between 115,000 and 214,000 m^3 (150,000–280,000 yd^3) per year and increases to the south.[46] Local reversals south of the Ocean City and Chincoteague Inlets transport sand northward.

Engineered structures such as groins and jetties intercept longshore transport, accumulating sand on the updrift side but starving the downdrift side and enhancing erosion. Nodal points form at the sites where transport diverges. For example, at South Bethany Beach, Delaware, transport is both to the north into the mouth of Delaware Bay and to the south toward Fenwick Island.[8] This divergence is in part due to the sheltering effect of Cape May Shoals and Hen and Chickens Shoal at the mouth of Delaware Bay. Storm waves approaching from the northeast lose energy by breaking across the shoals and refract around the shoals, changing the direction at which they hit the Delaware coast north of Bethany Beach. This same effect happens on a smaller scale downdrift of inlets and results in a curved or arc-shaped offset of the shoreline.

The southern end of Assateague Island in Virginia terminates in a large hook, or recurved spit, that bends sharply to the west and wraps around Chincoteague Island. This feature, comprising Toms Cove Hook and Fishing Point, receives sand transported southward from the entire coastal compartment that stretches south from the nodal point at South Bethany, Delaware.

The Virginia barriers of Wallops, Assawoman, and Metompkin Islands are





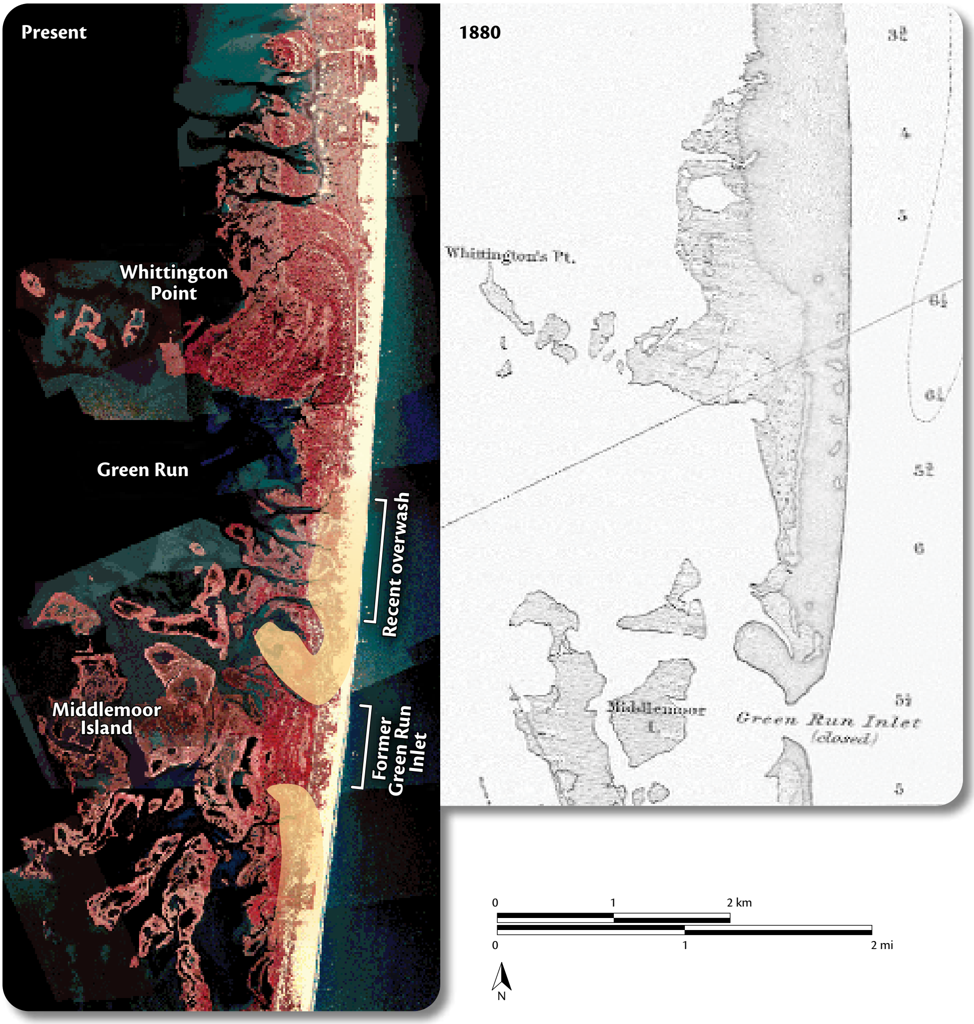
Several paleochannels cut into Tertiary shelf deposits were discovered in a recent seismic survey of the Chincoteague Bight.[21] These may be channels of an ancestral Potomac River that flowed across the shelf to Washington Canyon prior to the creation of Chesapeake Bay.

offset landward by almost 10 km (6.2 mi) from Assateague Island, forming an embayed area referred to informally as the Chincoteague Bight. The recent discovery during seismic surveys of the Bight of several large, deep paleochannels, possibly of an ancestral Potomac River, explains the presence of what appears to be a broad valley extending across the shelf toward Washington Canyon. This feature appears to have persisted through many sea level cycles and may be the underlying reason for the offset and change of character of the barrier islands south of Assateague Island.[21]

Islands roll over & inlets migrate

Viewed over several centuries, these same processes of storm overwash and creating and filling inlets result in island

Location of the former Green Run Inlet



The aerial photo (left) shows the location of a former inlet through Assateague Island at Green Run in Chincoteague Bay, and the nautical chart from 1880 (right) shows the inlet mapped as a shoreline feature. The former flood tidal delta—Middlemoor Island—is visible. Photo mosaic on left from Assateague Island National Seashore; historical chart from NOAA National Ocean Service.

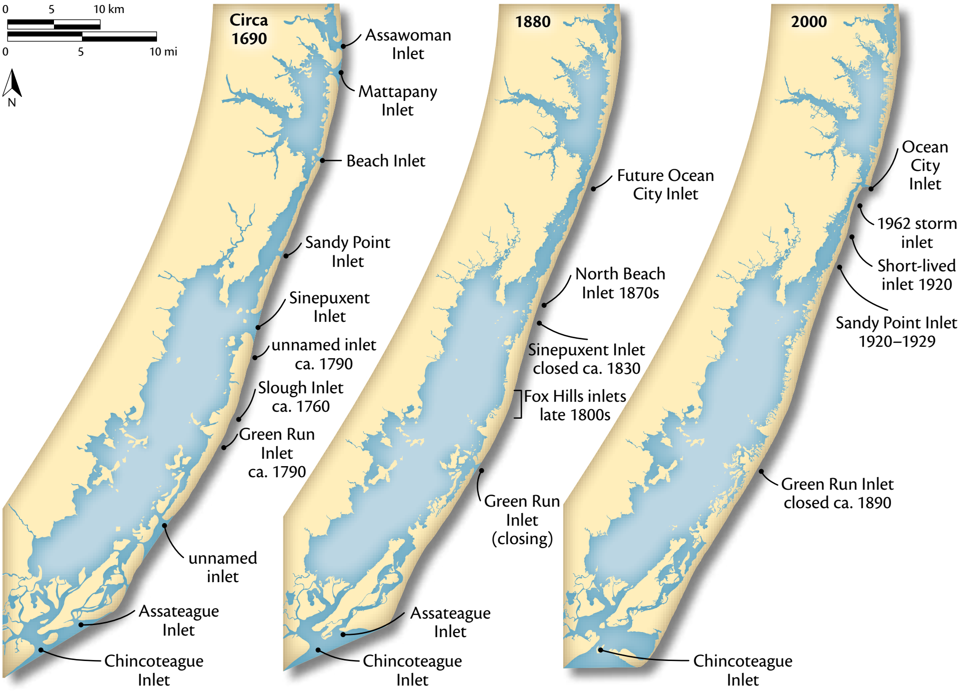
rollover and landward migration (coastal transgression). An inlet cut during a storm may remain open for years or decades if the *tidal prism*—the volume of water in the bay between high and low tide—is large enough to generate vigorous tidal flow that scours sediment and maintains the inlet.

However, the Delaware–Maryland coast is microtidal (tidal range of less than 1.5 m or 4.9 ft) and wave-dominated. Consequently, sand transported along the ocean shoreline from north to south usually fills and closes off the new inlet within a few years. Historical maps and charts going back to the first European colonists in the late 1600s show the sequence of inlets opening and closing along Fenwick and Assateague Islands.[1,27]

Natural coastal processes prevail along the length of Assateague Island beyond the influence of the jetties at the north end. Even so, since the closure of Green Run Inlet in the 1890s, only Sandy Point Inlet (1920–1929) remained open for any substantial length of time. Further, since construction of the jetties at Ocean City Inlet in 1933, no new inlets have formed other than at the north end. The reasons for this relative stability of Assateague Island are not entirely clear, but include the buffering of storm surges by flow through the two inlets, the construction in the 1960s of an artificial foredune along much of the length of the island,[24] and subsequent vegetative cover by grasses and scrub behind that dune.

Even under natural conditions, inlet creation and closure will affect the stability of that section of the island for several decades. This effect can be exacerbated by human activities. For example, the northern end of Assateague Island is classified by the U.S. Geological Survey as having 'very high vulnerability' to sea level rise because of its low elevation, frequent

Inlets on Fenwick & Assateague Islands, 1690–2000



The shoreline of Fenwick and Assateague Islands in 1690, 1880, and 2000, showing the locations of various inlets.

overwashing, and high rates of shoreline erosion.[36]

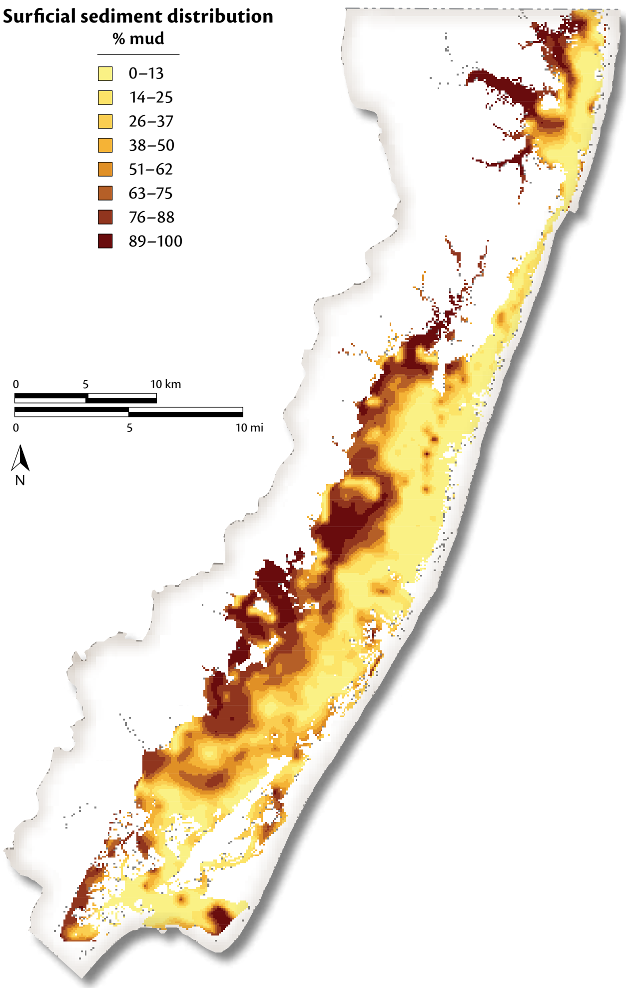
The underlying cause for this instability is the interruption of the longshore transport system by the jettied Ocean City Inlet, and enhanced capture of sand by the ebb shoal and other accretionary shoals well beyond the capacity of what natural features would have had at this location. Downdrift sediment starvation results on northern Assateague Island.

Wave & tide energy determine sediment type in the Coastal Bays

The two dominant sediment types in the Coastal Bays are medium to fine sand (particles with diameters of 0.062–0.5 mm) and organic-rich mud (a watery mixture of silt and clay with particles less than 0.062 mm diameter). The distribution of sediments in the bays is related to the proximity of the sediment source and the wave and tide energy available to transport the sediment particles. The tidal inlets, with deep channels and complex flood-tidal deltas, are composed almost entirely of sand with some gravel, although they grade into silty fine sand on the bayward end. The overwash sheets on the back-barrier flat also are dominantly sand, but commonly will be interbedded with marsh peats and lagoonal silts deposited between storm events.

Away from the inlets and channels, the Coastal Bays essentially are a large settling basin for fine-grained sediments. In Chincoteague Bay, sands dominate the eastern section, silts fill the navigation channel, and silt–clay mud covers the western one-third. The protected upper reaches of the bays, such as Newport Bay, the western tributaries of St. Martin River, Turville Creek, and Greys Creek, have minimal wave and tide action, and clays are deposited there.

Sediments deposited in the bays are derived from several local sources—suspended sediments transported by the streams, turbid seawater churned up on



Sediments in the Coastal Bays range from sandy sediments along the eastern margins to finer sediments along the landward shores.

MARYLAND DEPARTMENT OF NATURAL RESOURCES/MARYLAND GEOLOGICAL SURVEY & ASSATEAGUE ISLAND NATIONAL SEASHORE the shelf during storms, erosion of the mainland shoreline, and overwash across the barrier islands. A minor contribution comes from windblown sand lifted off the islands.

Sediments are habitat for the benthic community

The sediments of the bay floor of the Coastal Bays provide the substrate for the benthic community of plants and animals. Vastly different benthic communities occupy the different areas of predominant sediment type. This is due largely to the different geochemical environments, including concentrations of nutrients and dissolved oxygen, associated with sandy versus finer-grained sediments.

The silt and silt–clay sediments in the central and western sections of the Coastal Bays are typically dark gray to black, organic-rich, and hypoxic to anoxic (little to no dissolved oxygen) within a few millimeters of the sediment–water interface.[52] The sediment pore waters have high concentrations of nutrients, usually as ammonium (NH_4^+) and phosphate (PO_4^{3-}), released by the remineralization (decomposition) of organic matter, and methane gas produced by bacterial methanogenesis.[4] Because of the abundant organic matter, these sediments support a highly productive benthic invertebrate fauna. These sediments are also an important component of seasonal cycling within the Coastal Bays, acting at different times as both source and sink for nutrients and contaminants. For more information on nutrients, see Chapter 13—*Water Quality Responses to Nutrients.*

The resurgence of seagrasses (submerged aquatic vegetation or SAV) in the Coastal Bays since the 1980s[49] has been attributed to recovery from a wasting disease that devastated the grasses in the 1930s and improving water quality since the 1970s (although this resurgence trend has recently reversed). Although the habitat criteria monitored are associated with water quality (nutrient concentrations, Secchi depth, suspended solids), a sandy substrate appears to be a necessary condition for healthy seagrass beds. Nearly 85% of the seagrasses grow on the sandy subtidal overwash flats and flood-tidal deltas on the landward side of Assateague Island, including the two large deltas associated with previous inlets at Green Run and north Chincoteague. Most of the remaining seagrasses live on local patches of sand near shorelines where waves are eroding sandy Pleistocene deposits, such as at Mills Island and South Point in Chincoteague Bay. For more information on seagrasses, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*


JANE THOMAS

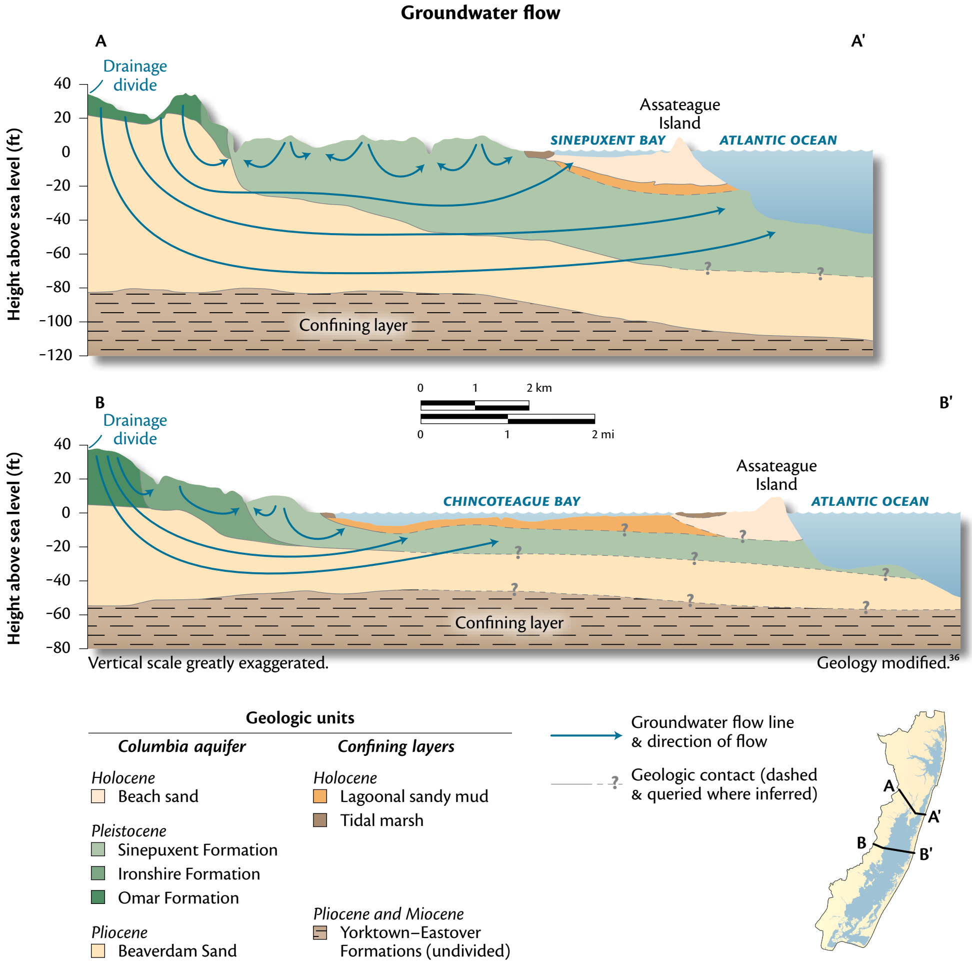
These overwash flats on the landward side of Assateague Island supply sand to Sinepuxent Bay, creating habitat for seagrasses.

Stream drainage into the Coastal Bays is limited

The morphologic character of the Coastal Bays varies along the length of the Delmarva coast, with substantially more drainage area contributing to the Delaware coastal bays than to either the Maryland or Virginia bays. Rehoboth and Indian River Bays in Delaware flood two fairly substantial incised valleys (the stream drainage network created during the last glacial lowstand of sea level). The watershed extends well inland and drains much of eastern Sussex County, Delaware. In contrast, the watershed contributing to Chincoteague Bay is made up of numerous small streams that extend the short distance to the drainage divide with the Pocomoke River and have a relatively low discharge of freshwater. The drainage landward of the lagoons behind the Virginia barrier islands is even more restricted, and these bays have the lowest ratio of drainage basin area to estuary area along the Delmarva coast.

Groundwater flows into & under the Coastal Bays

Because much of Delmarva has sandy sediments near the land surface, as much as 25–50% of annual precipitation infiltrates through the soil and recharges the water table.[2] This groundwater, which fills the pore spaces between sediment grains, then flows through the surficial, or water-table, aquifer. An *aquifer* is simply a body of sediment (or rock) that has sufficient permeability to allow water to flow through easily—these are typically continuous layers of sand in the subsurface. The surficial aquifer is open to the land surface, but deeper aquifers may be isolated by low-permeability layers (confining layers) composed of silt or clay that inhibit vertical water flow. Many municipal water supplies, including those for Ocean City and Salisbury, Maryland, draw from these deeper confined aquifers.



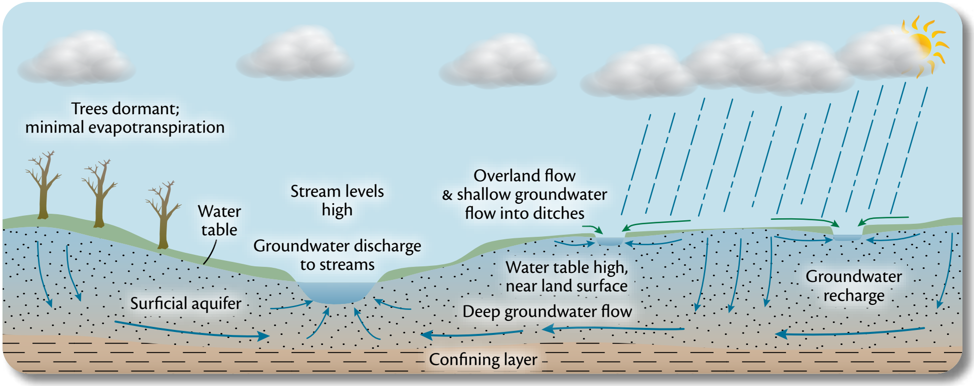
Local and regional flow of groundwater in the surficial aquifer of the Coastal Bays watershed.[11]

Groundwater in the surficial aquifer may follow a short flow path and discharge into a nearby stream or may sink deeper and enter a longer, regional flow path. During periods with no rain, and no overland runoff, stream flow is maintained by groundwater discharging upward through the stream bed—this is *stream base flow*. Analogous to the watershed comprising the stream drainage network, there is an equivalent ground-watershed contributing to base flow.

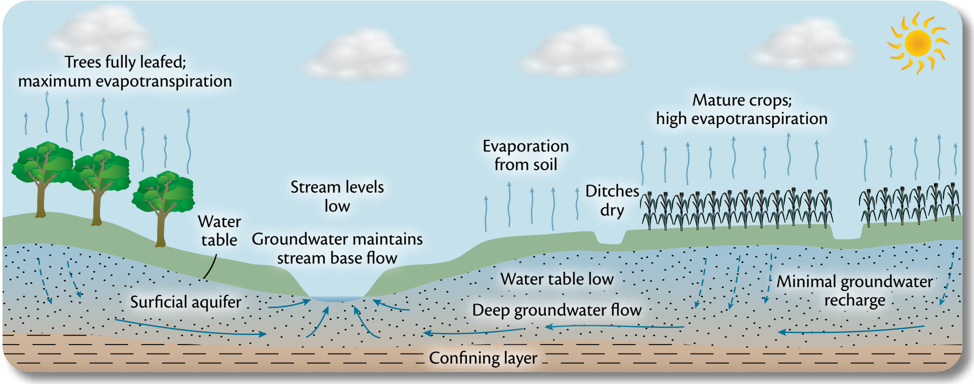
On Delmarva, much of the *groundwater recharge*—addition of new water from precipitation to the water table and surficial aquifer—occurs during the winter and spring, when evapotranspiration is low, precipitation is high, and the water table rises to near the land surface.[2] At this time, in ditched areas such as farmland, numerous short, shallow flow paths drain off groundwater into ditches and streams. Conversely, in summer and early fall, high rates of evapotranspiration remove moisture from the soil and unsaturated zone, the water table drops dramatically, and ditches and shallow streams dry up.

Groundwater flow in the vicinity of the Coastal Bays or other estuaries is complicated by the salinity, and thereby higher density, of the surface water. Similar to the mixing of riverine freshwater with seawater in an estuary, the dynamics of freshwater and saltwater mixing are mimicked in the subsurface beneath the bays. In general, areas close to the mainland shore will have fresh

Late winter & spring



Late summer & fall



Groundwater flow and recharge changes depending on the season and precipitation.

groundwater flowing out toward the bay, with the denser saline groundwater that recharges through the bay floor sinking and flowing landward beneath the fresh. In many coastal settings, this interaction produces a zone of fresh groundwater discharge that extends tens to a few hundred meters (up to 300–500 ft) into the bay, with an underlying wedge of saline groundwater pushing landward.

The balance between fresh and saline groundwater at the shore of the Coastal Bays depends on the hydraulic head generated by recharge on the mainland—think of the pressure produced by the height of a water tower that pushes water through the supply pipes and out a faucet—but also depends on the stratigraphy (type and layering of sediments). Modeling predicted that groundwater recharged on the mainland would flow beneath a narrow Coastal Bay, such as Sinepuxent Bay, and discharge offshore in the ocean.[11] Conversely, in wider bays such as Chincoteague Bay, which is 10 km (6.2 mi) wide in parts, the fresh groundwater meets significant resistance to flow from the saline groundwater recharged from the bay, and is either forced upward buoyantly to discharge through the bay floor or, more likely, mixes to form a brackish 'subterranean estuary.'[30]

Field observations in Indian River and Rehoboth Bays in Delaware, and Chincoteague, Sinepuxent, and Isle of Wight Bays in Maryland, using a marine electrical resistivity system towed behind a small boat, showed a complex interaction between fresh and saline groundwater beneath the bays[20,25] and generally verified model predictions.[11] Plumes of fresh or nearly fresh groundwater extend 1–2 km (0.6–1.2 mi) from shore under sections of the bays beneath thin semi-confining layers. The groundwater within and adjacent to these plumes was sampled by drilling temporary wells through the bay floor to evaluate the chemical characteristics and age of the water.[4,5]

The Coastal Bays that separate the barrier islands from the mainland also isolate the shallow groundwater of the island from fresh groundwater flowing from the mainland. Long, narrow barrier islands such as Assateague and Fenwick Islands will have a relatively shallow lens of fresh groundwater literally floating on saltwater flowing under the island from both the ocean and the bay. From field observations, the fresh lens on Assateague Island is 6–7 m (20–23 ft) thick in the middle of the island, and pinches to less than 1 m thick toward the ocean beach and the bayside marshes. The fresh lens is isolated vertically from the deeper fresh groundwater flowing from the mainland by the layer of saltwater.[16]

SEA LEVEL & THE EVOLUTION OF THE COASTAL BAYS

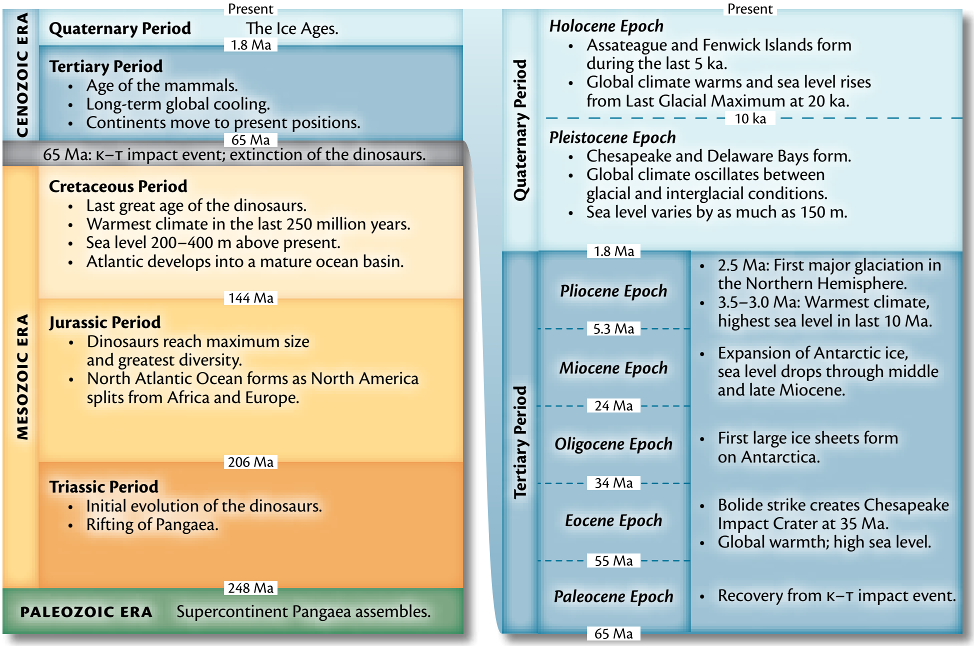
The Coastal Bays inherit a geologic legacy

While the modern processes shape the character of the Coastal Bays, the bays are a product of their geologic history. This legacy developed as the Atlantic Coast of North America evolved over 250 million years (Ma, or 'mega annum') and sea level has varied by nearly 150 m (500 ft) in glacial–interglacial cycles during the past 2.5 Ma.

The sediment layers of the Atlantic Coastal Plain record a long and complex history from the initial rifting of the supercontinent Pangaea in the early Triassic to form the Atlantic Ocean basin, through flooding of the margin by the ocean and deposition of marine shelf sediments on the edge of the continent, to the most recent rise of sea level since the last major Ice Age 20,000 years ago (ka, or 'kilo annum').

The Delmarva Peninsula as we now know it began forming during the Pliocene and early Pleistocene (from about 5–1.5 Ma) as the ancestral Potomac

Geologic timeline



The major subdivisions of geologic time for the Mesozoic and Cenozoic Eras are shown along with important events affecting global climate and sea level over the past 250 million years. ("Ma" is million years, "ka" is thousand years.)

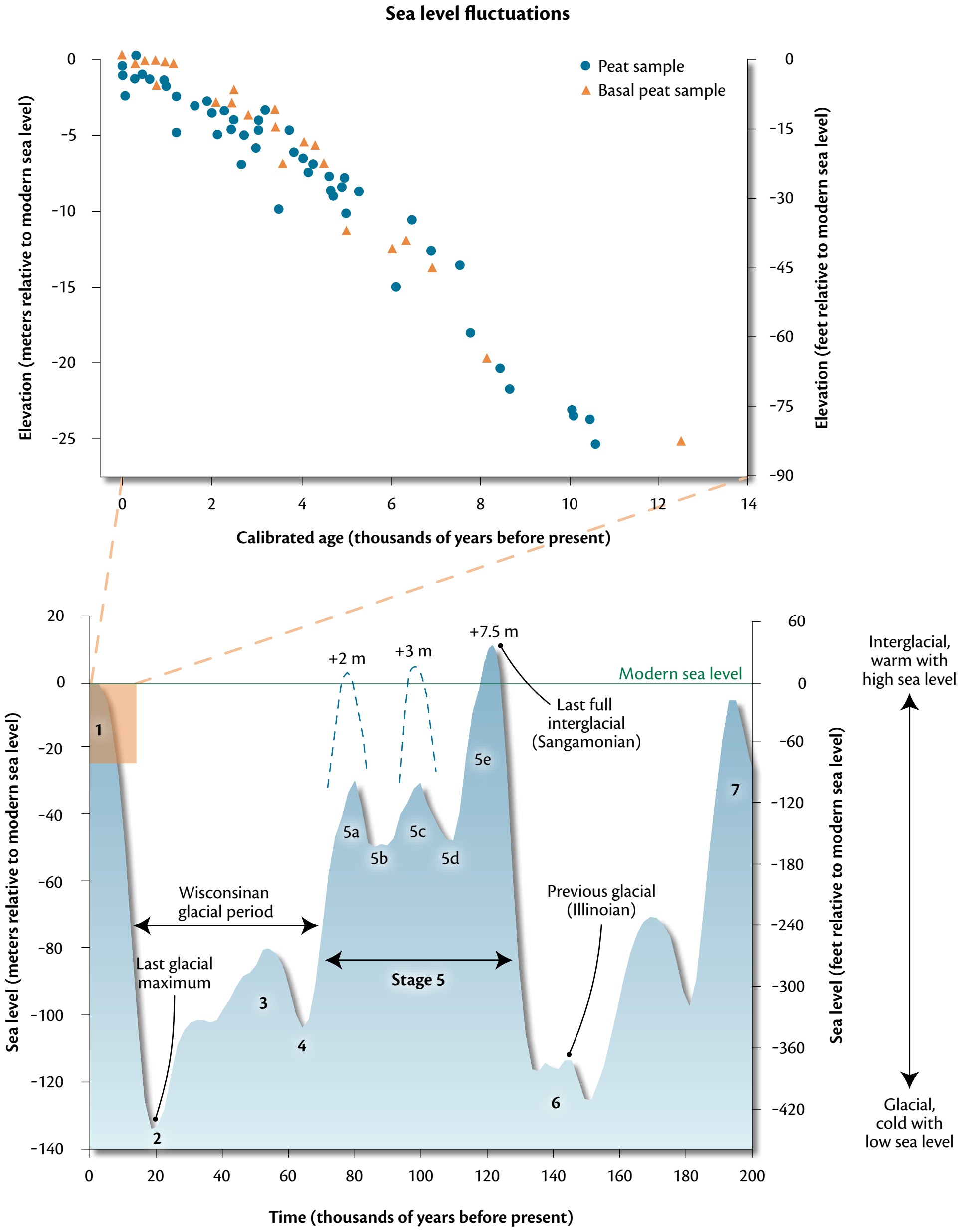
and Delaware Rivers deposited deltas and braided-river outwash plains that would become the core of the peninsula. Although continental glaciers did not extend this far south, many of the sediments deposited on Delmarva were derived from glaciers scraping off the land surface of Ontario, Quebec, Pennsylvania, and New York, and dumping large volumes of water and sediment into the major river systems.

Since approximately 2.5 Ma, global climate has oscillated between cold glacial and warm interglacial conditions. During glacial episodes, the Antarctic ice cap grows and ice sheets as thick as 3–4 km (1.8–2.4 mi) cover most of Canada and Scandinavia. The water stored in these continental ice sheets is removed from the oceans, and sea level drops by 120–150 m (400–500 ft).

During the glacial lowstands of sea level in the Middle Pleistocene (1–0.5 Ma), the Delaware and Susquehanna Rivers started cutting down through the Coastal Plain to create the basins for Delaware Bay and Chesapeake Bay, respectively. During the interglacial highstands of sea level, the ocean flooded landward across the Coastal Plain (presently the continental shelf), and wave action eroded the deltaic sediments deposited previously and redistributed them into sandy shorelines. As sea level dropped with the beginning of the next cooling phase, the highest shorelines would be stranded, creating long linear features that can be traced most of the length of the Delmarva coast.[10,29,44] The steep seaward face of these shorelines is a *scarp*, and the flat plain between scarps is a *terrace*.[7,29]

Prominent shorelines mark previous highstands of sea level

The most recent interglacial period with sea level as high or higher than modern occurred between 125 and 80 ka—this is referred to as the Sangamonian interglaciation or Marine Isotope Stage 5. As seen in the sea level plot for the past 200 ka, Stage 5 had a stair-step of three highstands at approximately 125 ka (substage 5e), 100 ka (5c), and 80 ka (5a). The peak sea level of substage 5e rose to 6.5–7.5 m (21–24.5 ft) above present, producing a prominent shoreline along most coasts around the world. Records



Sea level fluctuations

Sea level fluctuations globally and locally along the Mid-Atlantic coast over the past 200,000 years. The lower panel shows global ice volume converted to sea level relative to present.[26] Dashed blue lines indicate local elevations on Delmarva of sea level highstands associated with substages 5a and 5c. The upper panel shows the rise in sea level over the last 14,000 years for the Delaware coast from radiocarbon dates of peats and wood.[38]

NOAA NATIONAL CLIMATE DATA CENTER

of global ice volume for substages 5c and 5a indicate that these two subsequent sea level highstands should have risen only to about 20 m (65 ft) below present. However, shoreline deposits from these events are found between 2–3 m (6.5–10 ft) above present along the Delmarva coast and elsewhere in the Mid-Atlantic. This apparent anomaly may be explained in part by depression of the Mid-Atlantic shelf by the weight of seawater, thus allowing sea level to rise relatively higher in the region.[50]

The last three Pleistocene shorelines are most important for the development of the modern Coastal Bays. The highest and most prominent shoreline, created at 125–115 ka during substage 5e (shoreline 'A' on the map), can be traced from Cedar Neck on the south bank of Indian River Bay in Delaware[9] to the Joynes Neck Sand on the Atlantic side of Cape Charles, Virginia,[29] and correlates with the Ironshire Formation in eastern Worcester County, Maryland (shown on the cross section on page 229).[35] The lower-elevation and younger shorelines of substages 5c and 5a (~100 ka and ~80 ka) are associated with subtle lineations of the Bethany (Delaware)/Sinepuxent Neck (Maryland)/Wachapreague–Bradford Neck (Virginia) complex,[44] immediately west of the Coastal Bays (shorelines 'B' and 'C' on the map).

From the preceding warm period, global climate cooled and progressively falling sea level bottomed out at about 125 m (410 ft) below present at 22–20 ka during the Last Glacial Maximum of the Wisconsinan glaciation. At this time, the modern continental shelf was emergent as a broad, exposed coastal plain, and the shoreline was at the edge of the shelf. Locally, the stream drainage network incised to create the basins that would be flooded to form the Coastal Bays.

Sea level rose as glaciers melted

Deglaciation, or the melting of the continental glaciers, proceeded slowly at the start, but accelerated by about 18 ka. The water from the melting glaciers flowed back into the ocean and sea level rose. During some intervals between


Late Quaternary shorelines

The topographic relief produced by late Pleistocene shorelines partially controls the shape and character of the Coastal Bays. The trends of late Quaternary shorelines are shown on a color digital elevation model for the Delmarva coast. Late Pleistocene shorelines produced during highstands of sea level are correlated with periods of reduced global ice volume: [A] substage 5e, ~125–115 ka; [B] substage 5c, ~105–95 ka; and [C] substage 5a, ~85–75 ka. The Wallops–Chincoteague–Pope Island shoreline trend [D] may have been produced by a sea level event in the late Holocene.

15 and 10 ka, sea level was rising 10 times faster than today. The barrier islands that existed on the edge of the shelf during the lowstand migrated rapidly landward across the flooded continental margin. Sea level rise slowed by about 5 ka, and the barrier islands moved close to their present positions.

The Coastal Bays formed behind barrier islands

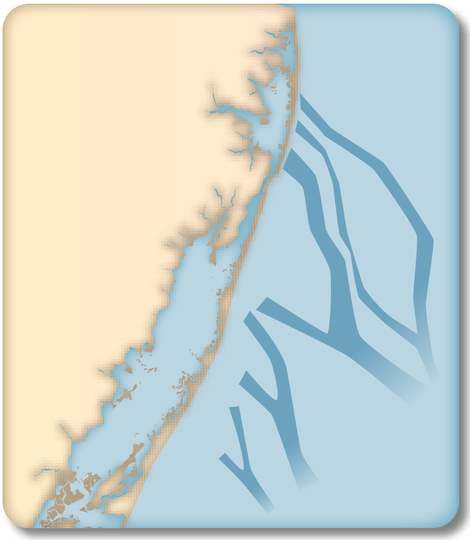
As sea level rose, the low-lying areas between the barrier islands offshore and the Pleistocene shoreline ridges on the mainland flooded to create the Coastal Bays.

Possibly around 2,500 years ago, although no radiocarbon dates are currently available, a precursor to Assateague Island formed slightly west of the modern island. This shoreline complex can be seen today as a linear trend that includes the western part of Wallops Island, Chincoteague Island, Pope Island, and Green Run Island—the latter two sections lie behind Assateague Island near the Maryland–Virginia state line.

Late Holocene Chincoteague shoreline

Shoreline complex showing the precursor to Assateague Island to the west of the current position of the island.

Ancestral stream valleys

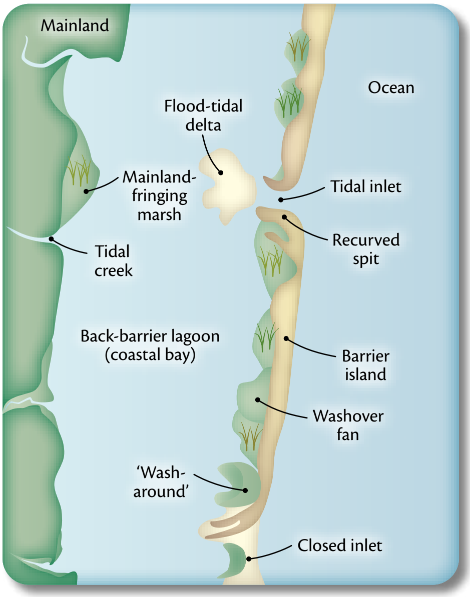


Stream drainage networks cut during the last Ice Age lowstand of sea level (including the ancestral St. Martin River) are now filled and covered by shelf sediments.[43,51]

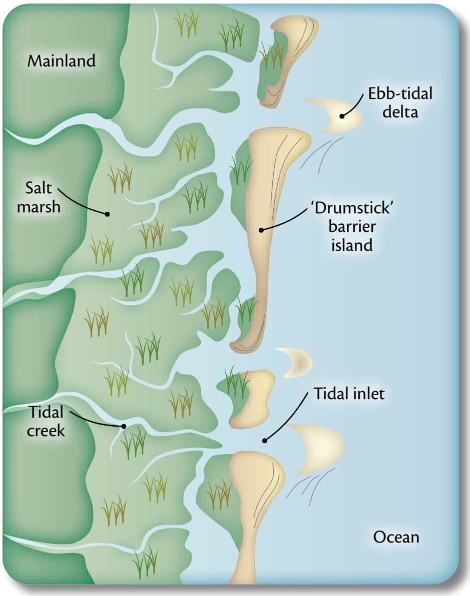
This older coastline has a morphology similar to the barrier islands of the Virginia Eastern Shore, with short island segments separated by relatively stable tidal inlets—a mixed-energy coast instead of the wave-dominated modern Assateague Island. Expansive flood-tidal deltas and sets of beach ridges on the north end of Chincoteague Island and at Green Run mark the locations of former inlets and suggest that the inlets were stable for long periods of time, possibly several hundred years.

Even in this initial phase of development, the individual bays were distinctly different because of their geologic heritage. The St. Martin River drainage is the largest of the Maryland coastal drainages, and the incised valley is wider, deeper, and extends farther inland than the other stream valleys. Consequently, Isle of Wight Bay (including the St. Martin River estuary) is more similar to Indian River Bay in Delaware than the other Maryland Coastal Bays. Assawoman Bay formed as the valleys of smaller tributary creeks to St. Martin River flooded; however, this basin was confined to the east by the extension of the late Pleistocene Sinepuxent Neck shoreline that trends under Fenwick Island near the Delaware–Maryland state line and creates the easternmost point of the Delmarva coast. Newport Bay, Sinepuxent Bay, and two small estuarine tributaries, Herring Creek and Ayers Creek (west of Sinepuxent Neck) formed in a trellis drainage network controlled by the coast-parallel trend of the Pleistocene shorelines, notably Sinepuxent Neck.

Microtidal, wave-dominated barrier island



Mixed-energy (wave & tide) barrier islands



The morphology of barrier-island coasts varies depending upon the balance between wave and tide energy.[17] The Coastal Bays fall into the top category, being microtidal and wave-dominated.

Because of the large, stable inlets, the ancestral Chincoteague Bay would have been different in character from the modern bay. The dynamics were probably more similar to the marshy coastal lagoons behind the Virginia barrier islands, with greater influence of seawater and exchange with the coastal ocean, more fine suspended sediment entering the Coastal Bays from the ocean, substantially larger tidal range and more vigorous tidal currents, and considerably shorter water residence time. If a new inlet were to form and stabilize in central Assateague Island, the dynamics of the Coastal Bays most likely would revert to this former character.

Sea level is still rising

The amount of water on the surface of the planet is finite and constantly circulated from the sea, through the atmosphere, to the land, before eventually being returned to the sea—this is the *hydrologic cycle*. The major storage components in the hydrologic cycle are the oceans, groundwater, and continental or glacial ice—lakes and rivers account for a small percentage of the total water volume.

As discussed above, the amount of water in the oceans fluctuates as global ice volume increases or decreases, causing a proportionate fall or rise of sea level, respectively. Over the past 2.5 million years, repeated episodes of glacial expansion and melting have corresponded with quasi-periodic falls and rises of global sea level. For the past 500,000 years, the major glacial lowstands and peak interglacial highstands of sea level have recurred with an approximate 100,000-year periodicity.

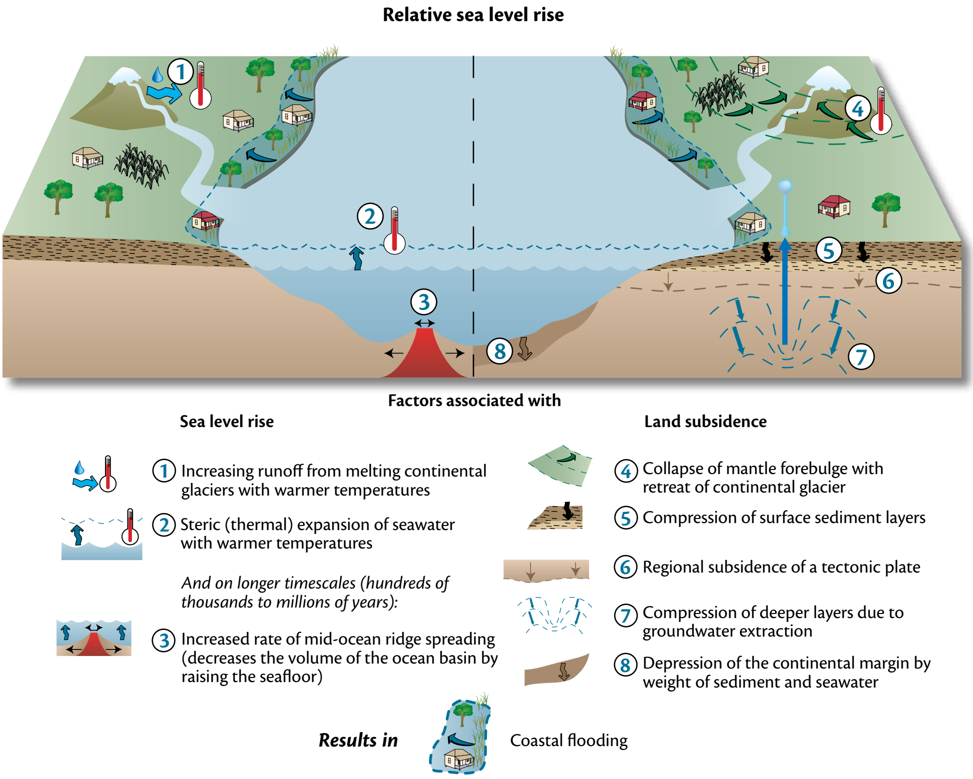
Relative sea level is a combination of sea level rise & land subsidence

Sea level has been rising for the past 18,000 years, although not at a constant rate. Global sea level during the 20th century rose at a rate of 2 mm (0.08 inch) per year, but this rate is nearly ten times that of the previous several millennia.[13,28]

Global warming contributes to sea level rise in two main ways—more runoff from melting ice sheets and glaciers enters the ocean, and as the water in the surface ocean (the upper 500 m or 1,650 ft) warms, the volume of the water increases from thermal expansion.

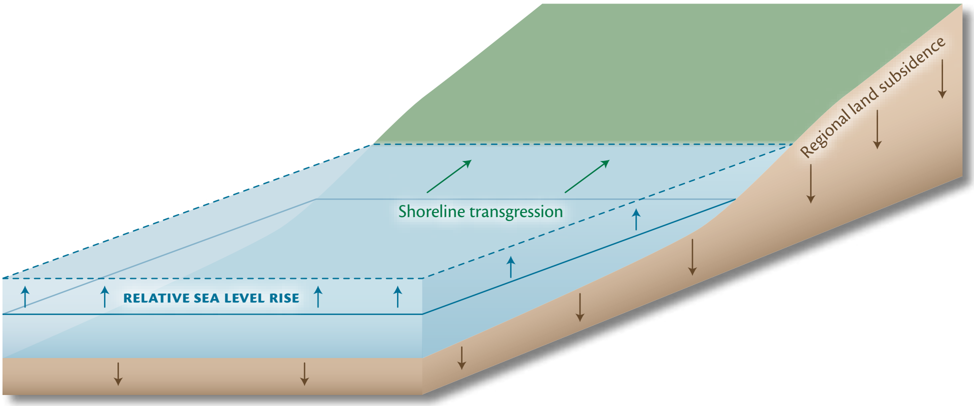
For a coastal area, the relative sea level is a combination of the global sea level rise and local or regional land subsidence. Relative sea level rise along the Delmarva coast during the 20th century ranged from about 3–4 mm (0.12–0.16 in) per year[33,53] or 30–40 cm (12–16 in) per century, but varied spatially with local geologic and hydrologic conditions.

Regionally, the position of the continent relative to sea level will change depending upon the history of loading and unloading of glacial ice onto the continent, or the flooding of the continental margin by the ocean. This process is *isostatic adjustment*, and it occurs because the hot rocks of the upper mantle are plastic and can flow slowly when uneven force is applied. For example, the rocky coast of Maine, which was depressed several hundred meters



Relative sea level is a result of a combination of factors.

Land subsidence & sea level rise



In the Mid-Atlantic region, regional land subsidence is a major factor contributing to relative sea level rise.

by the weight of glacial ice, has been rebounding, or uplifting, since the ice retreated.

During the maximum glaciation, the weight of the ice on North America depressed the crust under the ice, and created a bulge of mantle material around the edge of the ice—similar to pressing down on a closed tube of toothpaste. During the glacial period, the Mid-Atlantic region sat high astride this forebulge. As the ice sheet melted and retreated, the forebulge collapsed and migrated northward, and the land surface in the Mid-Atlantic subsided, even as the Maine coast rebounded.[31]

Throughout the last 15,000 years, in addition to the forebulge collapse, the ocean has been progressively flooding the Mid-Atlantic continental margin. As with glacial ice, the weight of the added seawater depresses the crust. The subsidence from these combined effects contributes the extra 1–2 mm (0.04–0.08 in) per year to the relative sea level rise for the Delmarva coast.

Rising sea level has myriad effects

Rising sea level has both regional and global consequences because of the potential to alter ecosystems and habitability of coastal regions, where an increasing proportion of the world's population lives.

Increasing sea level can result in coastal erosion, exacerbated flooding and storm damage, inundation and loss of wetlands and other low-lying areas, salt intrusion into aquifers and surface waters, and higher water tables.[13] Higher sea-surface temperatures associated with global warming are likely to increase the frequency and intensity of tropical storms such as hurricanes.[3]

The position and shape of barrier islands will change through time in response to sediment supply, changes in predominant wave direction and energy, and rate of sea level rise.[42] A barrier island is stable when the rate of sea level rise is approximately balanced by the input of new sediment to build up the island. In the case of substantial sediment input or relative sea level fall, the front of the island will build seaward, or prograde. This seaward *regression* will produce a series of beach ridges called a strand plain.

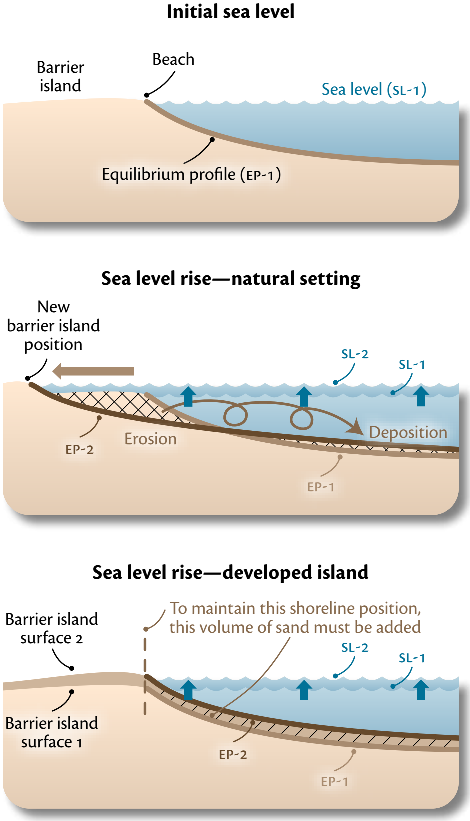
With a slow rise of sea level, the barrier island will retain its general morphology but will roll over and migrate landward, which is called *transgression*. However, in the case of rapid sea level rise, or an interruption of sediment supply, the transport processes that restore sand to the island cannot keep up with the rate of landward migration. These conditions result in low, narrow barrier islands that are vulnerable to storms and are frequently washed over and cut by ephemeral tidal inlets, similar to the north end of Assateague Island, or Metompkin and Assawoman Islands in Virginia.

Sea level rise may accelerate in the next century

A recent report by the United Nations Intergovernmental Panel on Climate Change[19] (IPCC) stated that the global average rate of sea level rise of 2 mm per year (about eight inches per century) that prevailed through most of the 20th century has increased to approximately 3 mm per year (1 ft per century). The same IPCC report also noted that global warming increased faster than expected in the past decade. Current predictions of global sea level rise for the coming century range from 50–90 cm (1.6–3 ft),[18,19] but have a degree of uncertainty because of complex interactions among global climate and the hydrosphere and cryosphere (global ice).

During the 20th century, sea level along the Delmarva coast rose by as much as 40 cm (16 in), or roughly twice the global average. The resulting landward retreat of the ocean shoreline was about 20 m (66 ft),[53] although this was not uniform for the entire coastline. Because the Mid-Atlantic continental margin has such a low slope—generally less than one degree of inclination—for each centimeter of sea level rise, the shoreline migrates landward 50–120 cm (1.6–3.9 ft).[53] Coastal engineers commonly use the 'Bruun rule'[6] to estimate the step-back of the shoreline.

The basic concept of the Bruun model is that a shoreface will have a parabolic 'equilibrium profile' that is a balance between available sediment and dissipation of wave energy. When sea level rises, the profile is translated upward and landward, resulting in erosion and transport of sediment from the beach. In a natural setting such as Assateague Island, this results in island roll-over as described previously.



Bruun[6] developed the concept of an 'equilibrium profile' for the shoreface, which has a parabolic shape caused by the gradual release of wave energy approaching shore. This model can be used by engineers to predict the landward movement of the shoreline with sea level rise and to estimate the volume of sand required for beach nourishment projects. Reproduced with permission from the American Society of Civil Engineers.

When faced with continuing shoreline erosion, some coastal communities with mostly small residential buildings are adopting a 'strategic retreat' policy in which ocean-front structures are removed from their foundations and moved landward. However, in the case of a barrier island developed with large hotels and condominiums, such as Ocean City, moving multi-story buildings is not feasible. The alternative is to add sand to the beach, in approximately the volume indicated by the difference between the old and new equilibrium profiles. Concurrently, artificial dunes are constructed and stabilized to minimize overwash and flooding during coastal storms.

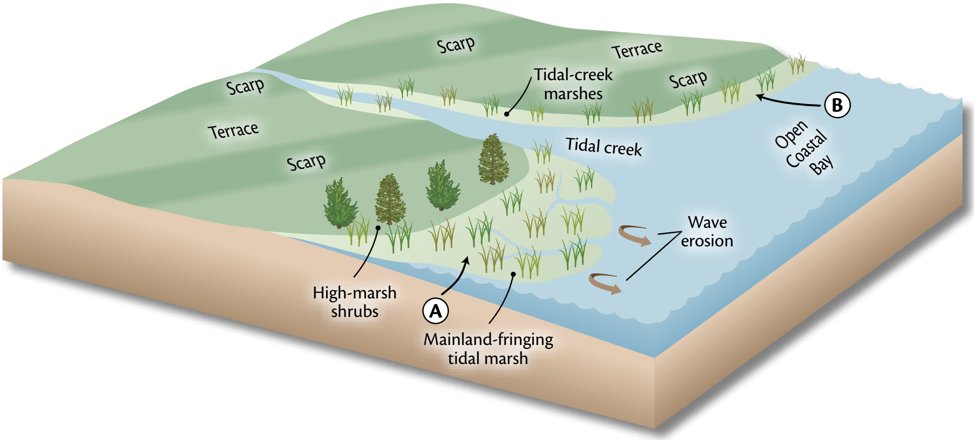
A renourished beach is an effective buffer for storm waves and will protect buildings. However, this approach does not allow for accretion, or increase in elevation of the island surface, by layers of overwash sand. If the rate of sea level rise increases over the next 50 to 100 years, proportionally more new sand will be needed to maintain the beach and position of the island. Even so, the low-lying interior of the island will be increasingly susceptible to storm flooding from both the ocean and bay sides.

During periods of accelerated sea level rise, the natural tendency of wave-dominated, microtidal barrier islands is to be breached by shallow inlets and to have extensive overwash, which flattens the dunes, moves sand across the island into the back-barrier bay, and moves the island itself rapidly landward. These are the likely responses of Assateague Island and other undeveloped sections such as Delaware Seashore State Park.

Rapid sea level rise also will affect the structure and function of the Coastal Bays. The tidal marshes that cover intertidal overwash flats and flood-tidal deltas on the back barrier, low platforms on the mainland side of the Coastal Bays, and margins of tidal creeks, will be at risk of drowning. Currently, these marshes keep pace with sea level rise by trapping sediment particles and raising the marsh surface. However, if accelerated sea level rise outpaces the supply of fine suspended sediment, the marsh surface will drop below mean low tide, and the marsh grasses will drown, creating large open areas, or pannes, in the marsh. Additionally, the outer edges of the marsh will be attacked more vigorously by waves and will erode quickly. Marsh islands in the Coastal Bays, which are important nesting areas for waterbirds, are likely to vanish.

The setting of a tidal marsh is critical for its response to sea level rise and its likelihood of surviving. As the rising sea floods the area, new tidal wetlands naturally form on the landward margin of

Sea level rise & marshes



As sea level rises, mainland-fringing marshes that are flanked on the landward side by a low-lying land surface (site A) can expand and maintain marsh area. Marshes adjacent to a steep landward slope, such as a scarp (site B), are likely to be eroded and destroyed. As tidal influence advances upstream in creeks, new marsh area will be created along the margins of the creek.

existing wetlands (for more information on wetlands, see Chapter 15—*Habitats of the Coastal Bays & Watershed*). A flat, low-lying land surface adjacent to a mainland-fringing marsh allows expansion to maintain the area of the marsh as the seaward edge erodes. In contrast, a marsh that abuts a steep slope to the upland, such as a scarp, cannot expand landward, and ultimately will be destroyed by the rising sea. Even as sea level rises, new marsh area may be created in protected intertidal areas behind forming, prograding spits, and along the margins of creeks draining the upland as tidal influence migrates upstream.

Existing tidal marshes on back-barrier flats, overwash fans, and flood-tidal deltas behind the barrier islands are gradually buried by new overwash deposits. However, as the barrier-island system retreats landward with continued sea level rise and old marshes are buried, new intertidal flats are created and can be colonized by marsh grasses.

One potential benefit to the Coastal Bays may result from rapid sea level rise. If Assateague Island is breached at one or more sites to create stable tidal inlets, the flushing of the Coastal Bays with seawater will increase dramatically. The most likely locations for new inlets are the low areas of Assateague Island that were previous inlets, such as Green Run, Fox Hills Level, and Little Level. Engineers are likely to fill and close off any breaches that might occur on Fenwick Island (Ocean City) before a permanent inlet could be established.

A new, stable inlet to Chincoteague Bay would have profound effects on the entire Coastal Bays system, and it probably would become more like the lagoons behind the Virginia barrier islands. The tidal range in the Coastal Bays would increase from 12 cm (4.7 in) to 1.2–1.5 m (4–5 ft), equivalent to the open ocean. Enhanced exchange with the ocean would partially alleviate nutrient enrichment and invigorate marsh growth both by increasing the amount of suspended sediment transported to the marsh and by flushing marsh soils of toxic, chemically reduced compounds, such as hydrogen sulfide. The salinity of the Coastal Bays would rise, and large areas would become intertidal flats.

Coastal systems are dynamic and adapt to changing physical conditions. Our perception of the effects of sea level rise and coastal retreat depends largely upon whether the barrier islands are relatively natural parks or highly developed resort areas. Management of each area will differ, but decision-makers need accurate predictions of coastal responses with the likelihood of increased frequency and intensity of coastal storms and accelerated sea level rise associated with global warming.

TIDAL INLETS & COASTAL ENGINEERING

Inlets migrate naturally

The creation of the Ocean City Inlet by the hurricane of 1933, separating Fenwick Island from Assateague Island to the south, was not a unique event. Inlets have formed, filled in, re-formed, and migrated throughout time. Many inlets have existed previously along Assateague and Fenwick Islands.

JOHN C. DIETZ, CENTRAL PHOTOGRAPHIC FACILITY

This photo, taken in January 1963, shows the inlet formed during the 1962 storm. This view is looking approximately southwest, with the Ocean City airport in the background.

Inlets have been a significant source of sediments to the Coastal Bays in the past. When the water velocity of an incoming tide decreases, sediment falls out of the water column and is deposited on the Coastal Bays side of the inlet, creating a flood-tidal delta. In areas where previous inlets have closed, their flood-tidal deltas remain as islands in the bays which eventually erode and become a source of sediments.

Engineering projects influence sand movement & inlet migration

In 1934, the U.S. Army Corps of Engineers stabilized Ocean City Inlet by constructing two rock jetties, one on the southern end of Fenwick Island and the other on the northern end of Assateague Island. This construction had profound consequences for sediment dynamics in the Coastal Bays. The jetties disrupted the southward longshore transport of sand, which once traveled the length of the Assateague peninsula.

In addition to the longshore transport impeded by the jetties, the inlet itself became a sink for sand that would otherwise reach Assateague Island. The twice-daily flooding tides transport sand through the inlet and deposit it as a flood-tidal delta and tidal shoals in Isle of Wight and Sinepuxent Bays. Some of these sand bodies are seen clearly just north of the Route 50 bridge in the sequence of aerial photographs on the facing page. Similarly, strong ebbing tides carry sand seaward out of the inlet and deposit it as a shallow ebb-tidal delta, or ebb shoal, that may extend nearly 2 km (1.2 mi) into the ocean from the inlet mouth. The outer edge of the shoal is marked by breaking waves that can be seen on all but the calmest days.

The U.S. Army Corps of Engineers documented evolution of the ebb shoal to -13 m (-43 ft) National Geodetic Vertical Datum from 1933 to 1995.[46] The ebb shoal grew rapidly in area from 1933 to 1962, but was relatively stable from 1962 through 1995. The volume of the ebb shoal


U.S. ARMY CORPS OF ENGINEERS

In this photo, both the ebb-tidal shoal (foreground) and the flood-tidal shoal (upper right) are visible. Part of the flood-tidal shoal, north of the Route 50 bridge, is actually an island—Skimmer Island, an important shorebird and waterbird habitat. Also visible is the ebb-tidal plume coming out of the inlet.

The changing face of the Ocean City Inlet

September 18, 1933, a month after the 1933 storm breached the island to create the Ocean City Inlet. The ebb-tidal shoal is already visible as breaking waves offshore.

October 9, 1934, approximately 13 months after the creation of the inlet. Here, the U.S. Army Corps of Engineers has begun to stabilize the inlet by constructing jetties. The inlet is substantially wider than when it was created, and the ebb- and flood-tidal shoals are becoming more extensive.

December 6, 1935. Stabilization of the inlet has changed the patterns of sediment transport, with sand accumulating on the northern side of the Ocean City jetty, and on the southern, landward side of the Assateague Island jetty.

June 8, 1952. The northern jetty is completely impounded with sand transported from the north, while the northern Assateague Island beach has retreated more than 115 m (375 ft). Extensive flood-tidal shoals are present in Isle of Wight Bay (west of Ocean City) and in Sinepuxent Bay (west of Assateague Island).

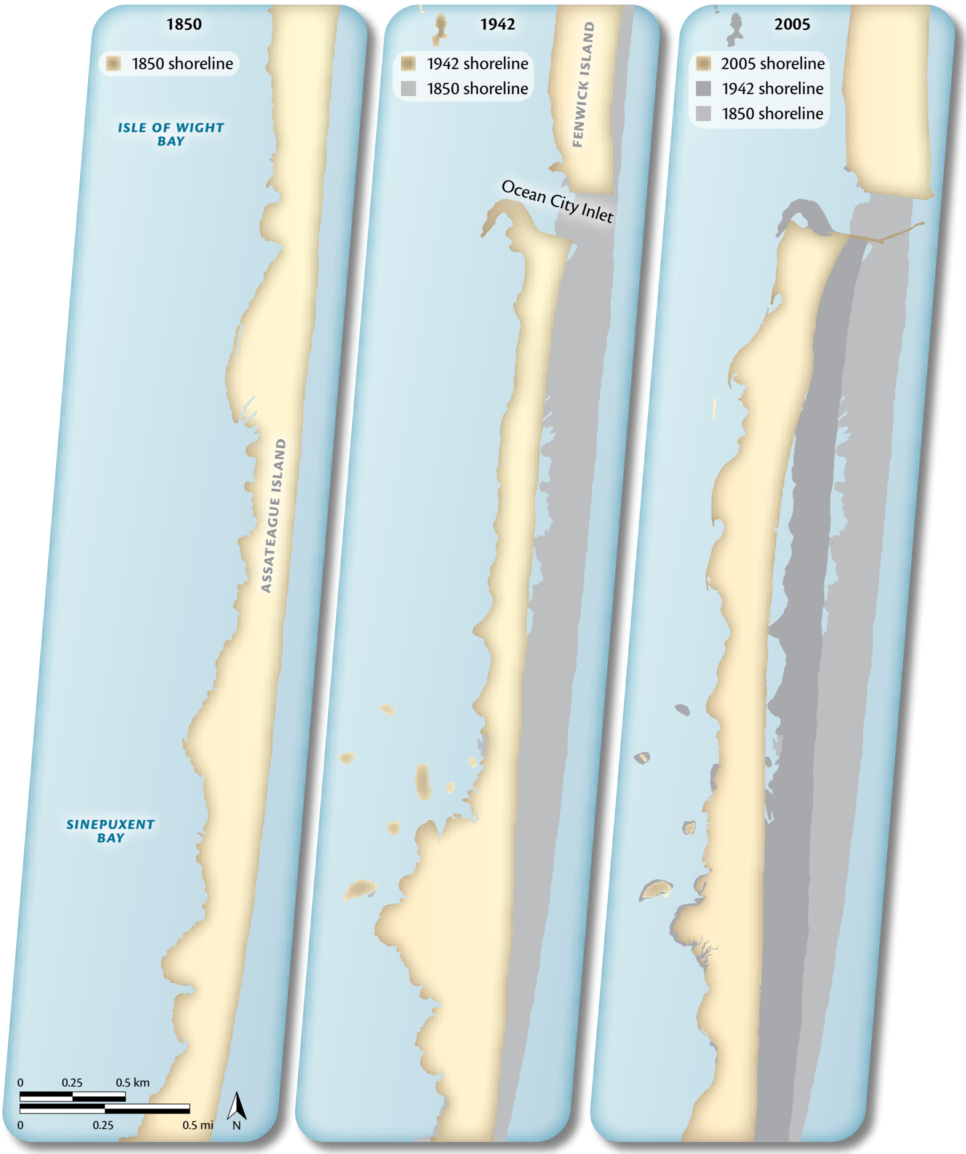
April 28, 1962, approximately one month after the Ash Wednesday nor'easter storm. The northern end of Assateague Island was submerged during the storm, and subsequently detached from the southern jetty. Much of the sand that eroded during the storm was washed into the channel behind the island.

April 16, 2004. This recent photo shows the current location of the Ocean City Inlet and islands.

U.S. ARMY CORPS OF ENGINEERS & MARYLAND DEPARTMENT OF NATURAL RESOURCES increased continuously from 1933 through 1995, although the most rapid rate was immediately after stabilization of the inlet.

The ebb shoal is still growing, and the ultimate equilibrium volume could exceed three million cubic meters (four million cubic yards) of additional sand beyond its 1995 volume—this volume possibly could be reached by 2040.[22] The U.S. Army Corps of Engineers is currently reassessing growth trends of the ebb shoal. Recent tightening of the south jetty now shunts sand farther offshore than previously, which effectively increases the volume needed for the ebb

The evolution of Fenwick & Assateague Islands, 1850–2005



ANDREW ROACH FOR ASSATEAGUE ISLAND NATIONAL SEASHORE

This series of maps shows the shoreline change of Fenwick and Assateague Islands since 1850. After the Ocean City Inlet opened in 1933 and was stabilized the following year, the northern end of Assateague Island has been migrating steadily landward.

Date[1]	Volume		Area		Volume increase	
	Millions of m^3	Millions of yd^3	Millions of m^2	Acres	Thousands of m^3/year	Thousands of yd^3/year
June 1933	0	0	0	0	0	0
March 1937	1.3	1.7	0.822	203	317	415
May 1962	4.4	5.7	3.339	825	123	161
January 1978	8.9	11.7	3.671	907	290	379
October 1995	10.3	13.5	3.638	899	79	103

U.S. ARMY CORPS OF ENGINEERS

Ebb shoal volume, area, and growth rate since stabilization of the Ocean City Inlet in 1933. Volume and area are to a depth of 13 m (43 ft).

1. The data presented for January 1978 are derived from surveys conducted in August 1977 and October 1978. The data presented for October 1995 are derived from surveys conducted in July, October, and December of that year.

shoal to reach dynamic equilibrium with the physical environment.

Barrier islands naturally migrate landward through overwash processes, but sand deprivation on the northern end of Assateague Island has accelerated beach erosion. In the area of the jetty, the island has retreated its entire width (about 500 m or 0.3 mi) since the inlet was stabilized.

This sediment starvation threatens Assateague Island with accelerated erosion and unnaturally high overwash potential due to lowered elevations. To address the cause of these threats, the U.S. Army Corps of Engineers and the National Park Service joined with the Town of Ocean City, Worcester County, and Maryland Department of Natural Resources to create the Long-Term Sand Management Project, which restores the southward transport of sand from Ocean City towards Assateague Island.

Wave energy, tidal currents, and sand transport in the vicinity of the Ocean City Inlet have been studied extensively by the U.S. Army Corps of Engineers,[46] Maryland Geological Survey, and others, and the inlet is among the best studied in the world. Twice each year, 72,000 m^3 (94,000 yd^3) of sand are moved from the ebb- and flood-tidal deltas around the Ocean City Inlet and deposited in the surf zone of Assateague Island, approximately 2.5–5 km (1.5–3 mi) south of the inlet. Natural processes of waves and longshore transport then deposit this sand in the surf zone and on the beach.

This project and another long-term project called the Atlantic Coast of Maryland Shoreline Protection Project, funded by federal, state, county, and city governments, also replenish the Ocean City beach and dunes with sand. Beach replenishment at Ocean City, in addition to the development of permanent structures on the island, means that the natural landward migration of Fenwick Island has been all but halted.

Hydrodynamic models developed by the U.S. Army Corps of Engineers show that there is a nodal point off Assateague Island, approximately 4 km (2.5 mi) south

Project year	Millions of m^3	Millions of yd^3
1988	1.76	2.30
1990	1.68	2.20
1991	1.24	1.62
1992	1.22	1.59
1994	0.96	1.25
1998	0.99	1.29
2002	0.57	0.74
2006	0.71	0.93
Total volume 1988–2006	**9.11**	**11.92**

U.S. ARMY CORPS OF ENGINEERS

Volume of beach nourishment sand added to Ocean City, Maryland, shoreline.[48]

of the Ocean City Inlet. North of this point, sediment has a net northward transport toward the jetty. South of this point, net longshore transport moves sand southward.

This nodal point is the reason why the long-term sand management project deposits sand about 2.5–5 km (1.5–3 mi) south of the inlet, instead of starting at the northernmost point of Assateague Island. This difference is due to the morphology of the ebb-tidal delta or shoal, which curves around the Ocean City Inlet and, at its southernmost point, is nearly perpendicular to Assateague Island.

Similar to the sheltering effect of Cape May Shoals and Hen and Chickens Shoal at the mouth of Delaware Bay, but on a smaller scale, the ebb-tidal shoal partially protects the Ocean City Inlet from wave attack. Waves approaching from the northeast are refracted around the shoal, changing the direction at which they hit the Assateague Island shoreline south of the shoal. Because of the wave refraction, resulting longshore transport is to the north immediately south of the inlet.

The physical setting and dynamic processes of the Coastal Bays provide the foundation for a complex and productive ecosystem. The interaction of the bays with the mainland watershed and the coastal ocean is mediated largely by fluxes of water, dissolved compounds, and suspended particles transported by surface water, groundwater, and tidal flow through inlets. Against the background of daily to seasonal weather cycles, a few major storms in a 50- to 100-year period exert a powerful influence by reshaping and restructuring the barrier islands and the Coastal Bays, and altering their function for decades to come. The bays inherit much of their character from their geologic legacy from preceding sea level highstands and lowstands of the late Pleistocene, and have continued to evolve over the past 5,000 years as sea level has risen slowly but continuously. Stresses to the Coastal Bays system and management challenges for the coming century are related largely to the increasing pace of development in the coastal zone and the prospect of accelerated sea level rise driven by global warming.

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ACKNOWLEDGEMENTS

A number of people contributed thoughts and ideas to this chapter. We thank Mitch Tarnowski of the Maryland Department of Natural Resources and Alice Newton of the University of Algarve, Portugal for constructive suggestions in their reviews. Bob Shedlock of the U.S. Geological Survey Water Resources Division discussed aspects of the regional hydrology and contributed figures. Woody Francis and Nick Kraus of the U.S. Army Corps of Engineers, Baltimore District Office, provided assistance with tracking down information. Arty Rodriguez and Andrew Roach with the National Park Service at Assateague Island National Seashore provided photographs and GIS support, and found archived data. The National Park Service has provided funding for recent projects to David Krantz and Darlene Wells related to the theme of this chapter.

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13. Water Quality Responses to Nutrients

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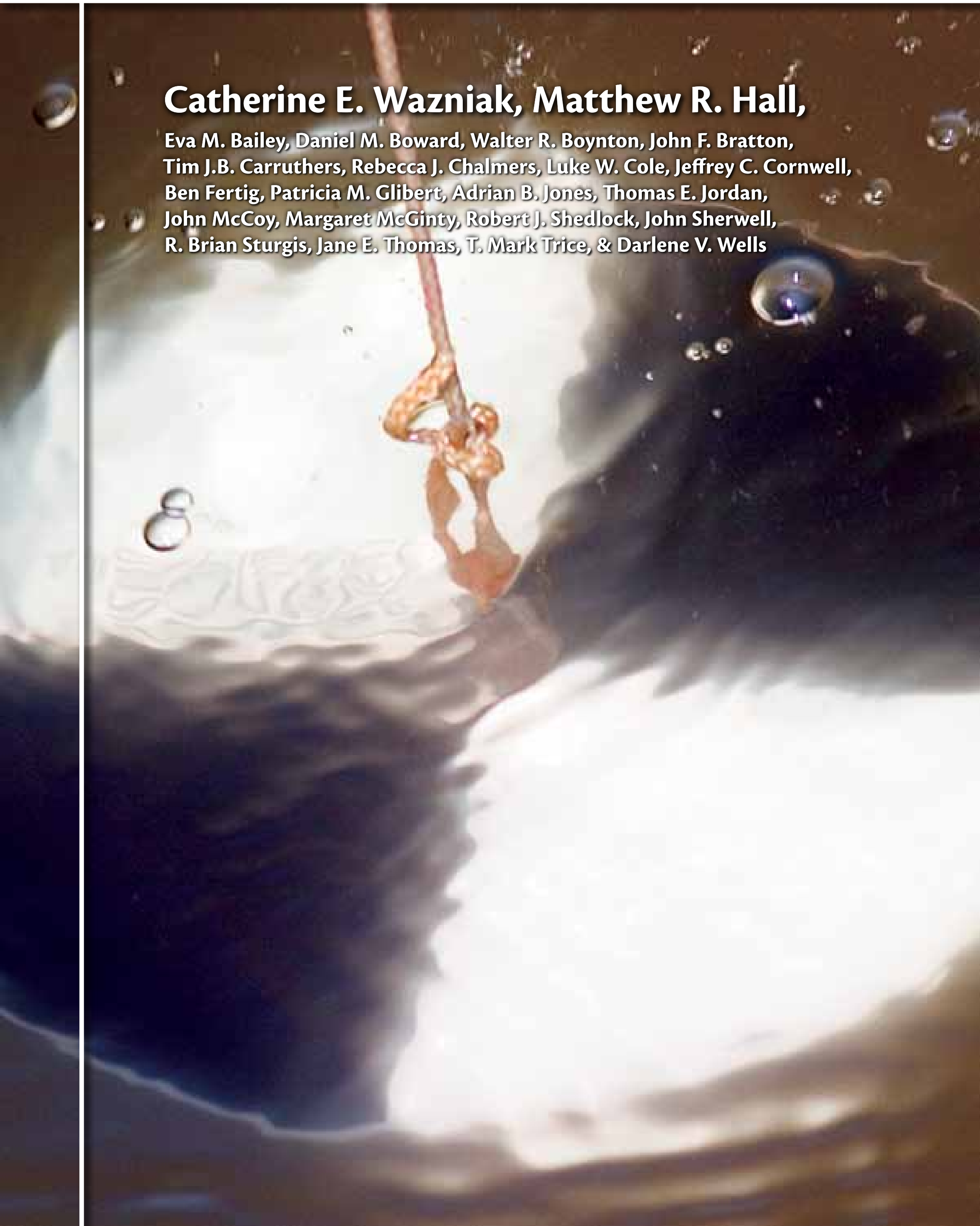


WHY IS WATER QUALITY IMPORTANT?

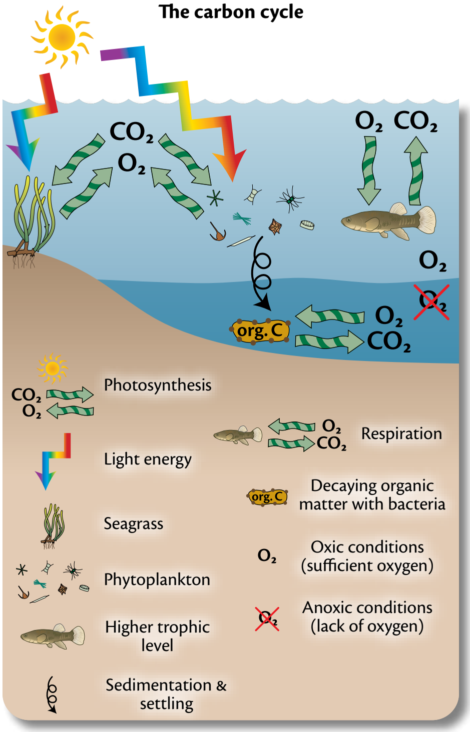
Good water quality is needed to keep aquatic organisms healthy

Excessive nutrients in an estuary cause over-production of phytoplankton in the water column (algal blooms) that can lead to reduction of light penetration (turbidity) and decreased dissolved oxygen levels (hypoxia or anoxia) as the algae decay. The combination of harmful algal blooms and low oxygen can be detrimental to fish survival, while the compound effects of algal blooms and decreased light penetration can limit seagrass growth. Furthermore, algal blooms can cause loss of the aesthetic and commercial values of estuaries, which can lead to economic losses for those who depend on these ecosystems.

The process of enrichment of a waterbody leading to algal blooms and their detrimental effects is called *eutrophication*. The two main nutrients that cause systems to become eutrophic are nitrogen (N) and phosphorus (P). Nutrient enrichment is commonly caused by anthropogenic (human) activities. These nutrients are transported across the land surface, through groundwater, and via the atmosphere. Water moves slowly through the ground and may take years to reach the bays. Therefore, if nutrient reductions are made to septic and agricultural sources today, it may take a decade for these reductions to be evident in coastal waters.

Many biological & chemical reactions depend upon carbon availability from organic matter

The amount of organic carbon in a system has a direct role in regulating the behavior of other chemical species such as nutrients and metals. Sources of organic carbon include plants and animals on land and production of organic matter in the water column by algae and submerged plants. Much of this organic matter settles to the bottom where it is either eaten by benthic organisms or decomposes. Too much organic matter can lead to depletion of oxygen in sediments and in overlying water (*hypoxia* [low oxygen] and *anoxia* [no oxygen]), which can have harmful effects on benthic and fish communities.



In the carbon cycle, carbon dioxide is transformed into organic matter by the process of photosynthesis, which is performed by primary producers such as seagrass and phytoplankton. Its partner process—respiration—involves the metabolism of organic carbon for energy. Respiration uses oxygen and produces carbon dioxide. Nutrient enrichment can lead to excess production of organic matter. As this organic matter sinks, the process of respiration performed by decomposing bacteria depletes the oxygen in the surrounding waters.

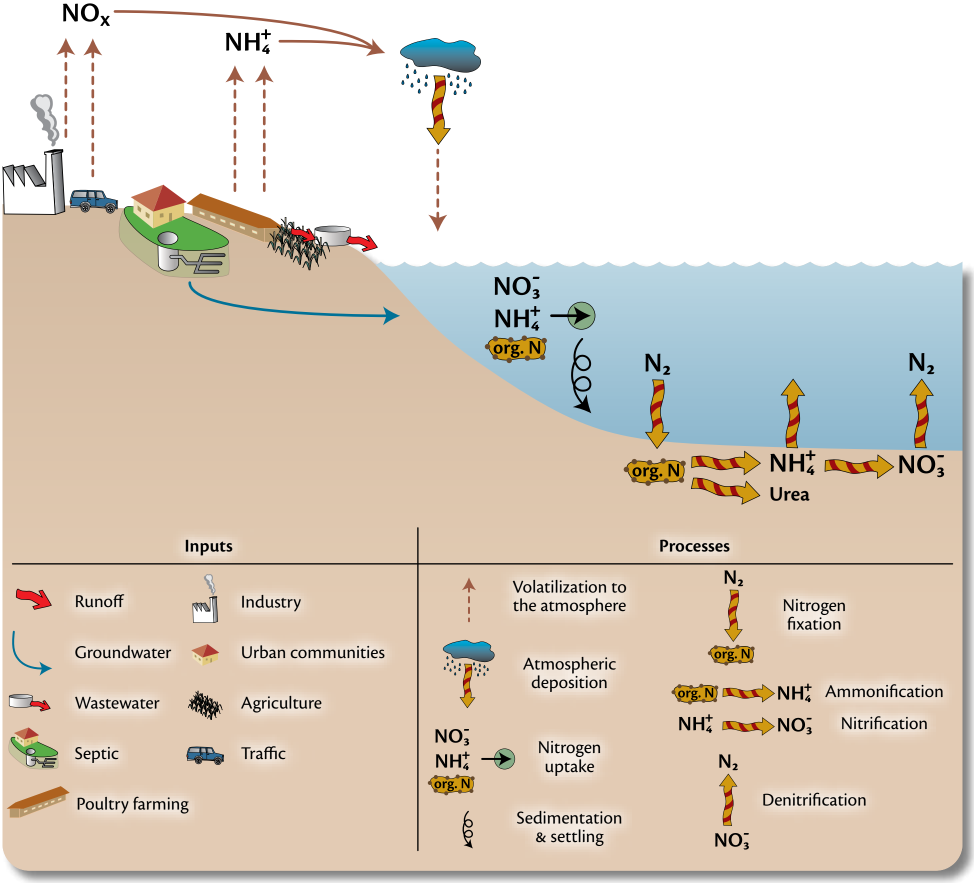
Under anoxic conditions, sediment organic matter may be metabolized by specialized bacteria which use various compounds, such as nitrate (NO_3^-), manganese dioxide (MnO_2), ferric oxyhydroxide (FeOOH), and sulfate (SO_4^{2-}), rather than oxygen. One such reaction converts sulfate to hydrogen sulfide (H_2S), the foul-smelling 'swamp gas' or 'rotten egg gas' which is harmful to benthic organisms, fish, and seagrasses.

Nitrogen transformations are complex

Nitrogen is an essential component of living cells, as it is the central element of amino acids and proteins. Although the earth's atmosphere is composed of nearly 80% gaseous nitrogen (N_2), this form of nitrogen is not available to aquatic organisms. Very few aquatic organisms have the capability to use N_2 gas, or 'fix' N_2 into biological tissues. Therefore, most nitrogen available to aquatic organisms comes from other sources.

Human sources of nitrogen to coastal ecosystems include sewage and animal manures, emissions and subsequent atmospheric deposition of nitrogen oxides (NO_x) from vehicles and industry, and ammonium (NH_4^+), nitrate (NO_3^-), and urea ($(NH_2)_2CO$) from agricultural fertilizer. NO_x, ammonium, and urea can be transported via the atmosphere and deposited onto the land or water. Aquatic plants can take up dissolved nitrogen as nitrate, ammonium, and urea (organic N), and may also release ammonium and urea through their excretion. Bacterial regeneration processes—temperature-regulated nutrient recycling from

The nitrogen cycle



The nitrogen cycle is complex and involves many transformations.

bacteria-related processes—also produce NH_4^+ and urea. NH_4^+ can also be oxidized to NO_3^- by bacteria. NO_3^- is converted back to N_2 gas by bacteria in a process called *denitrification*. The rate of each of these processes depends on many environmental factors, including temperature, oxygen levels, and the supply of organic matter to fuel the process.[15]

Increased nitrogen results in a change from seagrass to macroalgae to phytoplankton

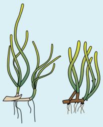
Primary production is the process, mainly achieved through photosynthesis, of production of organic matter (food) at the base of the food chain. In aquatic ecosystems, primary producers include seagrasses, macroalgae, and phytoplankton. Primary production in many coastal ecosystems, at least in temperate regions of the world, is limited by the availability of nitrogen, which means that rates of primary production are related to inputs of nitrogen.

As the nitrogen load to an ecosystem increases, from an oligotrophic (or low nutrient) state to an eutrophic (or high nutrient) state, the dominant primary producer of the system also changes. At low nitrogen levels, seagrasses are often the dominant primary producer. With increasing nitrogen, epiphytes cover more of the seagrass leaves, which decreases the amount of light reaching the leaves. Macroalgae also increase, as they generally grow faster than seagrasses and so can exploit higher nitrogen levels more effectively.

As nitrogen levels continue to increase, the amount of phytoplankton in the water column may increase. These microscopic

Primary producers

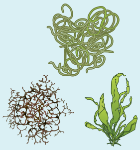
EVAMARIA KOCH



Seagrasses

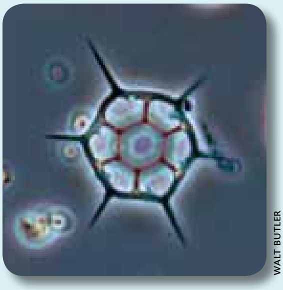
Seagrasses differ from macroalgae in that seagrasses have true roots that anchor them in the sediment. These roots can access and take up nitrogen from the sediments. Seagrasses can also obtain nitrogen that is fixed by cyanobacteria in the sediment or living as epiphytes on the seagrass leaves.

JILL BROWN



Macroalgae

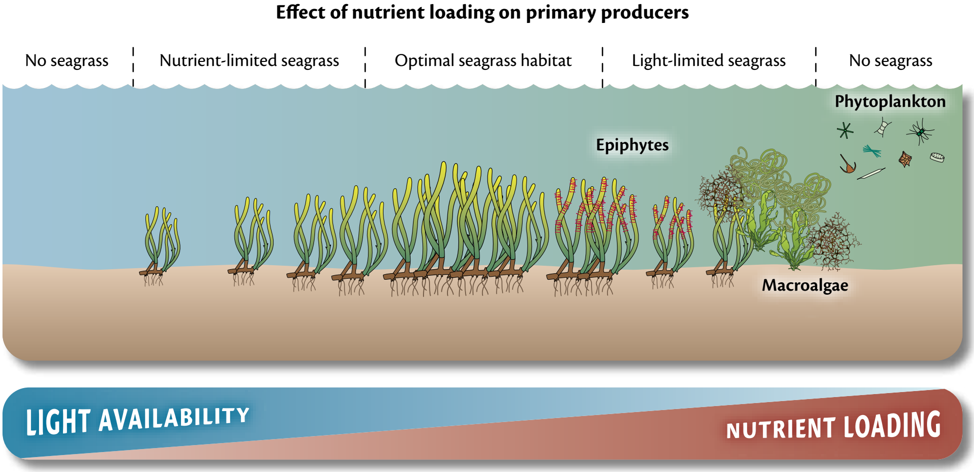
Macroalgae, or seaweeds, obtain their nitrogen from the water surrounding them. They take up nutrients over the surface of their leaf-like bodies. Increased nutrients can result in over-abundance of macroalgae.



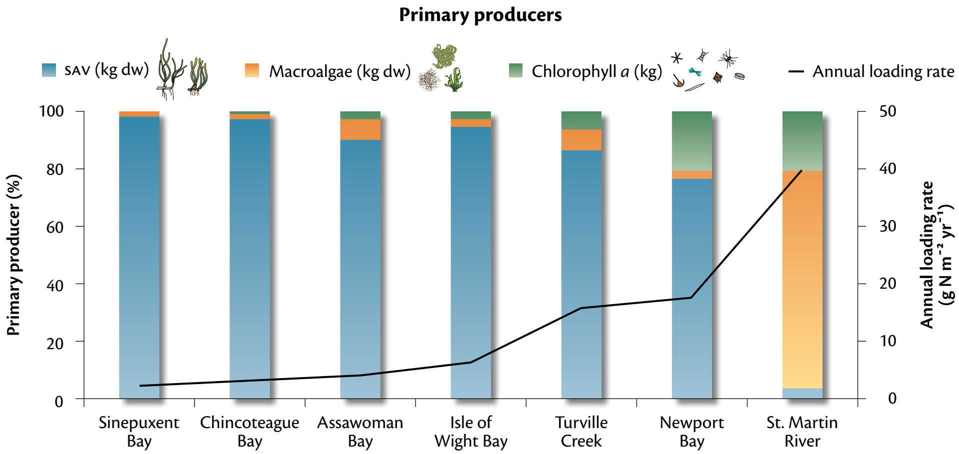
WALT BUTLER

Phytoplankton

Phytoplankton are single-celled, microscopic algae and they also obtain their nutrients (such as nitrogen) from the water surrounding them. The more nitrogen in the water, the more the phytoplankton can grow, which is why there are algal blooms in conditions of high nutrients. Some phytoplankton (cyanobacteria, or blue-green algae) can fix their own nitrogen from nitrogen gas dissolved in the water.



Increasing nutrient loading to an ecosystem changes the dominant primary producer, from seagrass to macroalgae to phytoplankton.



Proportion of primary producers in the subembayments of the Coastal Bays. Loading and weights are annual assessments over the whole subembayment.[47]

algae absorb light, which further reduces the amount of light reaching the sea floor. This shift from benthic (bottom-based) production to pelagic (water column-based) production is typical of eutrophic systems. Such changes are evident in the Coastal Bays, where phytoplankton are the dominant producers in the highly enriched St. Martin River and Newport Bay (these bays have very little suitable seagrass habitat; however they still only attain < 10% of the potential habitat), but the less-enriched Chincoteague and Sinepuxent Bays are dominated by macroalgae or seagrass. Furthermore, seagrass trends are inversely correlated to water quality trends in the bays. For more information, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Sediments play a large role in phosphorus availability

Phosphorus is used in metabolism and in the structure of DNA (deoxyribonucleic acid). Organisms take up phosphorus mostly in the inorganic form (phosphate; PO_4^{3-}). In coastal waters, phosphorus may adsorb to iron (Fe) in sediment particles. In this form, it is largely unavailable to organisms. When bound to sediments, phosphorus may be transported with the sediments.[15]

If sediments are anoxic (lacking oxygen), the reduced form of iron (Fe^{2+}) will dominate. This form is much less efficient at adsorbing or retaining phosphorus, and thus phosphorus may be released to the water column. If the sediments are oxic (containing oxygen), the iron will be oxidized (Fe^{3+}), and phosphorus will remain bound and unavailable.

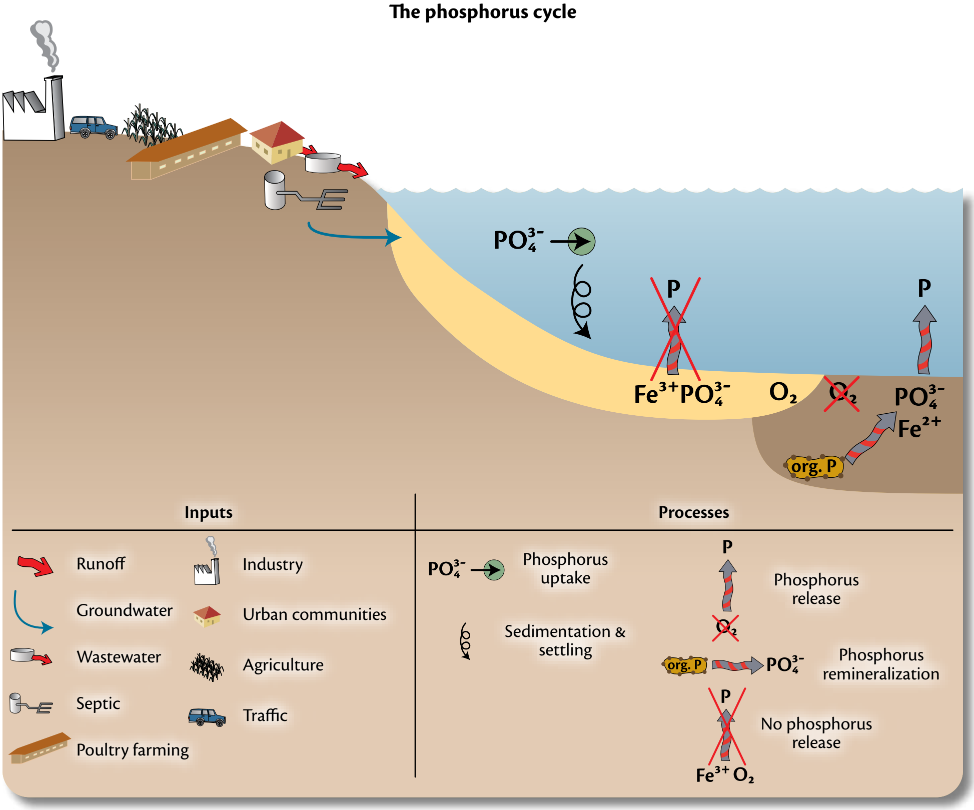
In the Coastal Bays, phosphorus levels are high and increasing. One source of phosphorus is the poultry manure which is used as fertilizer in the watershed.[27] Due to saturation of soil, phosphorus may now move through the groundwater, which means that any farm best management practices may take some time to result in improvements.[61,67] High phosphorus levels can lead to overproduction of algae, which can decrease water clarity and dissolved oxygen.

WATER QUALITY STATUS

Sediments of the upper tributaries were enriched in carbon

Sediments of St. Martin River, Herring Creek (Isle of Wight Bay), and Newport Creek (Newport Bay) contained significantly high concentrations of carbon, indicating that these areas were enriched in organic matter. The carbon content was also strongly associated with fine-grained sediments, especially

The phosphorus cycle

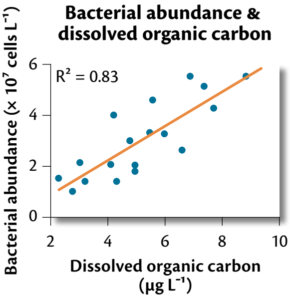


The availability of phosphorus to organisms is dependent on how much oxygen is present in the sediment.

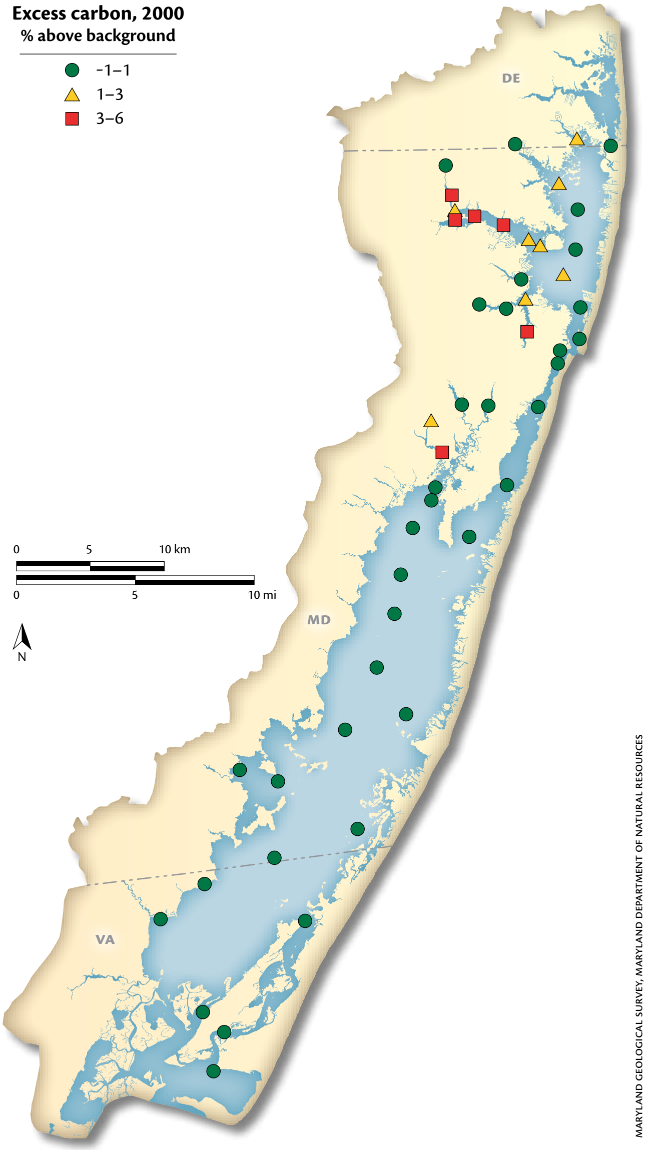
the clay content—the highest carbon concentrations were found in regions that had clay-rich sediments. This carbon enrichment may have an impact on benthic communities.[78]

Bacterial abundance & dissolved organic carbon were correlated

Naturally occurring bacteria in St. Martin River provide an important link in the food web and impact nutrient cycling. Samples taken in different sections of the river revealed that high organic nutrient concentrations were concurrent with bacteria, decreasing towards the mouth. Abundances were similar to those in nutrient-enriched systems such as Chesapeake Bay. Bacterial abundance displayed a strong correlation with dissolved organic carbon.[4]



Bacterial abundance and dissolved organic carbon were correlated in St. Martin River.[4]

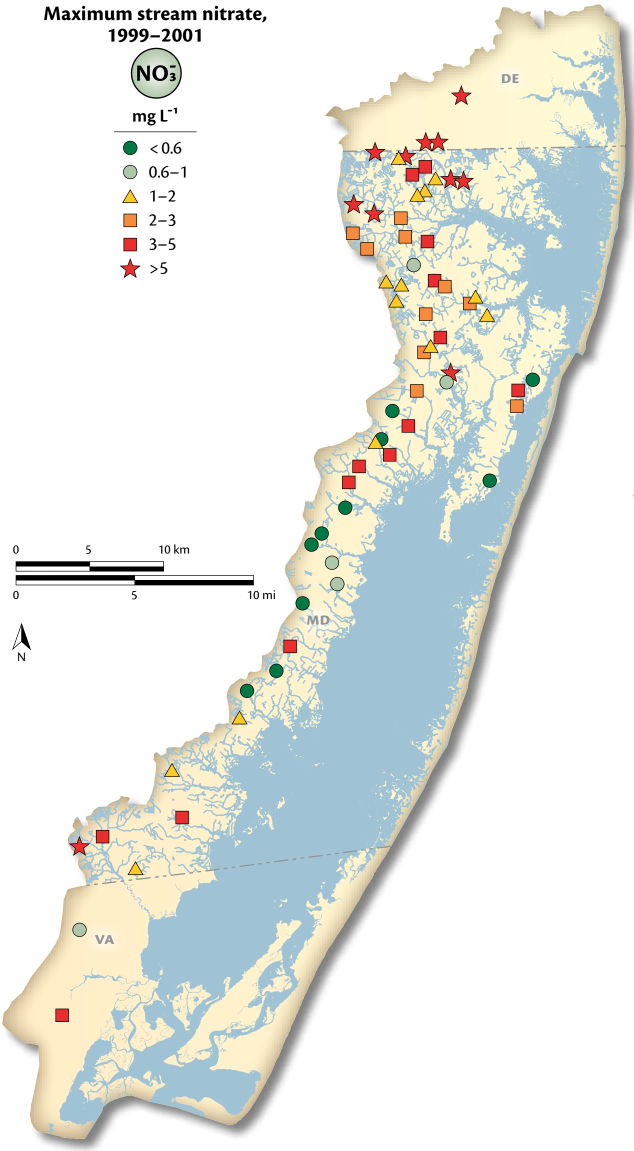


Excess organic carbon was calculated as the percentage above 'background'—that indicated by the natural clay content of the sediment, which varies throughout the Coastal Bays. Values between -1 and 1 are not considered excess, but are within the error of the prediction model.[78]

MARYLAND GEOLOGICAL SURVEY, MARYLAND DEPARTMENT OF NATURAL RESOURCES

High nutrient levels were observed in most Coastal Bays streams

Streams receive nutrients from runoff, groundwater, and atmospheric deposition. Nutrients are transported to the Coastal Bays via many small streams. Land use in the watershed is the source of these nutrients. Hog waste and chicken manure (including runoff from spray-field and spills and seepage from treatment lagoons), fertilizer applications, vehicle and power plant emissions, and sewer and septic systems all contribute nutrients. Many streams in the Coastal Bays were degraded from high (3–5 mg L^{-1}) and even excessive (>5 mg L^{-1}) levels of NO_3.[63] Similarly, high (0.03–0.07 mg L^{-1} [1.0–2.3 μM]) and excessive (>0.07 mg L^{-1} [>2.3 μM]) total phosphorus levels were also recorded in many of these stream systems.[63]



MARYLAND DEPARTMENT OF NATURAL RESOURCES, UNITED STATES GEOLOGICAL SURVEY, & ASSATEAGUE ISLAND NATIONAL SEASHORE/NATIONAL PARK SERVICE

Streams and upper tributaries were severely enriched with nitrate. Streams flowing into Sinepuxent Bay and northern Chincoteague Bay had the lowest total nitrogen. Note that the stream map was only available for the Maryland portion of the Coastal Bays.

Water quality was degraded, although better near Ocean City Inlet

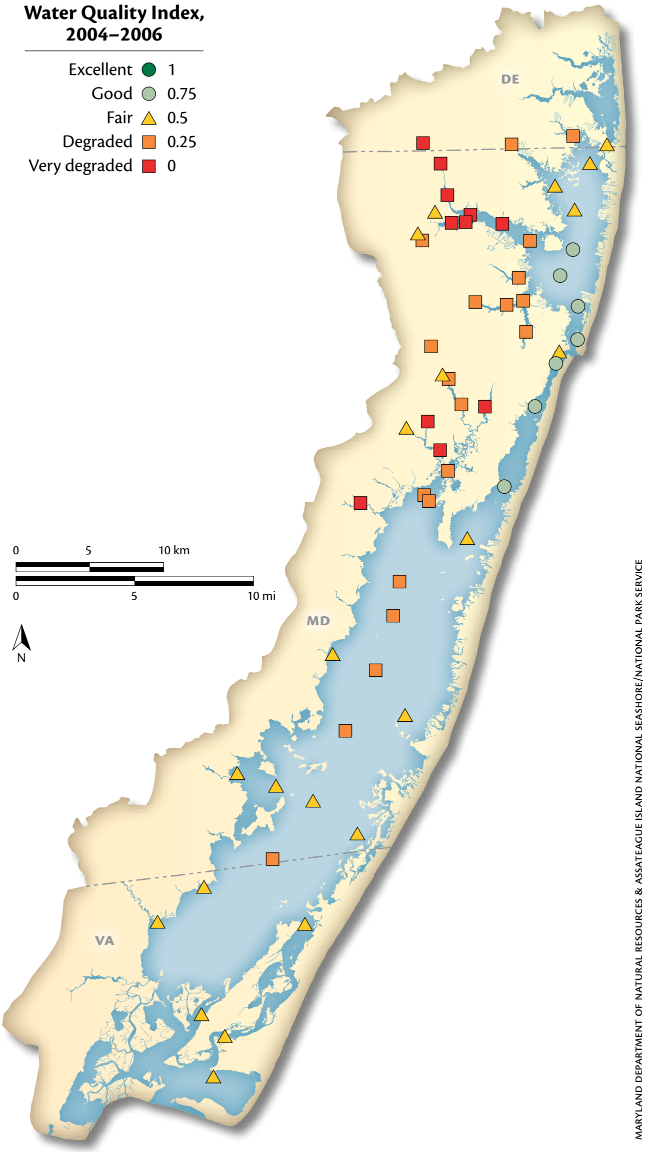
The synthesis of several key water quality measures results in a numeric indicator that can be compared between sites or watersheds. Like the familiar Dow Jones Index, which compiles information on multiple stocks and provides a simple number to track the economy, the Water Quality Index adopted here is just one approach for simplifying a range of complex parameters.

This Water Quality Index compared measures of four indicators (total nitrogen, total phosphorus, chlorophyll *a* [algae], and dissolved oxygen) to values that had been established as adequate to maintain healthy fisheries and seagrasses. The resulting index values ranged from 0.0 (poorest quality) to 1.0 (best quality).[73]

Between 2004 and 2006, upstream tributaries generally showed a degraded Water Quality Index (values < 0.5), largely due to high nutrient inputs, while the open bays ranged from degraded to good water quality. Sinepuxent Bay had the best overall water quality, while Newport Bay and St. Martin River ranked last. Water quality in Chincoteague Bay indicated fair to degraded conditions, while Isle of Wight and Assawoman Bays had good to fair water quality.

Water quality was fair to poor

Many sites throughout the system are displaying ecosystem effects of eutrophication, with high phytoplankton and reduced dissolved oxygen. Sinepuxent Bay had the best water quality conditions,



The Water Quality Index (2004–2006), synthesizing four water quality parameters, shows that the majority of the Coastal Bays had very degraded to fair water quality. A value of one means that all four indicators passed the threshold, a value of 0.75 means that three out of four indicators passed the threshold, etc.

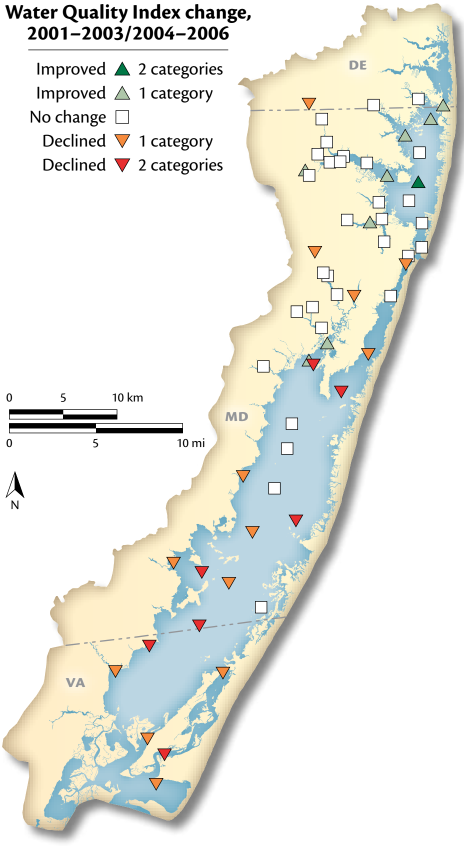
MARYLAND DEPARTMENT OF NATURAL RESOURCES & ASSATEAGUE ISLAND NATIONAL SEASHORE/NATIONAL PARK SERVICE followed by Isle of Wight, Chincoteague, and Assawoman Bays. Newport Bay and St. Martin River had poor water quality. The variability of seagrass coverage among segments is correlated to the subwatershed water quality index summaries. For more information on seagrass and water quality, see Chapter 14—*Habitats of the Coastal Bays & Watershed.*

The Water Quality Index suggested change

Although the Water Quality Index is meant to be a snapshot of current water quality conditions, a comparison of the current results to the last analysis done for the 2001–2003 period was made to quickly see differences between the two assessment periods. The change in the Water Quality Index results from

Measurement	Reference criteria
Total nitrogen	< 0.65 mg L^{-1} (46 μM)
Total phosphorus	< 0.037 mg L^{-1} (1.2 μM)
Chlorophyll *a*	< 15 μg L^{-1}
Dissolved oxygen	> 5 mg L^{-1}

Threshold values for the four indicators comprising the Water Quality Index.[2,8,9,17,18,34,41,43,45,46,56,57,59,62,64,68]



The change in the Water Quality Index from 2001–2003 to 2004–2006 shows that many places in the southern Coastal Bays have been degrading. Many of the sites that showed no change were already degraded.

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🟩 Good 🟨 Fair 🟥 Poor	Sinepuxent Bay	Isle of Wight Bay	Chincoteague Bay	Assawoman Bay	Newport Bay	St. Martin River
Total nitrogen (mg L^{-1})^{1}	🟩 0.4	🟨 1.0	🟩 0.6	🟥 1.1	🟥 2.0	🟥 1.8
Total phosphorus (mg L^{-1})^{1}	🟨 0.04	🟥 0.05	🟥 0.05	🟨 0.04	🟥 0.07	🟥 0.09
Chlorophyll *a* (μg L^{-1})^{2}	🟩 8.0	🟩 6.5	🟩 8.6	🟩 8.9	🟨 16.9	🟨 20.3
Dissolved oxygen (mg L^{-1})^{3}	🟥 4.9	🟥 3.7	🟥 4.2	🟥 4.1	🟥 4.5	🟥 2.9
Water Quality Index^{4}	🟨 ***0.65***	🟨 ***0.47***	🟨 ***0.43***	🟨 ***0.42***	🟥 ***0.21***	🟥 ***0.14***

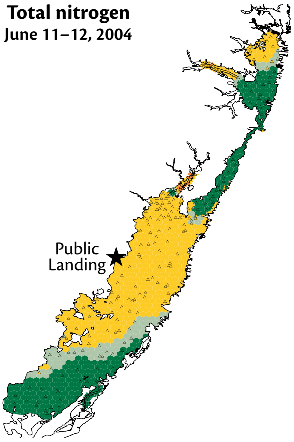
Water Quality Index and component measurement calculations for the Coastal Bays for the period 2004–2006.

1. Average of the median values (collected monthly over the entire year from 2004–2006) for all sites in each Coastal Bay.
2. Average of the median values (collected monthly March–November from 2004–2006) for all sites in each Coastal Bay.
3. 2nd percentile value (collected monthly June–September from 2004–2006) for all sites in each Coastal Bay.
4. Ranges from 0.0 (no reference criteria met at any site) to 1.0 (all reference criteria met at all sites). Calculated from total nitrogen, total phosphorus, chlorophyll *a*, and dissolved oxygen.

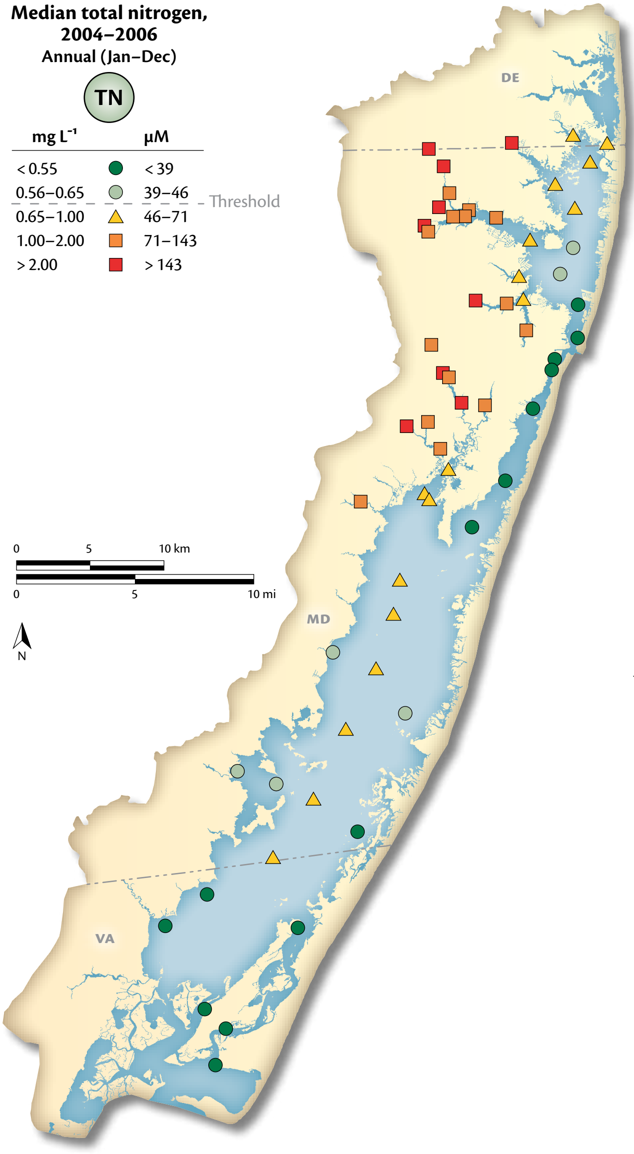
2001–2003 to 2004–2006 showed that some sites in the southern Coastal Bays degraded while some sites in the northern bays improved. The cause of the degraded conditions appeared to be due to sites failing the total phosphorus threshold, while improvements were related to sites passing the chlorophyll threshold. Many of the sites that showed no change were already degraded.

Upper tributaries were highly nitrogen-enriched

The upper tributaries, mostly in the northern Coastal Bays and Newport Bay, were severely enriched with nitrogen, while Assawoman and Chincoteague Bays were moderately enriched between 2004–2006. All these areas had concentrations exceeding thresholds for seagrass survival—67% of sites failed to meet the threshold (0.65 mg L^{-1} [46 µM]) over the period 2004–2006. Total nitrogen concentrations were lowest in well-flushed areas near the inlets (Isle of Wight, Sinepuxent, and Chincoteague Bays) and in areas where seagrass was found.


Total nitrogen
June 11–12, 2004

Total nitrogen during an intensive, two-day sampling event, which coincided with an intense brown tide bloom in the southern bays.[37]



Three-year status (2004–2006) of total nitrogen in the Coastal Bays.

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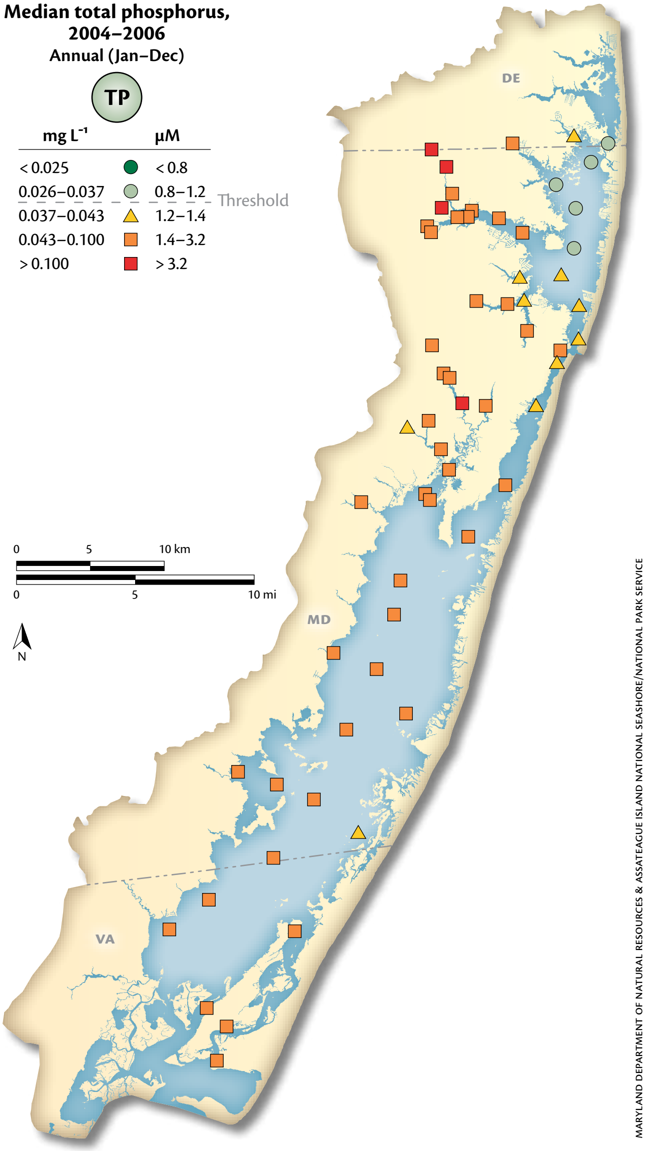
Phosphorus enrichment was more widespread than nitrogen enrichment

Nearly all of the Coastal Bays had phosphorus concentrations above the threshold for seagrassess (0.037 mg L^{-1} [1.2 µM]) between 2004–2006. Assawoman and Isle of Wight Bays had lower concentrations. Phosphorus concentrations were greatest in upper St. Martin River and Trappe Creek (Newport Bay); however, 92% of sites failed to meet the threshold over the period 2004–2006. Elevated phosphorus concentrations may be due to increasing frequency of low oxygen events, which mobilize phosphorus from the sediments, or due to phosphorus mobilization from the land due to soil saturation (see phosphorus section earlier in this chapter).



Three-year status (2004–2006) of total phosphorus in the Coastal Bays.

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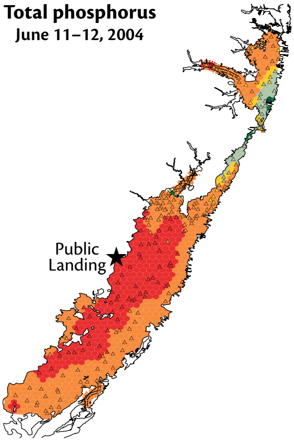
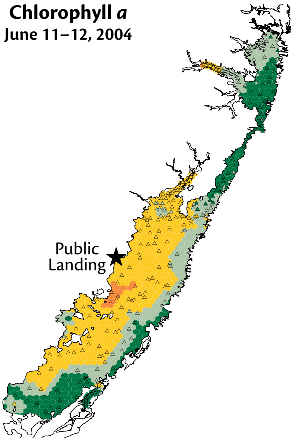
Total phosphorus
June 11–12, 2004



Total phosphorus during an intensive, two-day sampling event, which coincided with an intense brown tide bloom in the southern bays.[37]

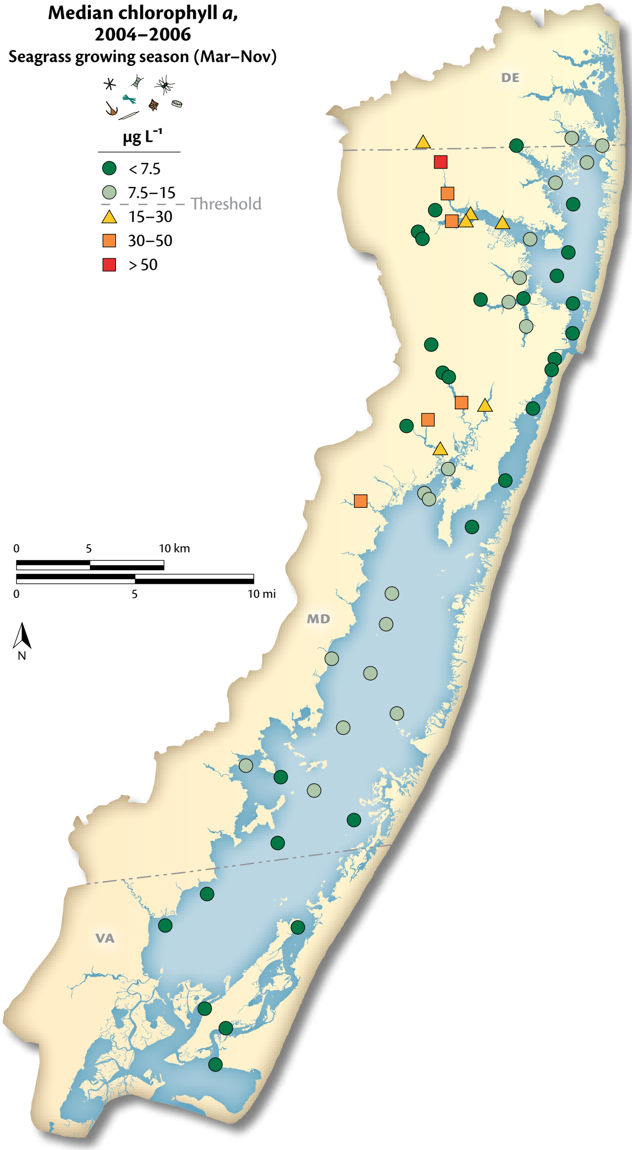
Algae levels were generally low in the open bays

Despite many areas exceeding nutrient thresholds in the Coastal Bays, chlorophyll *a* concentrations (an indicator of microscopic algae) were generally low in the open bays between 2004–2006. The quantity of chlorophyll *a* (the main pigment that makes plants green) in the water is an estimate of the amount of algae in the water. The chlorophyll threshold for seagrass survival (15 µg L^{-1}) was met in Isle of Wight, Sinepuxent, and Chincoteague Bays, while St. Martin River and upper Newport Bay failed. Probable reasons include that the majority of the algal biomass (organic matter) produced in the tributaries is deposited within these areas,[75] or that nutrients are sequestered in or utilized by other plant forms such as benthic microalgae (microphytobenthos), benthic macroalgae, and seagrasses instead of water column phytoplankton.[73] Overall, the water quality goal of all sites having less than 15 µg L^{-1} chlorophyll *a* was obtained at 78% of sites.



Chlorophyll *a*
June 11–12, 2004

Chlorophyll *a* during an intensive, two-day sampling event, which coincided with an intense brown tide bloom in the southern bays.[37]



Three-year status (2004–2006) of chlorophyll *a* in the Coastal Bays.

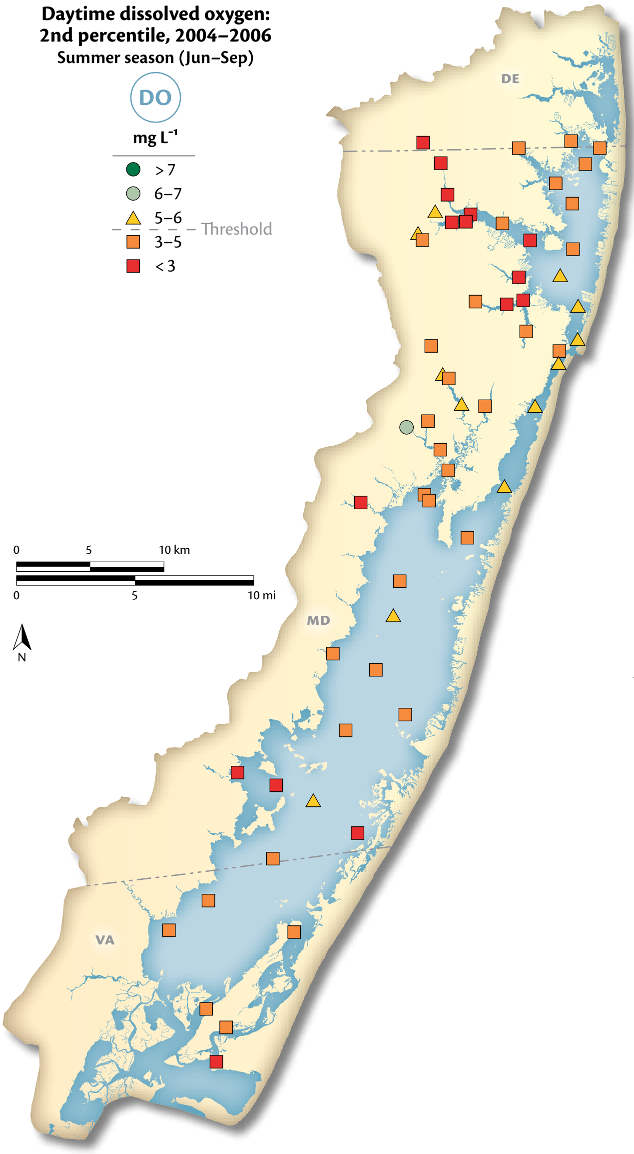
Oxygen values were low in some areas

Although the Coastal Bays are shallow lagoons which typically do not stratify, oxygen values were frequently low in some areas between 2004–2006. A total of 78% of sites monitored during the daytime failed the oxygen threshold for living resources (5 mg L^{-1}). High-frequency data (collected continuously in 15-minute intervals) further showed that dissolved oxygen was below the state standards 30–50% of the time during summer. Such daily, recurring low oxygen values provide a stressful environment, especially for fish and other biota.

Low dissolved oxygen may be due to high sediment oxygen demand from organically enriched sediments in many areas and from the decay of phytoplankton, macroalgae, seagrasses, and/or marsh vegetation.[3,75] These effects are all compounded by limited circulation within the bays, especially at stations far removed from the two inlets. Low oxygen may be occurring more frequently than in previous decades, thus modifying the pathways by which nutrients are consumed, recycled, and exported from the system (see the section on the nitrogen cycle earlier in this chapter).

Intensive temporal monitoring provides information on the duration of water quality problems

While monthly sample collections provide important information on seasonal and annual patterns of water quality variation, they can often miss events occurring on smaller time scales or during times of the day when it is impractical to deploy field



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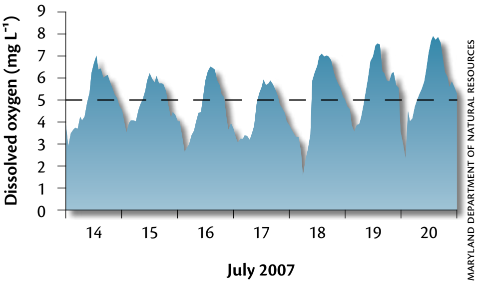
Three-year status (2004–2006) of dissolved oxygen in the Coastal Bays.

crews. Monthly sampling cannot provide data on the duration of poor water quality events. In order to assess these smaller time scales, four continuous monitoring sites have been sampled in the Coastal Bays—Bishopville Prong (St. Martin River), Turville Creek (Isle of Wight Bay), Newport Creek (Newport Bay), and Public Landing (Chincoteague Bay). The monitors measure a suite of water quality parameters every 15 minutes and transmit these data to a website for viewing (*www.eyesonthebay.net*).This real-time technology allows scientists, managers, and the public to view important water quality data the same day they are collected.

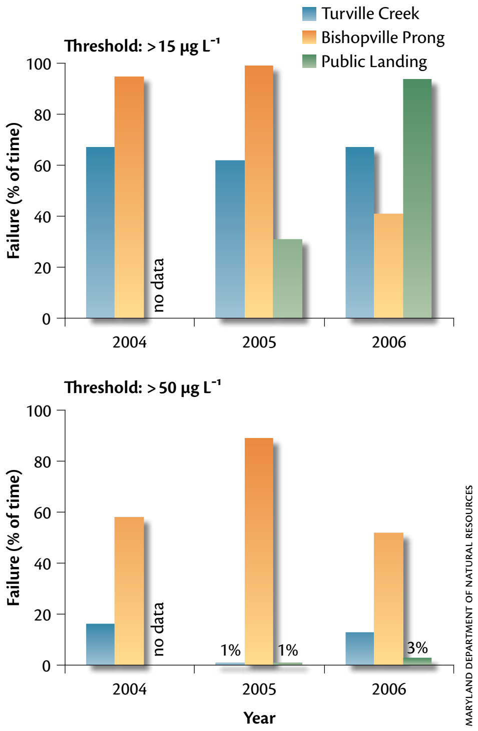
Continuous monitoring data also allows scientists to learn more about these river systems by tracking daily fluctuations in dissolved oxygen, chlorophyll, and other parameters.

Dissolved oxygen at Public Landing, July 2007



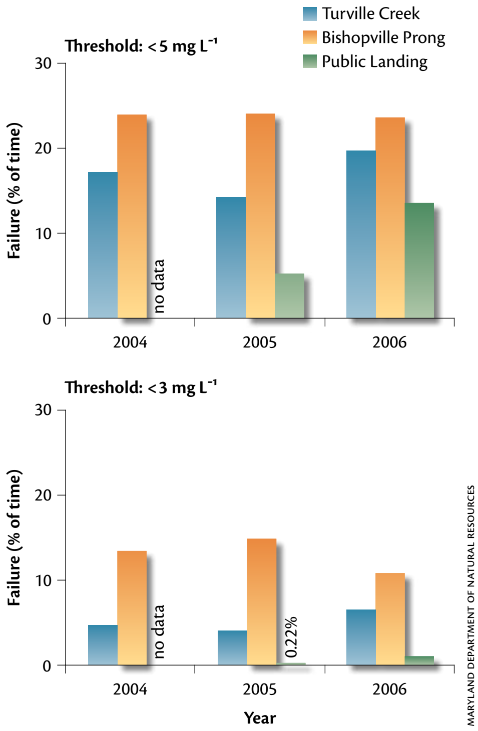
Daily fluctuations in dissolved oxygen at Public Landing in Chincoteague Bay, as recorded by the continuous monitor. Night-time dissolved oxygen levels are regularly lower than the threshold for sustaining fisheries (5 mg L^{-1}).

Chlorophyll *a* percent failure



Percentage of time that the threshold levels for chlorophyll *a* concentration was not met between 2002–2006. The 50 µg L^{-1} chl *a* threshold is based on modeled values for the Coastal Bays Total Maximum Daily Load (see Chapter 3—*Management of the Coastal Bays & Watershed*).

Dissolved oxygen percent failure



Percentage of time that the threshold levels for dissolved oxygen concentration was not met between 2002–2006. The 3 mg L^{-1} DO threshold is the general requirement for fish, crabs, and shellfish.[11]

By tracking these changes, a better understanding of the conditions surrounding events such as fish kills and harmful algae blooms can be gained.

Water quality mapping shows the majority of bays annually pass chlorophyll thresholds

Traditional monitoring programs have collected data monthly at fixed sampling locations. These measurements provide a good baseline for watershed assessment and long-term trends, but may miss small-scale gradients in water quality as well as near-shore habitats that are critical for seagrasses and other living resources. Water quality mapping has been conducted in a small outboard boat equipped with specialized sensors that record water quality data every three to five seconds as well as Global Positioning Satellite (GPS) coordinates for each sample as the boat moves along a prescribed track. This allows data to be aggregated spatially and temporally (due to monthly cruises) within watershed units to aid in the evaluation of entire systems. Evaluation of algal concentrations as measured by chlorophyll concentration in the water indicate that 13% of the Coastal Bays area failed in 2003, 15% in 2004, and 9% in 2005. Most of Assawoman, Isle of Wight, Sinepuxent, and Chincoteague Bays passed the thresholds. St. Martin River and Newport Bay consistently had a significant area failing the threshold. 2004 had the highest failure rate over all the Coastal Bays.

Coastal Bay	% of area failed		
	2003	2004	2005
Assawoman Bay	5.4	6.8	2.5
St. Martin River	67.2	40.8	29.1
Isle of Wight Bay	4.7	2.9	3.3
Sinepuxent Bay	0.3	39.3	1.5
Newport Bay	49.5	45.8	80.4
Chincoteague Bay	0.8	10.5	2.8
Total	**13.3**	**15.3**	**8.7**

Percentage of area of the Coastal Bays that failed the chlorophyll *a* threshold of 15 $\mu g\ L^{-1}$, as measured by the water quality mapping.

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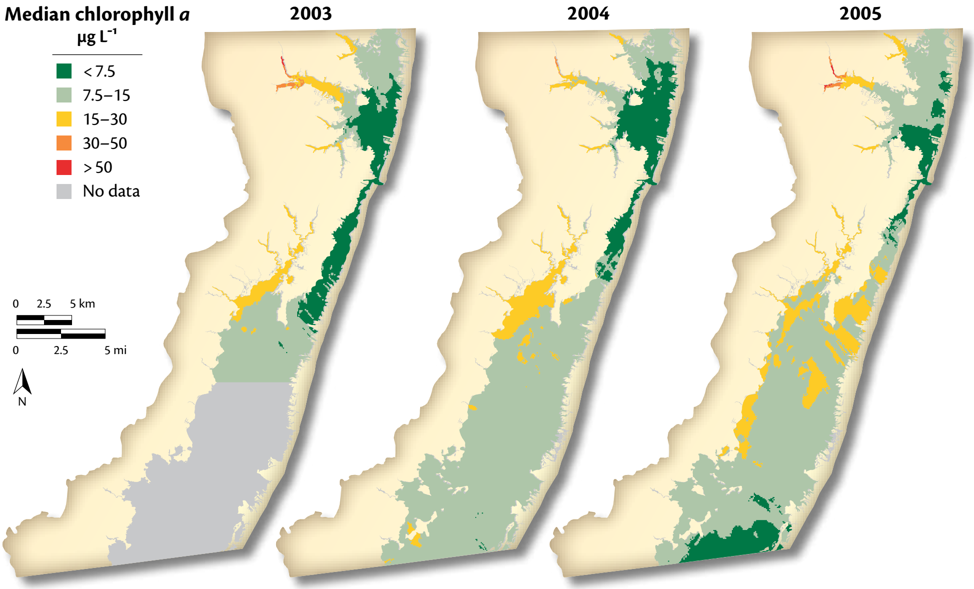

Water quality mapping results for chlorophyll *a* from 2003–2005, showing that algal concentrations increase with distance from the inlets. Data were collected monthly from April–October.

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The Coastal Bays are naturally turbid

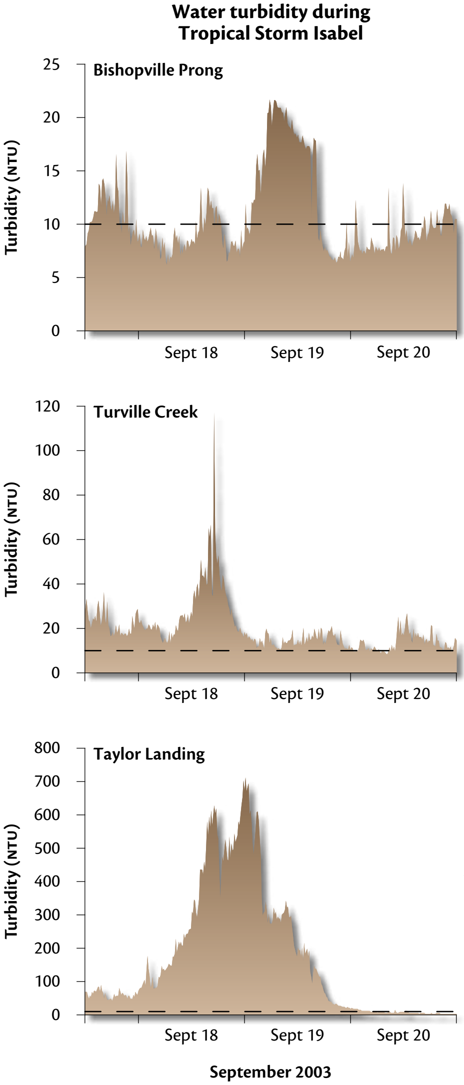
Turbidity, or opaqueness of water, is caused by a number of factors. Wind events often cause resuspension of sediments in the shallow Coastal Bays. Additionally, rain events can cause sediment runoff from land—see the three graphs (right) showing turbidity during Tropical Storm Isabel in September 2003. Lastly, algal blooms can also reduce water clarity—this is the common cause of turbidity in tributaries.

Brown tide blooms can also significantly decrease light penetration in the bays down to Secchi disk depth of ~1 ft or 30 cm (the Secchi disk is a device used to measure water transparency). In Long Island, brown tide blooms have blocked light to seagrasses for long enough to kill the plants.[16]

Light models suggest turbidity in the open bays is naturally high and may block the light necessary for seagrasses to grow in deeper water.[24] Because of naturally high turbidity, temporal variability, and limited data availability (monthly), water transparency was not thought to be a good response variable in these shallow coastal lagoons.

JANE THOMAS

Turbid water in eastern Assawoman Bay contrasts with the blue Atlantic Ocean water offshore.



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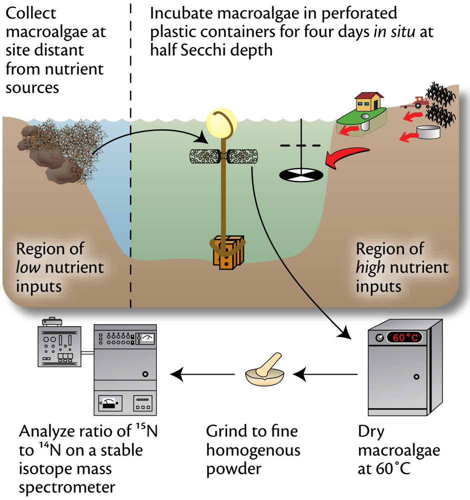
Turbidity at three sites during Tropical Storm Isabel in September 2003. Note the different scales of turbidity on the vertical axis. The relatively low precipitation during Tropical Storm Isabel suggests that this turbidity was wind-driven. The black dashed lines represent 10 NTU—DataFlow calibration has suggested that this is the threshold for seagrass survival.

High resolution turbidity data have been collected through use of continuous monitors since 2002. Turbidity and chlorophyll data were collected every 15 minutes from April to October, 2004 from Turville Creek. Simultaneously, the National Park Service collected rainfall data, allowing comparisons between turbidity and precipitation. These data showed that chlorophyll *a* tracked turbidity well throughout the year, while peak precipitation did not track turbidity nearly as well, although lag effects may be apparent. Other areas of the Coastal Bays may be more affected by precipitation or factors not tested, such as hydrology or wind.

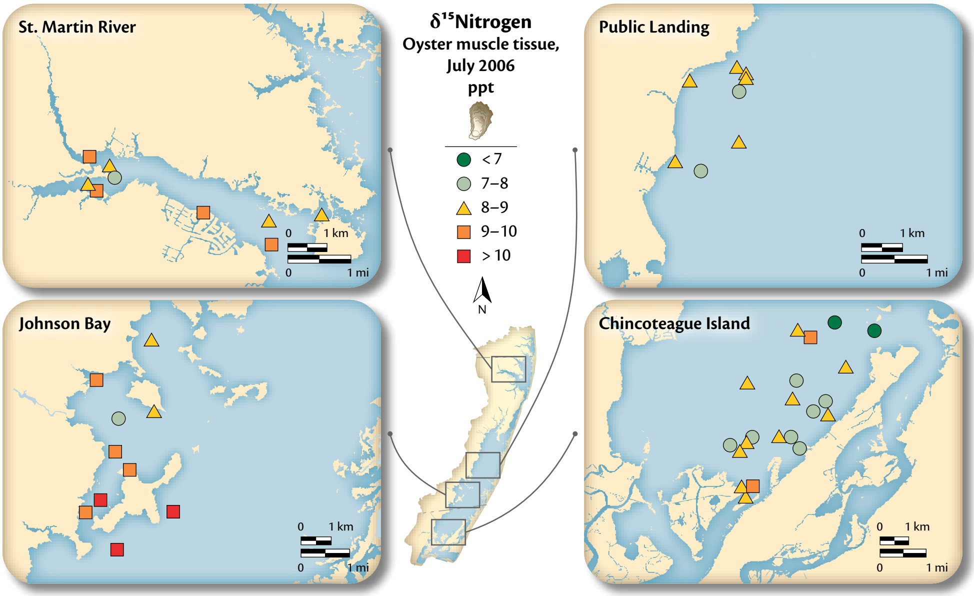
Bioindicators detect areas of nitrogen inputs

Nitrogen stable isotope analysis is a technique used to identify the source and distribution of sewage, septic, or agricultural nitrogen. Nitrogen (N) occurs in two naturally stable forms, ^{15}N and ^{14}N, with ^{14}N being the predominant form (99.6%). When compared to a standard, the ^{15}N to ^{14}N ratio (δ^{15}N) of samples can be used as a tracer of nitrogen source, including sewage and septic effluent and agricultural runoff, with a higher ratio indicating processed nitrogen (such as sewage, septic, or poultry litter) and a lower ratio indicating sources such as man-made fertilizer.[30,44,48,58] A technique has been developed to detect and integrate the effects of nitrogen inputs by analyzing δ^{15}N in bioindicator organisms (a macroalga [*Gracilaria*] and the Eastern oyster [*Crassostrea virginica*], in this case) actively deployed and incubated in the water.[14,36]

Nitrogen stable isotope methodology



Nitrogen stable isotope methodology involves using macroalgae as a bioindicator. This methodology has also been adapted for use with oysters as a bioindicator.



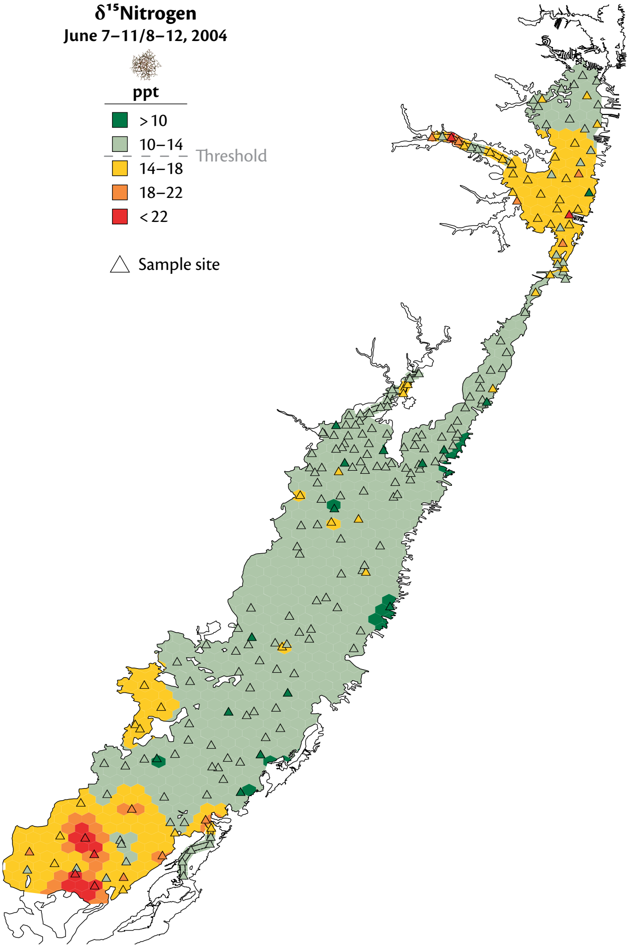
Oysters reveal patterns within regions. The longer deployment period (~two months) is more robust against short-term nutrient fluctuations, so longer-term patterns within regions can be found. δ^{15}N is measured as parts per thousand (ppt), expressed as the relative difference between the sample and a standard, with higher relative values indicating processed nitrogen. Note: the different scales used for the oyster data and the *Gracilaria* data on the following page are due to different ways animals and plants process nitrogen. Modified.[23]

δ^{15}N was high in macroalgae samples deployed in St. Martin River, Isle of Wight Bay, Johnson Bay (adjacent to Mills Island in Chincoteague Bay), and the southern portion of Chincoteague Bay (Virginia) during 2004, suggesting sewage or septic inputs or runoff from agriculture using poultry litter as fertilizer. Public Landing had low values of δ^{15}N, suggesting minimal loads from processed nitrogen sources. A spike of δ^{15}N inside Mills Island had an unknown source, although seagrass dieoff or marsh erosion could be potential sources, as microbial processing of plant matter could be elevating δ^{15}N in this area. An intensive regional study of these areas in 2006 using the oyster bioindicator revealed patterns within regions. This was particularly apparent in the southward trend in the Johnson Bay and Chincoteague Island regions indicating increasing anthropogenic effects.[23]

Macroalgae are abundant & distributed throughout the bays

Macroalgae, commonly known as seaweeds, are multicellular, photosynthetic organisms with less complex structural organization than vascular plants. They can be attached or free-floating and, with seagrasses and phytoplankton, form the base of the lagoon food web, collectively known as primary producers. Three main types of seaweed, divided by coloration, are present along the Atlantic coast—green, red, and brown. Macroalgae can appear as small fur-like clumps, moderate-sized branched specimens, or large leaf-like structures.

Shallow water estuaries and lagoons with a generally well-illuminated sea floor and moderate to high nutrient inputs can be optimal environments for macroalgal growth.[6] In relatively unimpacted Atlantic coast estuaries, seagrasses are the dominant primary producer, with macroalgae and phytoplankton present in varying, but lesser, concentrations. A shift in dominance to macroalgae, which grows faster than seagrasses in reaction to high



Nitrogen isotope distribution of macroalgae, integrated over four days in June, 2004.[37]

nutrient inputs, is indicative of excessive nutrient concentrations (eutrophication) and may represent an intermediate condition leading ultimately to a phytoplankton-dominated system (severe eutrophication).[22,50,51,69]

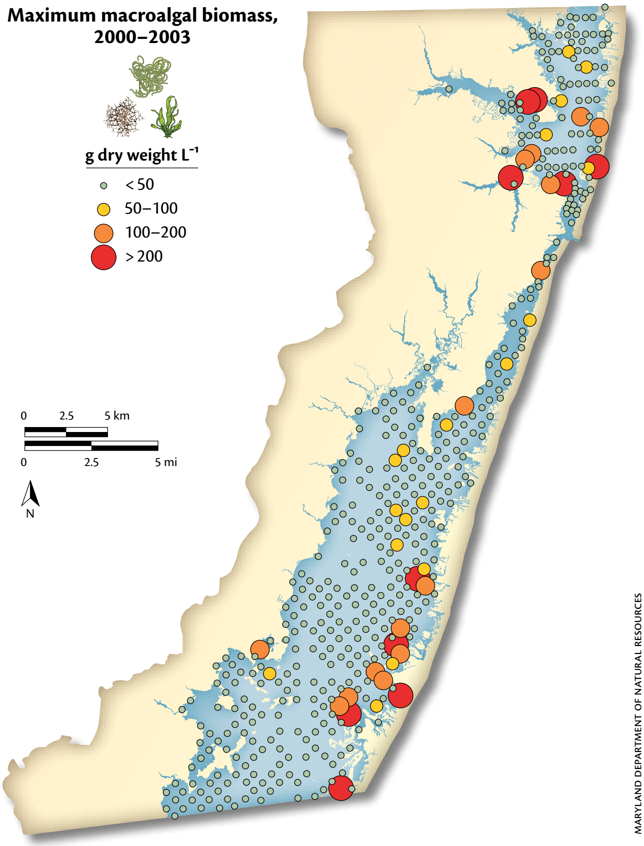
In order to understand this potential problem in the Coastal Bays, the distribution and biomass of macroalgae were investigated in tidal locations during winter, spring, summer, and fall seasons from 1998 through 2003. Eighteen taxonomic groups of macroalgae were identified in Maryland's Coastal Bays, including six green, eight red, and four brown macroalgae. There was no statistical difference in abundance among seasons. However, different taxonomic groups were dominant during different seasons. Total biomass averaged 4.3 grams per liter of water (g L^{-1}) for all samples, with peak biomasses of 316 g L^{-1} in Turville Creek and 444 g L^{-1} in Chincoteague Bay.[49]

Species of macroalgae that are classified as nutrient-responsive (i.e., grow in large concentrations when nutrient levels rise) made up 39% of the overall biomass and were dominant in the northern Coastal Bays and in seagrass beds in Chincoteague Bay. These investigations showed weak, but significant, relationships between nutrient concentrations and macroalgae volumes.[49]

Macroalgae occur at harmful levels in some areas

Although macroalgae are part of any healthy estuarine ecosystem, an excess of macroalgae can be problematic for aquatic life. Such excessive levels are categorized as harmful algal blooms (HABS). Bay animals can be impaired or killed as a result of decreased oxygen levels when algae die and decompose. In addition, boaters can experience propellor fouling, and the odor caused by decaying macroalgae is undesirable to local citizens and tourists. This can be a problem in dead-end canals where high nutrient loads and limited flushing make ideal environments for some macroalgae species.

Two types of macroalgae qualify as HAB species in two areas of the Coastal Bays. First, *Gracilaria* spp. in Turville Creek



Macroalgae surveys were conducted seasonally from 2000 to 2003 at 600 stations. Where macroalgae occurred, the maximum observed total biomass (all genera combined) for each station is represented on this map.

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was so dense from 1999 through 2001 that it caused the Maryland Department of Natural Resources fisheries monitoring program to relocate its long-term monitoring site in this tributary. This system is prone to low dissolved oxygen levels that are probably influenced by these blooms. Second, *Chaetomorpha* spp. levels in Chincoteague Bay were extremely dense from 1998 through 2001. This is believed to have impacted seagrass density in some areas as well as scallop restoration efforts (see nitrogen section earlier in this chapter).

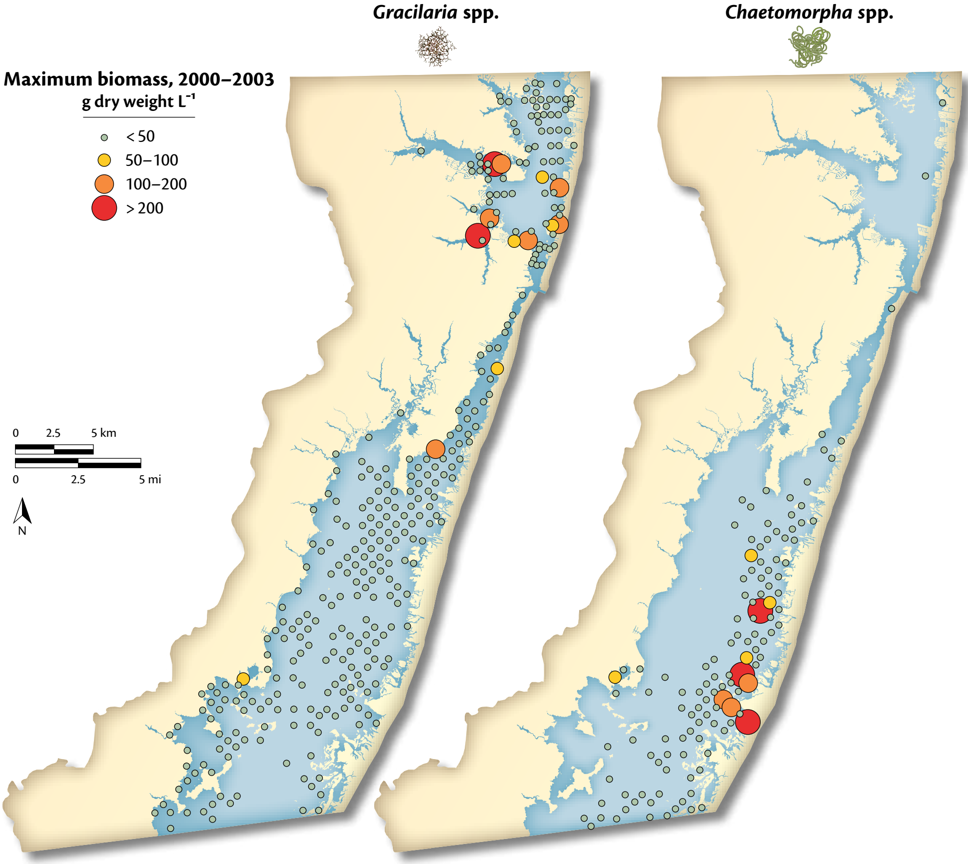
MARGARET MCGINTY

Gracilaria spp., a macroalgae that commonly blooms in the Coastal Bays.

TRENDS IN WATER QUALITY

Water quality has changed since the 1980s

Trend analyses allow resource managers to track changes in water quality over time and determine if management actions are helping to improve conditions in the Coastal Bays. Eighteen stations sampled by the National Park Service have a long enough water quality record (1987 or 1991



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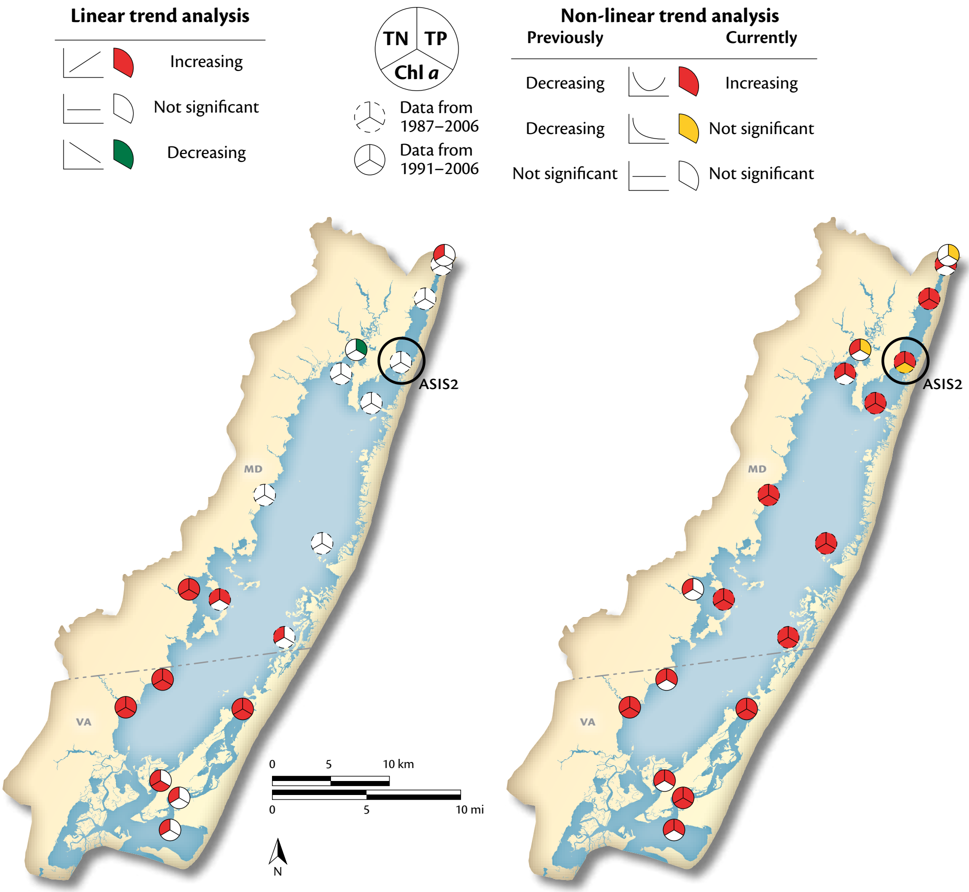
Biomass of *Gracilaria* spp. and *Chaetomorpha* spp. macroalgae in the Coastal Bays between 2000 and 2003.

to 2006) to determine meaningful trends. These stations are all in the southern Coastal Bays (south of the Ocean City Inlet) and include Sinepuxent, Newport, and Chincoteague Bays. Stations in southern Chincoteague Bay are currently more degraded than in the late 1980s—they have straight-line degrading trends in total nitrogen (TN), total phosphorus (TP), and/or chlorophyll *a* (chl *a*). The other nine stations showed few statistical differences in these parameters between 1991–2006. However, managers know that things have changed during the years between these endpoints and that conditions are currently getting worse.

Historically improving trends have reversed at many sites

Resource managers are often interested not only in how current water quality compares to past conditions, but also in what changes have happened over time that may impact the state of the bays. In other words, were conditions improving but then changed direction at some point in time or vice versa? Searching for reversals in trend direction is known as non-linear trend analysis. A significant trend reversal indicates a split between what was happening before and after the reversal (see figure below).



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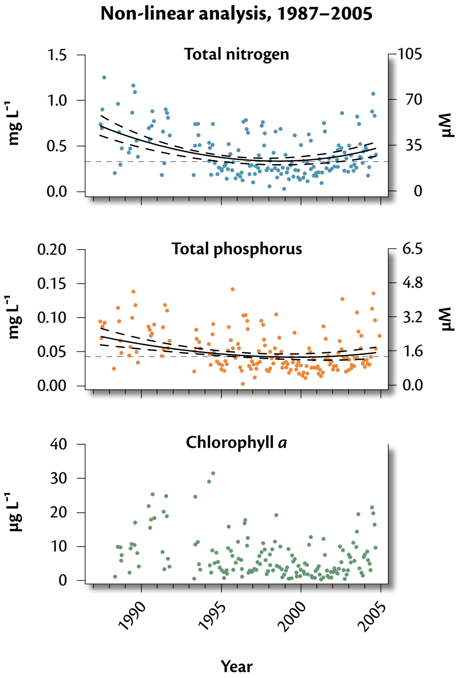
Linear (left) and non-linear (right) water quality trend analyses for total nitrogen (TN), total phosphorus (TP), and chlorophyll *a* (chl *a*) in Sinepuxent, Newport, and Chincoteague Bays. Station ASIS2 is the site of the linear and non-linear analysis on the facing page.[73]

In the Coastal Bays between approximately 1987 and 2006, 94% of the 18 National Park Service stations had significant trend reversals (from improving to degrading) in TN and 88% for TP. Nutrients may have been improving prior to the inflection due to improvements in wastewater treatment, a phosphate ban, and improved agricultural practices. Total nitrogen trends are driven by increases in dissolved organic nitrogen, likely from fertilizer sources on land.[29] Currently (post-reversal), total phosphorus concentrations may be caused by several factors. Recent evidence shows that phosphorus moves through shallow groundwater due to saturation in the soil.[67] Also, nutrient management plans for farms historically focused on nitrogen as the nutrient of primary concern, so even though current nutrient plans include phosphorus, improvements may take time as the excess phosphorus diminishes. Another factor may be that low dissolved oxygen is occurring at greater frequency, releasing more phosphorus from sediments (see phosphorus section earlier in this chapter). Since shallow groundwater may take 10 or more years to reach the Coastal Bays and serves as one of the dominant pathways for nutrient inputs to the bays, nutrient reduction strategies implemented today may require substantial time to improve water quality.



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These figures demonstrate non-linear analysis at station ASIS 2 in Sinepuxent Bay. *Top:* The solid black line is the quadratic curve fit of total nitrogen (TN) over time with surrounding dashed lines representing the upper and lower 95% confidence intervals. The horizontal dashed line (in gray) is the critical inflection value, or the hypothetical date where trend reversal occurred. Toward the end of the date range, the critical value is not encompassed by the confidence limits, so the trend in TN can be said to be significantly increasing. *Middle:* This figure is similar to TN, except the critical value for TP is encompassed by the confidence limits. Therefore, the post-critical value upward trend in TP is not significant. *Bottom:* No trends were found in the chlorophyll *a* data for this station.[73]

In addition, half of the 18 trend stations showed significant trend reversals in chl *a*. Most of these were in the middle of Chincoteague and Sinepuxent Bays, away from inlets. This pattern suggests that stations closer to inlets are flushed before phytoplankton has a chance to reproduce to high levels and produce high chlorophyll signals. Although chl *a* status has not surpassed threshold levels for seagrasses (see chlorophyll section earlier in this chapter), currently degrading trends indicate these thresholds may

BRIAN STURGIS

National Park Service personnel deploy remote water quality sensors in Chincoteague Bay.

be surpassed in the future unless management actions go into effect.

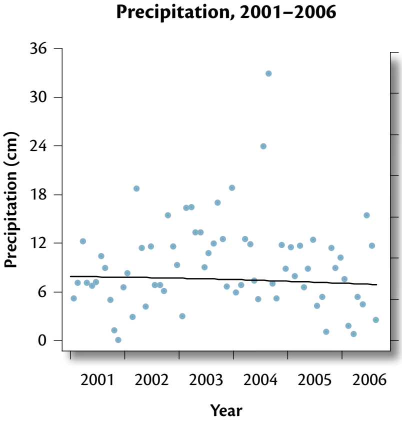
Increasing nutrients and phytoplankton are impacting seagrasses

Large areas of what was thought to be pristine habitat (i.e., Chincoteague Bay) show significantly degrading water quality trends. Seagrass beds, a major habitat of this system, are likewise declining. Throughout the Coastal Bays, seagrass abundance had increased between 1986 and 2001, with an overall 320% increase that may have been related to historically improving nutrient trends. However, these increases leveled off or declined over the next several years.[52,53] One possible explanation for the leveling off trend could be that seagrasses had occupied all viable habitat. However, recent analyses estimate that current seagrass coverage is only 49% of the total potential habitat goal for the Maryland Coastal Bays.[73]

Another hypothesis is that the leveling off of seagrass abundance coincided with the trend reversals in nutrients and chlorophyll *a* previously discussed. Further, seagrass experienced a large decrease in coverage during 2005. For more information on seagrasses, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Nutrient increases are rainfall-independent

Nutrient levels tend to increase during and after large amounts of precipitation due to increased runoff from the land. Rainfall varies in the Coastal Bays on an annual basis. However, statistical analysis relating precipitation data to nutrient levels shows no significant relationship.[47] In fact, no significant trend in precipitation exists between 2001 and 2005 (see graph), the time period during which most of the reversals in nutrient and chlorophyll *a* trends likely occurred. These findings provide evidence that rainfall is not a significant factor in recent nutrient trend reversals. For more information on the physical setting of the Coastal Bays, including rainfall patterns, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*



BUREAU OF LAND MANAGEMENT/ASSATEAGUE ISLAND NATIONAL SEASHORE, REMOTE AUTOMATED WEATHER STATION ASTM2

There is no significant trend in precipitation from 2001–2006. The line on the map represents the 'best fit' for the precipitation data, but does not represent a statistically significant relationship between precipitation and year, i.e., there is no trend in rainfall driving water quality trends.

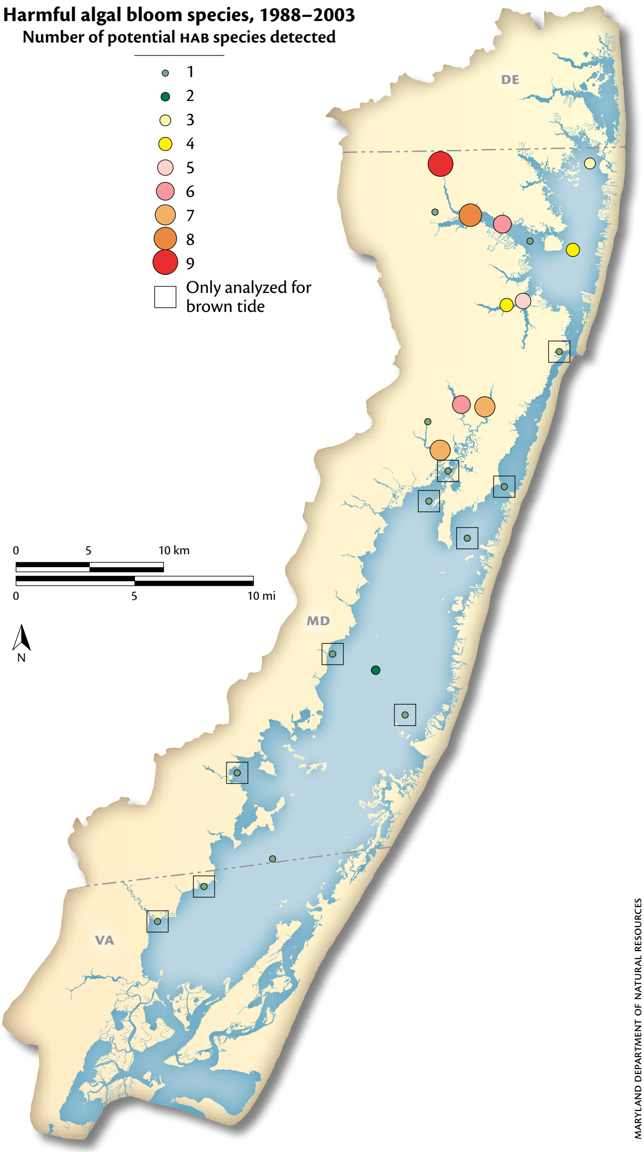
Harmful algal blooms are a potential problem in nutrient-impacted waters

Planktonic algae are important components of aquatic ecosystems, forming the base of the food chain by converting sunlight to energy through the process of photosynthesis. Certain types of algae may become harmful if they occur in an unnaturally high abundance or if they produce a toxin that can harm aquatic life or humans. HABs have the potential to cause economic losses related to decreased recreational and commercial fishing as well as tourism. Many have been related to increases of nutrients from human activities.

The Maryland Department of Natural Resources phytoplankton monitoring program has identified 12 *potentially* harmful algae taxa at 14 stations in the Coastal Bays. This equates to approximately 5% of the total phytoplankton species identified in the bays. The observed species include *Aureococcus anophagefferens* (brown tide), *Pfiesteria piscicida*, *Pfiesteria shumwayae*, *Chattonella* spp., *Heterosigma akashiwo*, *Fibrocapsa japonica*, *Prorocentrum minimum*, *Dinophysis* spp., *Amphidinium* spp., *Pseudo-nitzschia* spp., *Karlodinium veneficum*, and two macroalgae genera (*Gracilaria* and *Chaetomorpha*). Presence of HAB species is richest in the tributaries of St. Martin River and Newport Bay segments. These segments also contain the highest median concentrations of nitrogen (see nitrogen section earlier in this chapter), supporting the relationship between nutrient enrichment and algal blooms.

The presence of HAB species does not necessarily indicate toxic effects. Some of these algae species have complex life cycles and may produce toxins only under specific conditions or during certain life stages. *To date, no toxic activity has been detected among Coastal Bays phytoplankton***.** However, some species, including *Pfiesteria piscicida* and *Chattonella* spp., have produced positive toxic bioassays or generated detectable toxins in the nearby Delaware Inland Bays and Chesapeake Bay.

In addition to their potentially toxic properties, HAB species can pose a threat to the ecosystem due to their ability to produce large blooms which can negatively affect light and dissolved oxygen resources (e.g., brown tide). Brown tide has been the most widespread and prolific HAB species in the Coastal Bays in recent years, producing growth impacts to


Harmful algal bloom species, 1988–2003
Number of potential HAB species detected

Number of HAB species found at sampling stations.The presence of HAB species does not necessarily indicate a harmful algae bloom as these species are present in non-threatening background concentrations.

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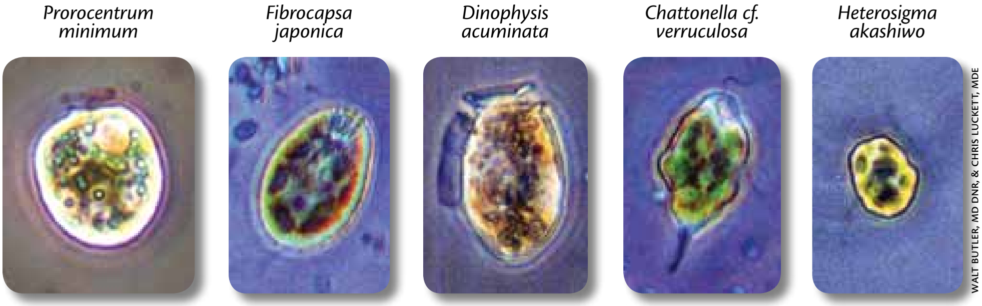


Prorocentrum minimum

Fibrocapsa japonica

Dinophysis acuminata

Chattonella cf. verruculosa

Heterosigma akashiwo

WALT BUTLER, MD DNR, & CHRIS LUCKETT, MDE

Some harmful algae under the microscope (~0.05 mm or 0.002 in).

juvenile clams in test studies and potential impacts to seagrass distribution and growth.[72]

Some harmful algal blooms are occurring more frequently

HABS are growing in frequency around the world and their ecosystem effects are being better recognized and understood. HAB events occur more often and are of longer duration than decades ago, and many more species are now recognized to have potentially harmful effects.[1,26,28]

An additional class of HAB species of growing concern in the Coastal Bays are raphidophytes, including *Heterosigma akashiwo* and *Chattonella subsalsa*. These two species are common in fish aquaculture operations (although there are not any of these operations in the Coastal Bays) and have been responsible for fish kills in many parts of the world including the Delaware Inland Bays. For more information on non-harmful algae, see Chapter 14—*Diversity of Life in the Coastal Bays*.

Brown tide is a problem in the Coastal Bays

In the Coastal Bays, brown tide is fairly common.[29] Brown tide was first identified in the Coastal Bays in the late 1990s, although evidence from earlier data suggests that it was present, although in low abundance, from at least the early 1990s.[66] Brown tide blooms can have serious impacts on shellfish populations (scallops, hard clams, and mussels) and seagrasses. Brown tide was first identified in the United States in northeast coastal embayments in 1985.[13] Blooms of this organism wiped out the seagrass beds of Long Island and with it the lucrative scallop fishery. Brown tide blooms are categorized based on their potential impacts to living resources (see "Categories of brown tides" sidebar).

Bloom intensity and distribution has varied annually across the Coastal Bays.

Categories of brown tides[25]

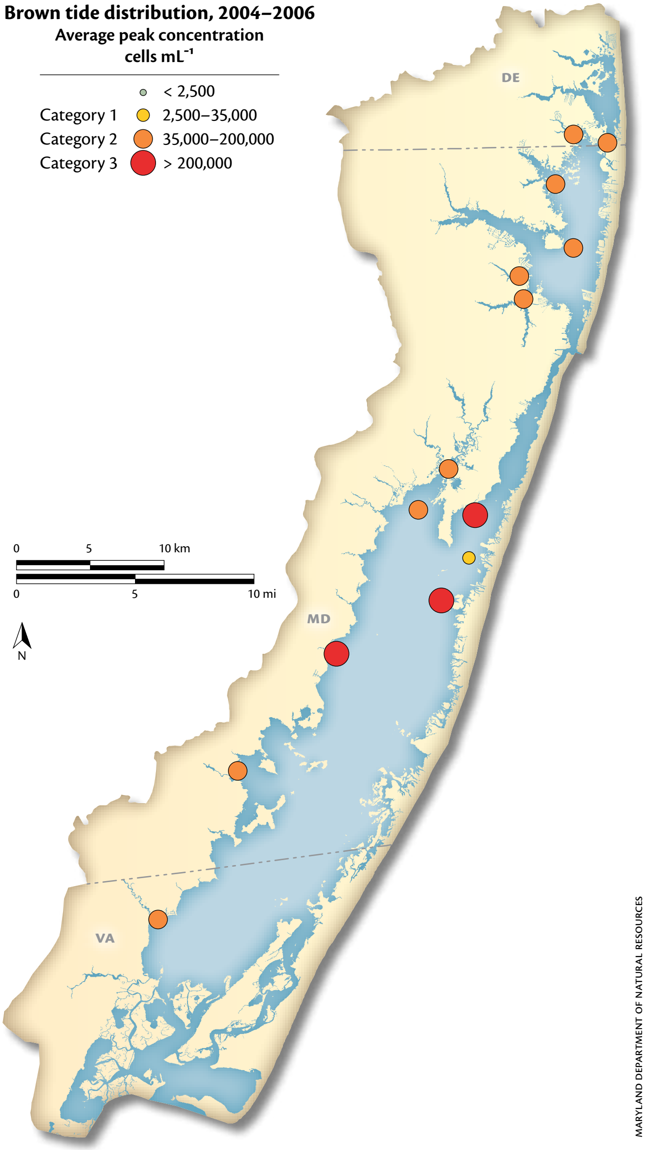
Category 1: <35,000 brown tide cells per milliliter of water (cells mL^{-1}):
- No observed impacts.

Category 2: 35,000–200,000 cells mL^{-1}:
- Reduction in growth of juvenile hard clams.
- Reduced feeding rates in adult hard clams.
- Growth reduction in mussels and bay scallops.

Category 3: >200,000 cells mL^{-1}:
- Water becomes discolored yellow-brown.
- Feeding rates of mussels severely reduced.
- Bay scallops fail to reach maturity.
- No significant growth of juvenile hard clams.
- Negative impacts to seagrass due to algal shading.
- Copepod production reduced and negative impacts to protozoa.

In 1999, Category 2 blooms were broadly distributed, including Montego Bay and Ocean Pines canals in Isle of Wight Bay and all of the southern bays; lowest concentrations were found in Virginia. In 2000, 2001, 2003, and 2004, no significant blooms were observed in the northern bays while the southern bays experienced Category 3 blooms. Peak concentrations for the southern bays typically occurred at Public Landing in Chincoteague Bay during early to mid-June.

During 2003, the southern bays were hit by the most spatially and temporally extensive blooms since the inception of the monitoring program. This occurred in a year when no other areas in the northeast U.S. experienced a significant brown tide event. The bloom peaked in June and ended in mid-July. Highest concentrations were at Green Point in Chincoteague Bay on June 10 (~745,000 cells mL^{-1}), and other exceptionally high cell counts were observed throughout Chincoteague Bay. Only during 1999, 2002, and 2006 were widespread Category 2 blooms found in northern and southern bays. Cool spring temperatures during 2005 kept brown tide from blooming in May. However, rapidly increasing water temperatures in early June led to a brief bloom in the southern bays. Here, water temperatures quickly exceeded the optimum growth range for brown tide and the bloom crashed.



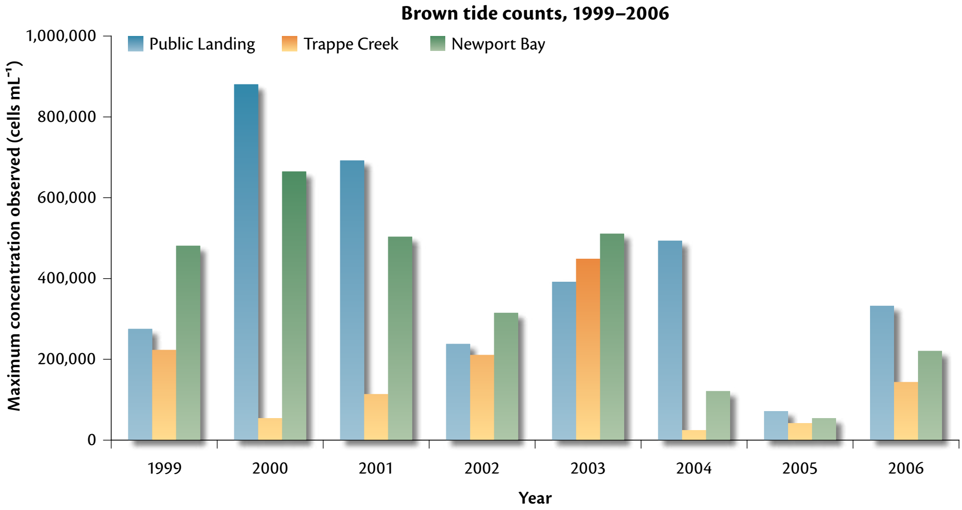
Brown tide distribution, 2004–2006
Average peak concentration
cells mL^{-1}

Occurrence of Category 1 or higher brown tide blooms.

In 2006, brown tide bloomed as Category 2 in the northern bays and Category 3 in the southern bays through most of June.

Organic nitrogen is a factor in brown tide trends

Coastal Bays water quality has been declining over the past 5–10 years, as evidenced by increases in total



Abundance of brown tide cells at three sites in the Coastal Bays area over time using various methodologies.

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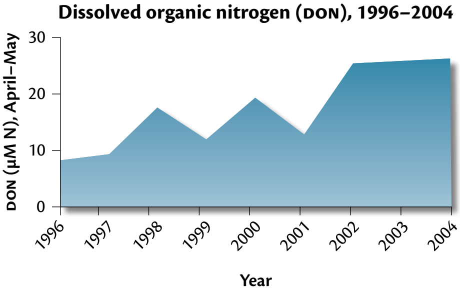
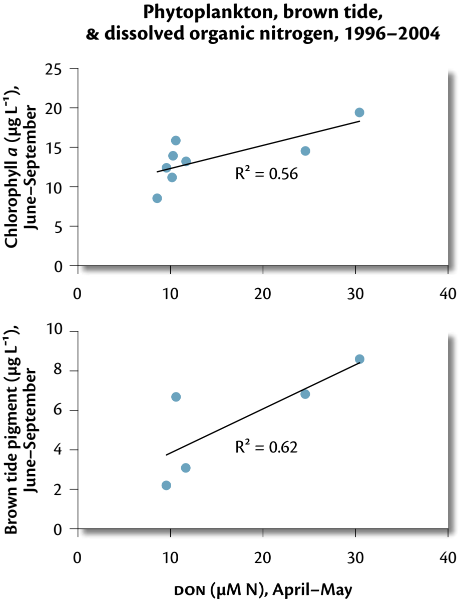
nitrogenous nutrients and in outbreaks of brown tides.[29,73] However, the increases in total nitrogen are not a function of increases in inorganic nitrogen, but rather a function of increases in dissolved organic nitrogen (DON).[29] For more information, see Chapter 9—*Chincoteague Bay.*

While most algae prefer inorganic nitrogen, some algae, such as brown tide, can use organic nitrogen. A near-decadal record (1996–2004) demonstrates that an approximate doubling of DON over this time period correlates with a similar increase in total chlorophyll, and an even larger increase in the proportion of chlorophyll that is composed of brown tide.[29]



Spring-time concentrations of dissolved organic nitrogen (DON) at Public Landing have increased almost three-fold since 1996.[29]

Additionally, on an annual basis, overall chlorophyll levels and strength of the brown tide blooms were related to the availability in DON that developed during the prior months. Brown tide preferentially uses DON for its nutrition

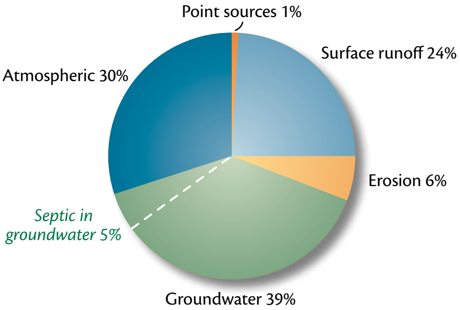


Spring-time concentrations of DON at Public Landing correlate with summer algal concentrations, including brown tide. Chlorophyll *a* is used to estimate total microalgal abundance, while brown tide pigment is used to estimate brown tide abundance.[29]

GEORGE BONIELLO

Summer brown tide bloom at Public Landing in Chincoteague Bay.

Nitrogen inputs to the Coastal Bays



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The majority of nitrogen inputs to the Coastal Bays come from surface runoff, groundwater, and atmospheric deposition. Data are for the Maryland portion of the Coastal Bays.

over inorganic nitrogen forms and thus is a symptom of organic, rather than inorganic, nitrogen-based eutrophication.[29]

NUTRIENT LOADS & BUDGETS

The Coastal Bays have mixed levels of nutrient loads

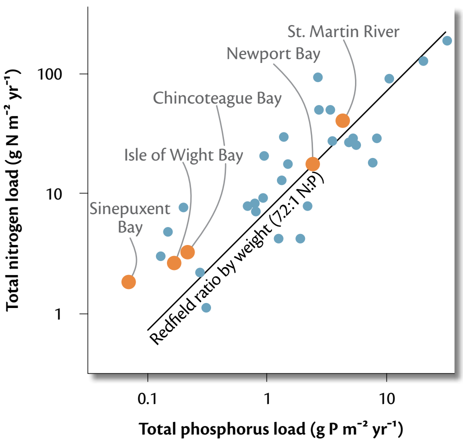
Data for 34 estuaries, including some coastal lagoons, where inputs of both total nitrogen (N) and total phosphorus (P) (g N or P m^{-2} yr^{-1}) were available, show that there is a very large range in N and P inputs among estuaries.[5] Nitrogen loads varied by a factor of almost 200 and phosphorus by just over 300—the majority of these coastal ecosystems had N and P inputs (as g N or P m^{-2} yr^{-1}) ranging from 5–50 and 1–10, respectively. Despite the different biogeochemistry of N and P, there was an obvious correlation between loading rates of these elements. Loading rates for a few systems had high N:P ratios because sewage was a major nutrient source and P, but not N, was removed at treatment facilities. In others, elevated N:P ratios were the result of diffuse source inputs that were naturally more enriched in N (mainly NO_3^-) than P.

Subembayments of Maryland's Coastal Bays had quite different input rates, ranging from among the lowest (Sinepuxent Bay) to quite high (St. Martin River). Finally, it is important to note that nutrient inputs alone are not generally sufficient to predict the eutrophication status of an estuary. Several investigators have noted that estuarine morphology, water residence times, light conditions, and biological communities all have potentially strong influences on the impact of loading rates.

Where is nitrogen coming from?

Large-scale analyses are needed to improve our understanding of how

Total nitrogen vs. total phosphorus



Subembayments of the Coastal Bays have varying N:P ratios.[5]

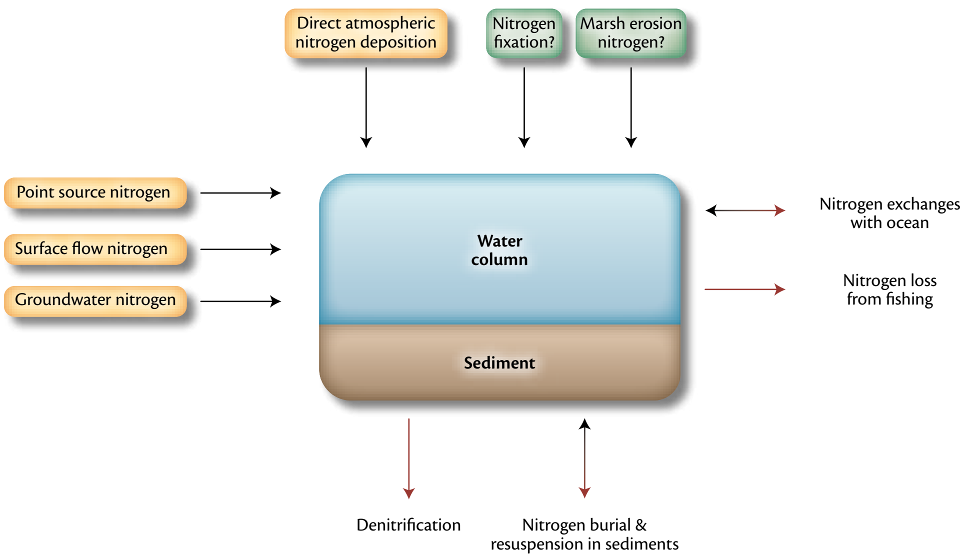
nutrients influence coastal systems, as well as how estuarine dynamics influence the fate of nutrients once they enter the bays. Construction and evaluation of nutrient budgets at the scale of whole ecosystems, such as the Coastal Bays, provide a conceptual framework from which to gain such a perspective. The type of budgets considered here include all major nutrient inputs and loss terms for annual time periods. With these budgets we can evaluate such issues as: which of many nutrient inputs are largest; what are the largest nutrient loss terms; and where can we spend restoration money for the biggest return.

Nitrogen budgets used to reveal sources

Simple mathematical models, such as the one represented below, are often used by scientists to organize thinking about an issue. The blue box represents the water in the Coastal Bays where nitrogen is available to be used by a variety of plants. The brown box at the bottom represents the bottom sediments of the Coastal Bays where most of the nitrogen is stored and where several very important nutrient processes occur. The orange boxes represent sources of nitrogen to the Coastal Bays and the green boxes indicate other nitrogen sources, the magnitude of which are currently uncertain but thought to be small. Finally, the red arrows indicate the losses of nitrogen from the Coastal Bays.

Nitrogen can be exchanged with the ocean on a tidal basis, but nitrogen is probably exported from the Coastal Bays to the ocean on a seasonal and annual basis. When fish and shellfish are harvested, some nitrogen, probably a small amount, goes with them and thus represents another loss. The two major nitrogen loss pathways are denitrification and long-term burial of nitrogen in the sediments. Denitrification is a process where biologically available forms of nitrogen (e.g., ammonium or nitrate) are transformed by bacteria to nitrogen gas (N_2), the same form of nitrogen that makes up most of the atmosphere we breathe. Finally, nitrogen, mainly in the dead bodies of small plants and animals,

Conceptual model of nitrogen exchanges



This conceptual representation of a mathematical model represents nitrogen inputs and exports from the Coastal Bays.

can be buried in the bottom sediments of the Coastal Bays. Some of this material is rapidly recycled and used again and again by plankton, but a portion is resistant to decomposition and is buried, essentially becoming disconnected from the everyday biology of the Coastal Bays. As more is learned about the structure and function of coastal lagoons, these simple models can be expanded to include new processes.

Reductions to all sources will improve water quality

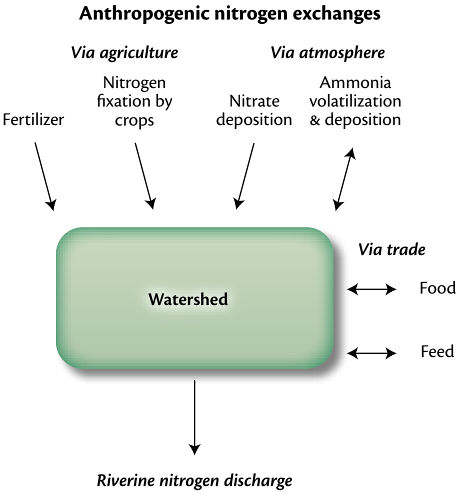
Nitrogen inputs to the Coastal Bays are estimated to be approximately 1.3 million kg (2.9 million lb) total nitrogen per year. Groundwater (39%), atmospheric deposition (30%), and surface runoff (24%) are the main pathways.[74] The major sources of nutrients to groundwater include septic systems and fertilizer use on farmland as well as residential/commercial lawns. The major sources of nutrients to surface runoff (water that runs off the land immediately after a rain storm) include fertilizer, pet/animal wastes, and runoff from impervious surfaces. The burning of gasoline, oil, or coal in automobiles and power plants releases nutrients into the air which are later deposited into the bays through rain or settling. The amount of nutrients coming from an area is largely dependent on the predominant land use, with agriculture and developed lands generally contributing more nutrients than wetlands and forests.

Agriculture is a primary source of nitrogen

Net anthropogenic (human-caused) nitrogen inputs to the watersheds of the Coastal Bays were calculated using methods similar to those of previous studies.[10,38,39] This approach balances the trade of agricultural products such as food for people or feed for livestock as either inputs or as outputs of nitrogen to the watershed. Major anthropogenic nitrogen inputs came via agriculture from fertilizer applications or from nitrogen fixed by crops, such as legumes, and via atmospheric deposition of nitrate or ammonium.

Anthropogenic nitrogen inputs were calculated from county-level data for Sussex (Delaware), Worcester (Maryland), and Accomack (Virginia) Counties, which include the watershed of the Coastal Bays. Data were prorated to account for only the portion of the county within the Coastal Bays watershed. Nitrogen input as food was calculated based on the number of people in the watershed multiplied by 6.4 kg (14.1 lb) nitrogen per year as an estimate of food nitrogen demands. The largest net inputs of nitrogen were from net feed imports to Sussex and Worcester Counties amounting to 106 and 71 kg nitrogen ha^{-1} (95 and 64 lb acre^{-1}) per year, respectively (per ha/acre of the whole county), mainly for poultry.

Loadings to cropland are about 10 times those to non-cropland and are dominated by applications of animal waste. Note that manure is not considered a net input to the Coastal Bays watershed because most of the manure applied to the land



A conceptual model for anthropogenic nitrogen exchanges for watersheds.

	Inputs (kg N ha^{-1} yr^{-1})				Discharges		
Coastal Bay	**Cropland**	**Non-crop**	**Food**	**Anthro. inputs total**	**Nitrate N**	**Total N**	**% input disch.**
Little Assawoman Bay	55	6.1	3.8	65	5.9	9.9	15
Assawoman Bay	57	6.1	2.5	65	6.1	11	16
Isle of Wight Bay	75	5.4	1.6	82	6.9	11	14
Sinepuxent Bay	35	7.3	1.6	43	3.1	5.8	13
Newport Bay	63	5.9	2.0	71	5.3	8.6	12
Chincoteague Bay	41	6.9	1.1	49	3.4	6.1	13

Anthropogenic nitrogen inputs to Coastal Bays watersheds entering as loads to cropland, non-cropland, or food imports, expressed per hectare of the entire watershed, and discharges of nitrate and total nitrogen from the watersheds compared to net anthropogenic inputs to the watersheds (expressed as per hectare of the watershed land area). The percentage of the net input discharged as total nitrogen is also shown.

in the watershed is produced within the watershed. The nitrogen which is incorporated into manure is supplied by other agricultural nitrogen inputs to the watershed. At smaller spatial scales, such as the scale of individual crop fields, manure nitrogen can certainly be an important input.

The amount of animal waste nitrogen input to croplands is uncertain due to unknown losses from ammonia volatilization, which can release half the waste nitrogen to the atmosphere,[60] as was assumed in this calculation. The proportion of the total nitrogen loading coming through croplands ranges from 80% for the Sinepuxent Bay watershed to 91% for the Isle of Wight Bay watershed.

Discharges of nitrate and total nitrogen from the watershed to the Coastal Bays were calculated from the land use composition of the watershed. The calculation used relationships between the percentage of cropland[39] or the percentage of developed land,[40] and the concentrations of nitrate or total nitrogen in water discharged from the watershed.

The amount of water discharged was based on average water yields in the region,[39] adjusted upward for the effect of impervious surfaces in developed lands.[40] Most of the total nitrogen discharged is in the form of nitrate. The total nitrogen discharged is only 13–16% of the net anthropogenic nitrogen input. The relatively low amount of nitrogen discharge compared to the input to the watershed has been noted in many watersheds.[35]

Despite many uncertainties in estimating nitrogen loads to and discharges from watersheds, agriculture emerges as the primary source of nitrogen load and discharge for the Coastal Bays watershed. The biggest single anthropogenic input is likely to be the import of poultry feed into the watersheds.

The biggest nitrogen loss from the watershed may be either ammonia volatilization or denitrification. The relatively low amount of nitrogen discharged from the watershed to the bays compared to the amount of nitrogen loaded onto the land suggests that most of the net nitrogen input is denitrified, released as ammonia gas, or stored in the watershed (in plant biomass, soil organic matter, or groundwater).

Agriculture exports 7% of nitrogen input

Mathematical models can also be used to estimate nitrogen loadings to coastal waterbodies by developing annual budgets of the inputs and potential outputs of nitrogen to the watershed draining into the bay or estuary. In 2005, this was performed for the southern Coastal Bays, including Sinepuxent Bay, Newport Bay, and Chincoteague Bay (both Maryland and Virginia).[12]

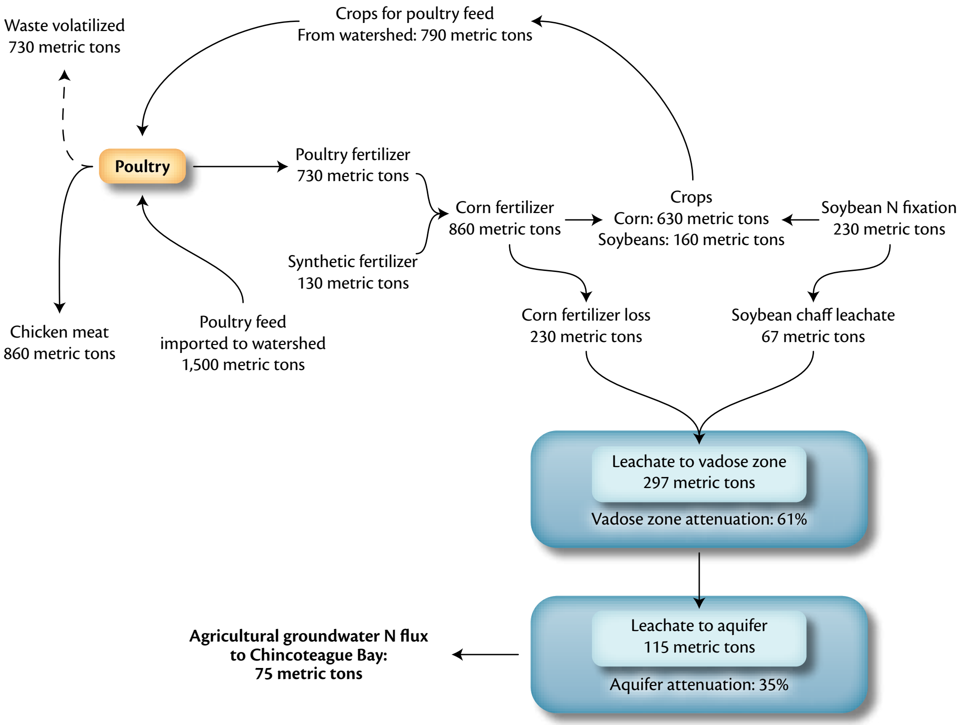
Despite the large agricultural base in the watershed, not enough corn and soybeans were produced to feed the 27 million poultry that were grown there. An additional 1,500 metric tons (1,650 U.S. tons) of nitrogen (as poultry feed) were imported to satisfy the poultry nutritional requirements.

Approximately 68% of the feed grown locally used poultry manure as fertilizer (i.e., recycled the nutrients from manure to plants). An additional 130 metric tons (143 U.S. tons) of nitrogen was imported into the watershed as synthetic fertilizers. A watershed model developed for a shallow bay in Cape Cod[70,71] and applied to the Maryland Coastal Bays determined that of the total 860 metric tons (948 U.S. tons) of nitrogen imported and generated in the watershed, about 6.7%, or 58 metric tons (64 U.S. tons), of nitrogen entered the Coastal Bays. If nitrogen fixed by soybeans is included, 6.9% or 75 metric tons (83 U.S. tons) of nitrogen reached the Coastal Bays in 2000.

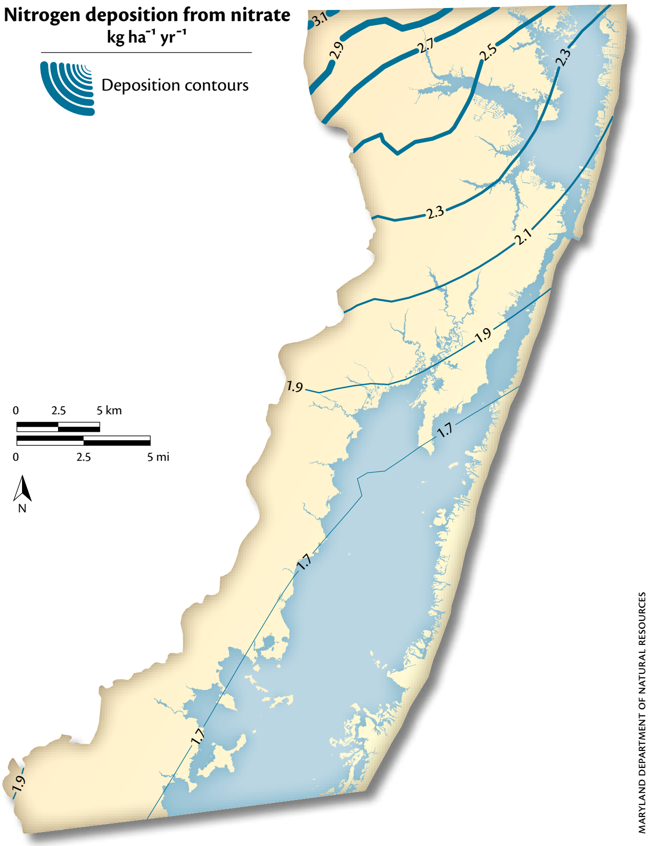
Air pollution is a large source of nitrogen

Approximately one-third of the total nitrogen inputs to the Coastal Bays may be derived from the atmospheric deposition of man-made emissions.[47] Model-derived estimates of anthropogenic nitrate deposition over the Maryland Coastal Bays showed a gradient in deposition increasing from the coast inland.

Nitrogen budget for the Coastal Bays



Model results of a nitrogen budget for the southern Coastal Bays, based on data from 2000.[12] The vadose zone is the zone between the ground surface and the water table.



Modeled nitrate deposition in the Coastal Bays watershed.

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Using a modeling technique, estimates for contributions to nitrogen deposition from individual sources within the airshed were made. The airshed is a large geographic region whose atmospheric emissions contribute to deposition in the Coastal Bays. The table below shows the top 10 contributors. For modeling purposes, sources were divided into four categories: Electricity Generating Unit (U); large (tall stack) industrial (I); on-road vehicles (M); and small industrial, domestic heating, off-road vehicles/internal combustion engines, etc. (A).

To help the nutrient reduction efforts of the Maryland Coastal Bays Program, the deposition model was used to identify sources where

State	Sector	NO_x emissions (metric tons per year)	Total N deposition (kg)	Source/County Name
Delaware	A	7,359	11,289	Sussex County
Delaware	M	6,806	10,414	Sussex County
Maryland	A	2,810	4,560	Maryland Eastern Shore counties
Maryland	U	23,615	4,471	Morgantown power plant
Ohio	U	113,357	3,851	General James M. Gavin power plant
Maryland	U	22,987	3,422	Brandon Shores power plant
Virginia	U	26,474	3,357	Dutch Gap power plant
Maryland	U	15,024	3,312	Chalk Point power plant
North Carolina	U	82,288	2,962	Belews Creek power plant
West Virginia	U	46,601	2,793	Mt. Storm power plant

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This table shows the top 10 contributors to nitrogen deposition within the Coastal Bays. Both NO_x emissions and total nitrogen deposition are shown. Sectors are: Electricity Generating Unit (U); on-road vehicles (M); and small industrial, domestic heating, off-road vehicles/internal combustion e-ngines, etc. (A). Maryland M sources are not in the top 10 list as most of the sources are west of Chesapeake Bay and so their signal is attenuated by the time it reaches the Coastal Bays.

State	Sector	Sensitivity load/ emission	Source/County Name
Maryland	A	1.616	Maryland Eastern Shore counties
Delaware	M	1.530	Sussex County
Delaware	A	1.528	Sussex County
Virginia	I	0.441	Virginia Eastern Shore counties
New Jersey	I	0.402	Stony Brook Regional Sewerage
New York	I	0.402	Champion Products Inc.
Maryland	M	0.361	Wicomico County
Delaware	I	0.336	DuPont
Maryland	U	0.316	Vienna power plant
Maryland	A	0.278	Dorchester County

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This table shows the 10 most sensitive nitrogen deposition sources, i.e., those where emission reductions would have the biggest effect on deposition. Sectors are: Electricity Generating Unit (U); large (tall stack) industrial (I) on-road vehicles (M); and small industrial, domestic heating, off-road vehicles/internal combustion engines, etc. (A).

reductions would have the biggest effect on deposition per unit of emission. The 10 most sensitive sources are listed in the table above. Under the current Clean Air Act, the M and I sectors are considered well regulated. New regulations are being implemented for the U sector, but controls on the A sector are still many years away. For more information, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Shallow groundwater transports nitrogen to the bays primarily via streams

Groundwater is estimated to contribute as much as 40% of the total nitrogen load to the bays.[74] All significant groundwater contributions of nitrogen to the bays are from the surficial aquifer, which ranges in depth from the land surface to approximately 40 m (130 ft) below mean sea level.[65] Based on previous data,[20] the residence time of water in the surficial aquifer is several years to several decades, depending on the length of the flow path. Because slightly deeper, confined aquifers are available in the area, the surficial aquifer is not used extensively as a source for drinking water supply.

A simplified net flow analysis in the Maryland Coastal Bays watershed in another study[19] suggests that most of the shallow groundwater (85–90%) is discharged to streams in the watershed, meaning that as much as 10–15% of the shallow groundwater recharged in the Coastal Bays watershed could discharge directly to the open bays. Some of the discharging groundwater is probably routed to wetlands that fringe the streams and Coastal Bays. The map on the next page shows major recharge areas where precipitation replenishes the surficial aquifer.

Subsequent studies of the groundwater beneath the watershed and the Coastal Bays of both Delaware and Maryland show areas of direct groundwater discharge to the tidal creeks and main lagoons of the Coastal Bays.[7,42] The shallowest pore fluids (water located within bay sediment/around tiny grains of sediment) in the bays' sediments are brackish, with ammonium as the dominant form of dissolved nitrogen.[7] Several meters below the sediment–bay water contact, the pore fluids are fresh, commonly oxygenated waters with dissolved nitrate. These freshwater zones are underlain by brackish water and are interpreted as plumes of groundwater recharged in the Coastal Bays watershed.

This vertical sequence of alternating layers of brackish and freshwater in the pore fluids of bay sediments is the most common condition in the bays based on studies performed to date. At locations where this vertical layering is found, the groundwater is not likely to be discharging to the Coastal Bays estuary.

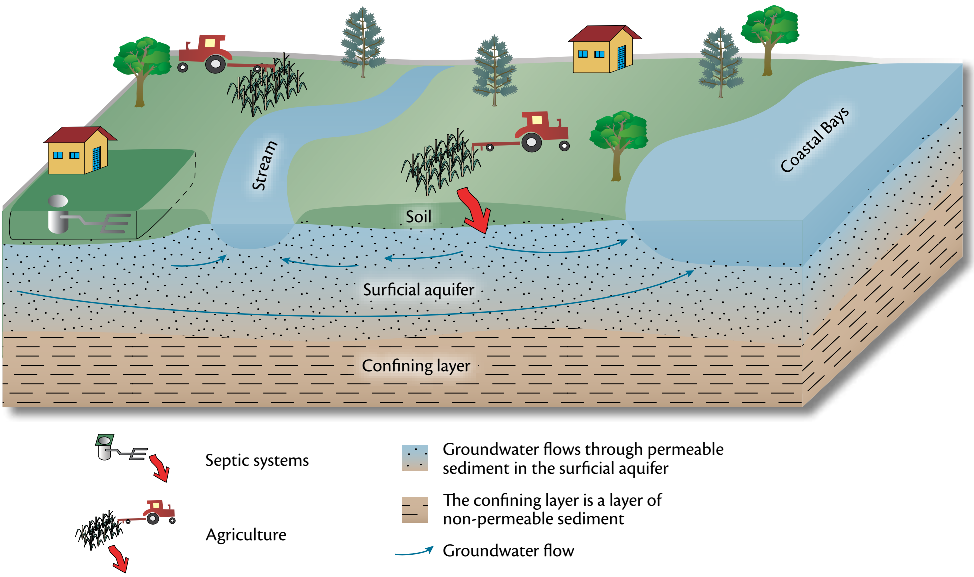
The submarine freshwater must discharge somewhere, but the location(s) of the discharge zones and the fate and transport of the nitrate in them is not known. The groundwater could discharge in a diffuse manner farther offshore, or could also discharge directly to the estuary in discrete zones of higher permeability in the bottom sediments.

Nitrogen in streams is related to the amount of agriculture in the watershed

Investigations of stream base flow showed that shallow groundwaters with elevated nitrate concentrations are discharging to the non-tidal portions of the streams in

Location of recharge areas in the Coastal Bays—areas from which recharge to the aquifer is discharged directly to the Coastal Bays.[19]

Groundwater transport



Nutrients in groundwater are delivered to tributaries of the Coastal Bays, to the Coastal Bays themselves, and to the open ocean.

the Coastal Bays watershed.[20] This study found the nitrate concentration of stream base flow in the Coastal Bays watershed tended to be higher in sub-basins with higher agricultural land use. Another study found similar relationships between nitrate concentrations in stream base flow and agricultural land use throughout the Delmarva Peninsula.[55]

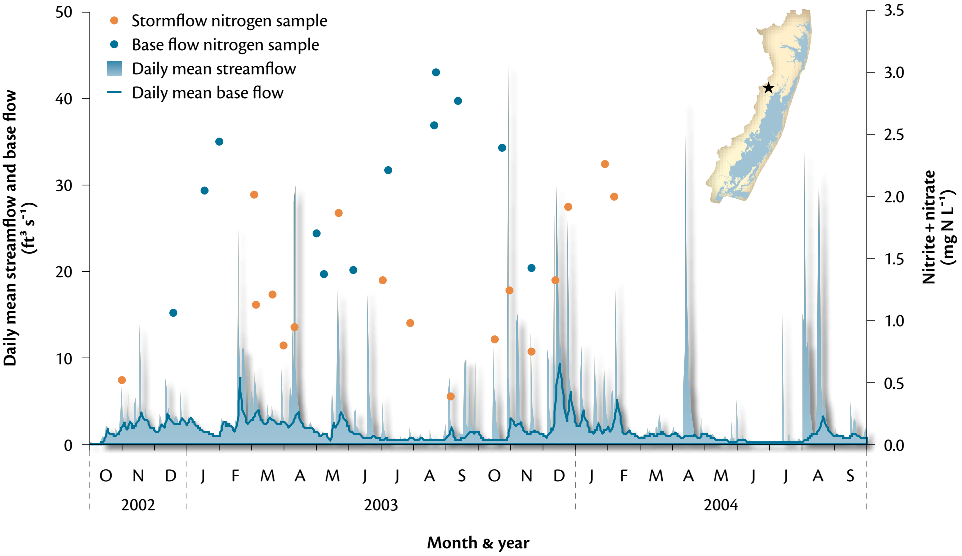
A recent study performed a more intensive monitoring study of Bassett Creek, a tributary of Newport Bay.[21] The estimated load of nitrate and nitrite (NO_2^-) to the downstream tidal reaches in water years 2003 and 2004 was on the order of 10 kg (22 lb) per day for this 3.16-km^2 (1.22-mi^2) basin. Flow-weighted concentrations of nitrate + nitrite were also calculated to be on the order of 1.5 mg L^{-1} for Bassett Creek for this period. This value is somewhat above flow-weighted concentration of nitrate + nitrite of 1.3 mg L^{-1} for the Choptank River near Greensboro, Maryland (in the Chesapeake Bay watershed) from 1985–2004. The Choptank River site represents a larger watershed with a similar percentage of agricultural land. The Bassett Creek value is significantly below the range of annual flow-weighted concentrations (4.2–6.7 mg L^{-1}) for Chesterville Branch in Kent County, Maryland, a Chesapeake Bay watershed in which agriculture is the predominant land use.

While all of these recent and previous studies have improved our understanding of nutrient inputs to the Coastal Bays, a few important science questions remain. The stream studies referenced here used sites above the head of tide. New research needs to be done to determine the fate and mass transfer of nutrients from non-tidal reaches to tidal sections of the Coastal Bays tributaries. Other important questions remain about the behavior and transport of freshwater-borne nitrate in submarine groundwater, and of ammonium carried by saline pore fluids in groundwater discharge zones within the bays.

Nutrient inputs via ditches are highly variable

On the Eastern Shore of Maryland, ditches are a major feature of the

Flow rate & nitrogen concentrations in Bassett Creek



Streamflow, base flow, and concentrations of nitrite + nitrate at base flow and stormflow conditions in Bassett Creek near Ironshire, Maryland, water years 2003 and 2004.[21]

landscape. Ditches circumvent the natural groundwater paths, significantly extending the number of miles of streams and increasing nutrient flows. For example, in a subwatershed of the Pocomoke River (Chesapeake Bay watershed), the streams were documented at 82 km (51 mi) but if the ditches were counted it would add another 195 km (121 mi).

The ratio estimator was used for Birch Branch in the St. Martin River watershed to calculate actual loads (~1,600-ha or 4,000-acre watershed). In 2003, the nitrogen load was 38,105 kg (84,007 lb) and in 2004 it was 40,931 kg (90,237 lb). Nitrate and nitrite accounted for almost 50% of the load (this gave yields of 23.05 kg N ha^{-1} (20.57 lb $acre^{-1}$) in 2003. These loads are an estimate of loads to the system which can be highly variable. For example, a long-term record (10 years) of inputs to the Pocomoke River show loads to be highly variable (5.6–56 kg ha^{-1} or 5–50 lb $acre^{-1}$), primarily due to water flow and stream management activities (ditch management).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Drainage ditches are a common sight in the Coastal Bays.

Shoreline erosion contributes nutrients

The Maryland Coastal Bays shoreline is 727 km (452 mi) long. Based on changes in shoreline position in the 27 years between 1962 and 1989, the shoreline, on average, is retreating about one foot every five years (6 cm or 2.4 in per year). However, erosion tends to be highly variable spatially and episodic in its occurrence. Over the entire period of study, 1850–1989, the Coastal Bays lost 1,521 ha (3,758 acres) to erosion.[31,32,33]

That translates into an average annual loss of 11 ha (27 acres) throughout the Coastal Bays, again offset by a 3-ha (7-acre) gain along eastern Sinepuxent Bay. Overall, shore erosion in the northern and middle Coastal Bays contributes approximately 4% of total nitrogen entering those bays. Shore erosion contributes 5% and 9% of total phosphorus entering northern and middle bays, respectively.[76,77] However, nutrients from erosion may not be in a form that is easily used by aquatic plants and algae. For more information, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*

Sediments are not a large source of nutrients to the Coastal Bays

Estuarine water quality and habitat conditions are directly affected by fluxes of nutrients from sediments, especially at high summer temperatures during hypoxic and anoxic events. The magnitudes of these fluxes appear to be directly influenced by nutrient and organic matter loading to the waterbody. Both annual

	1989 shoreline length (m)	Total sediments (kg yr^{-1})	Total carbon (kg yr^{-1})	Total nitrogen (kg yr^{-1})	Total phosphorus (kg yr^{-1})
Assawoman & Isle of Wight Bays & St. Martin River	165,389	11,566,114	424,565	23,373	2,344
Sinepuxent, Newport, & Chincoteague Bays	202,146	11,351,800	373,279	22,166	3,431

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This table shows the annual loadings of sediments and nutrients contributed by shoreline erosion in the Coastal Bays.

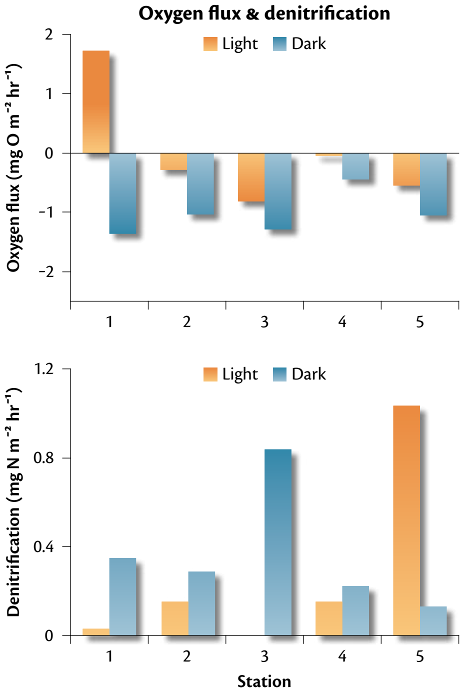
and interannual patterns demonstrate that when these external nutrient and organic matter loadings decrease, the cycle of organic matter deposition to the sediments, sediment oxygen demand, and the release of nutrients into the water column also decrease and water quality conditions improve.[5] Evaluation of nutrient loadings from the watershed and estuarine sediments provides information important for diagnosing the health of an estuary.

Sediment fluxes at 21 stations within Assawoman Bay, Isle of Wight Bay, Sinepuxent Bay, Newport Bay, Marshall Creek, and Trappe Creek were evaluated in the summer of 2003.[3] Sediment oxygen (O_2) consumption (SOC) in the tributaries averaged about 3 g O_2 m^{-2} day^{-1} (ranging from 1–4) and was between 1-2 g O_2 m^{-2} day^{-1} in the open bays. All 21 sites had an average SOC of 1.5 g O_2 m^{-2} day^{-1}. In comparison, rates measured in the upper Anacostia River (a very nutrient-polluted tributary of the Potomac River and Chesapeake Bay) were about 4 g O_2 m^{-2} day^{-1}.

Overall, the Coastal Bays sediments were not releasing large amounts of ammonium. Releases were generally between 0–1.4 mg N m^{-2} hr^{-1}; however, one site in Manklin Creek averaged almost 9.8 mg N m^{-2} hr^{-1}. These rates differ from places like the deeper Chesapeake Bay which is highly hypoxic, light-limited, and has rates of significant ammonium release (5.6–11.2 mg N m^{-2} hr^{-1}). At some Coastal Bays sites, ammonium flux into the sediments was measured. This is a sign of photosynthetically active sediments, and is evidence of good sediment conditions. Nitrate + nitrite fluxes were generally low and averaged 0.02 mg N m^{-2} hr^{-1}. Rates ranged from -0.56–1.4 mg N m^{-2} hr^{-1}. Nitrate + nitrite fluxes from sediments to the water column are evidence of nitrification and probable dentrification, further supporting the notion that most sites are not oxygen limited.

Sediment phosphorus fluxes were low, as expected at sites with good sediment quality. The majority of sites had fluxes between 0.15–0.31 mg P m^{-2} hr^{-1}. The exception was the site in Manklin Creek, which had high ammonium flux rates (averaging over 0.93 mg P m^{-2} hr^{-1}). In general, such levels (< 0.62 mg P m^{-2} hr^{-1}) are not sufficient to grow large phytoplankton communities.

Another study shows that the production of oxygen by benthic microalgae usually did not result in a net production of oxygen, but did result in lower sediment oxygen uptake rates and either uptake or decreased efflux of ammonium from sediment.[54] Denitrification rates were always lower than 1.4 mg N m^{-2} hr^{-1}; most rates were in the 0.14–0.84 mg N m^{-2} hr^{-1} range. At most sites, denitrification rates were lower during illuminated conditions than during dark conditions, a result of benthic microalgal photosynthesis. Despite some loss of denitrification, the presence of



Sediments did not show a net production of oxygen (top), and denitrification rates were generally lower in illuminated conditions than dark conditions.[3,54]

benthic microalgae clearly has a major benefit to this ecosystem, resulting in minimization of ammonium effluxes.

Nutrient loading is showing measurable impacts on the ecosystem

Current water quality shows many warning signs of ecosystem change. In general, water quality is degraded within and close to the major tributaries (Assawoman Bay, St. Martin River, Isle of Wight Bay, and Newport Bay) and better near the inlets. In the more highly flushed regions of Sinepuxent Bay and southern Chincoteague Bay, water quality is currently fair. Large areas of the bays exhibit nutrient enrichment above threshold levels needed to maintain certain biotic communities. Differences in overall water quality among regions reflect variation in algae abundance and dissolved oxygen. Water quality status analyses show that many stations, even those in Chincoteague Bay, currently fail seagrass thresholds for one or both nutrients. The variability of seagrasses among segments (3% available habitat occupied in St. Martin River vs. 70% in Sinepuxent Bay) is correlated to the regional water quality index summaries and water quality trends were inversely related to seagrass trends. For more information on seagrass and water quality, see Chapter 15—*Habitats of the Coastal Bays & Watershed*.

Many sites throughout the system are displaying ecosystem effects of eutrophication, with high phytoplankton abundance and reduced dissolved oxygen. This has implications for aquatic communities, suggesting that many regions within the Coastal Bays do not provide suitable habitat for seagrasses. The system is changing, and the commercial and recreational potential of the Coastal Bays will decline if nutrient inputs are not reduced.

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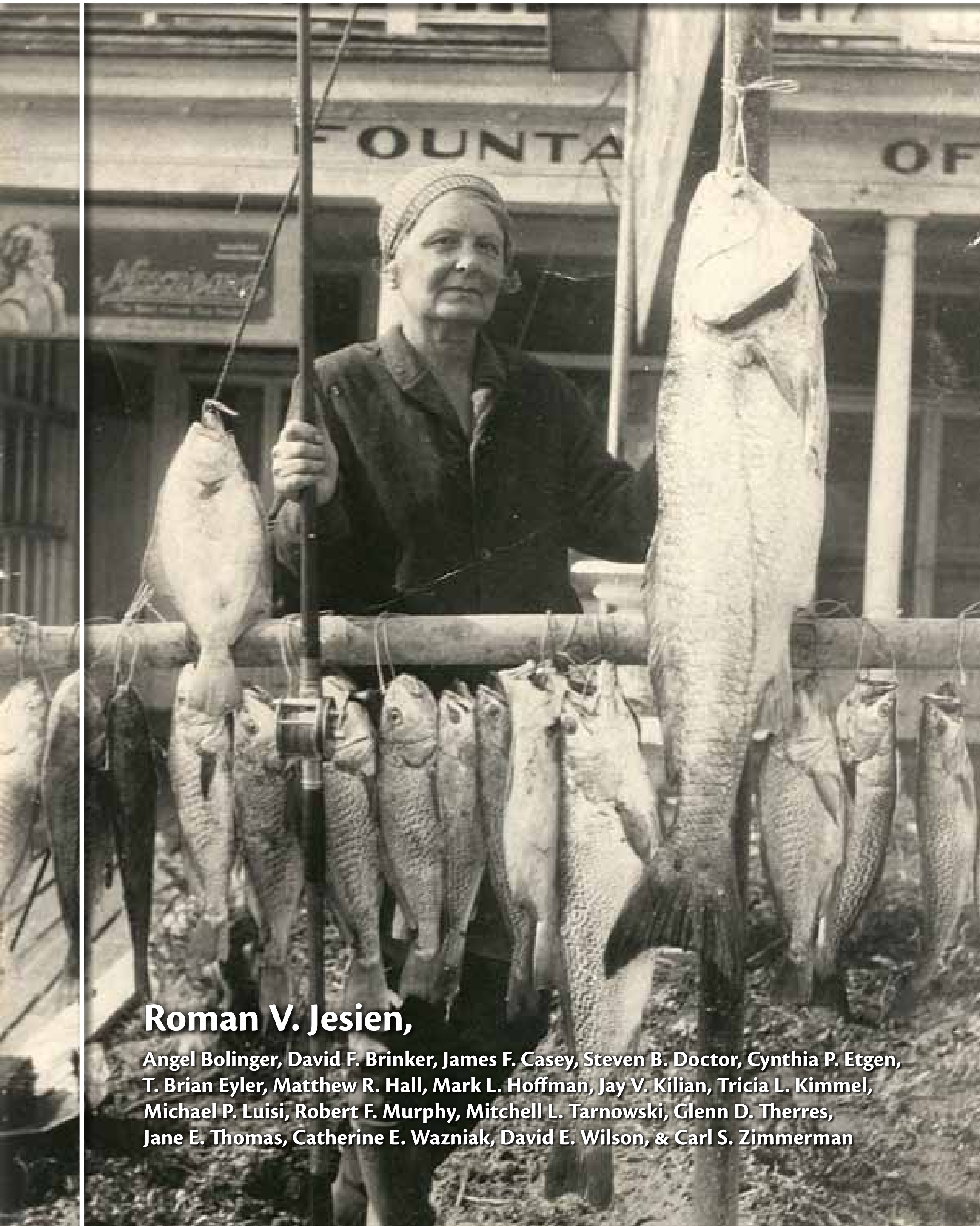
14. Diversity of Life in the Coastal Bays



Roman V. Jesien,

Angel Bolinger, David F. Brinker, James F. Casey, Steven B. Doctor, Cynthia P. Etgen, T. Brian Eyler, Matthew R. Hall, Mark L. Hoffman, Jay V. Kilian, Tricia L. Kimmel, Michael P. Luisi, Robert F. Murphy, Mitchell L. Tarnowski, Glenn D. Therres, Jane E. Thomas, Catherine E. Wazniak, David E. Wilson, & Carl S. Zimmerman

BIODIVERSITY

The Coastal Bays' high biodiversity stems from their location in the landscape

Biodiversity refers to the variety of plant and animal life in an area. It includes all types of life from algae and bacteria to large mammals, such as the Assateague Island horses. Environmental attributes, such as moisture and temperature, structure the communities and types of organisms that make up biodiversity at a site.

Biodiversity is interwoven into the healthy functioning of the ecosystem. Living things use energy from the sun to turn minerals and nutrients into living tissue, then recycle the tissue back to its components to restart the process. A loss of biodiversity interferes with this process and decreases the ability of the ecosystem to function adequately. A well known analogy of biodiversity relates species to rivets on an airplane—as the rivets hold the plane together, so too do species provide the connective fiber of the ecosystem. The rhetorical question of how many rivets the plane can lose before it falls apart takes on significance in the face of current trends that show rapid loss of biodiversity world-wide.[16,69]

Ecologists have long observed heightened biodiversity when different habitats come together, such as water and land, or grassland and forest. The mix of these habitats is called an *ecotone* and typically, ecotones are home to plants and animals that are specially adapted to this mixing zone, in addition to organisms that live in each separate habitat. The rich biological diversity of the Coastal Bays is due to the variety of ecotones within the system that provide habitat to a remarkably diverse biota in a relatively small area. Mixing zones such as fresh and ocean water, land and water margins, and the proximity of the biogeographic break at Cape Hatteras, North Carolina, affect biodiversity of the Coastal Bays. In addition, a relatively undisturbed barrier island and lagoon system, large expanses of coastal marshes, and relatively large forested tracts support rich biodiversity.

JANE THOMAS

The variety of habitats in the Coastal Bays—such as the bays, wetlands, and forests seen here in Chincoteague National Wildlife Refuge—support high biodiversity.

Why is biodiversity important?

> *Biological diversity is the key to the maintenance of the world as we know it. Life in a local site struck down by a passing storm springs back quickly: opportunistic species rush in to fill the spaces. They entrain the succession that circles back to something resembling the original state of the environment.*
> —E.O. Wilson, *The Diversity of Life*, 1992.[86]

The Coastal Bays are a permanent or transient home to over 350 bird species and over 140 fish species. Reptiles and amphibians are represented by more species than anywhere else in Maryland. Although historically more common, southern forests of baldcypress reach their northernmost extent in the area.

The federal Endangered Species Act and the Maryland Nongame and Endangered Species Conservation Act are the laws allowing and governing the listing of endangered species in Maryland. Thirteen animal species that use the Coastal Bays, its watershed, or adjacent coastal ocean are currently listed as federally endangered or threatened—Delmarva fox squirrel (*Sciurus niger cinereus*), piping plover (*Charadrius melodus*), five sea turtle species, and six whale species.[48] An additional 14 animal species are on the Maryland list of rare, threatened, or endangered species (for the entire list, see *www.dnr.state.md.us/wildlife/rteanimals.asp*). The bald eagle (*Haliaeetus leucocephalus*) was listed as threatened. However, because of increased population levels throughout its range, on June 28, 2007, the Department of the Interior took the American bald eagle off the federal List of Endangered and Threatened Wildlife and Plants.

MAMMALS

Mammals occupy a wide range of habitats

The Coastal Bays region supports a variety of mammals, including 38 species of land mammals and 25 species of marine mammals. Mammals include squirrels, weasels, shrews, moles, bats, rodents, foxes, deer, feral horses, dolphins, porpoises, and whales. Land mammals inhabit a variety of habitats including forests, marshes, dunes, agricultural fields, and even urban areas. Most species are nocturnal and are thus observed infrequently, though many are very common to the area. The gray squirrel (*Sciurus carolinensis*) is the daytime mammal most people see throughout the area. The one endangered land mammal species in the region is the Delmarva fox squirrel, which is the only species that is both federally and state listed in the Coastal Bays. Six other mammal species are of conservation concern because of rarity or declining populations—least shrew (*Cryptotis parva*), Southeastern myotis (a small bat; *Myotis austroiparius*), silver-haired bat (*Lasionycteris noctivagans*), red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), and Southern bog lemming (*Synaptomys cooperi*).[46]

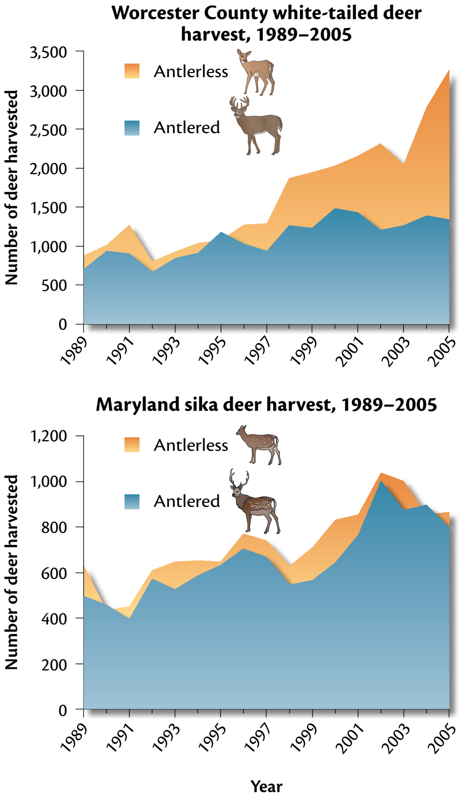
One of the most recognizable mammals in the Coastal Bays region, the native white-tailed deer (*Odocoileus virginianus*) was essentially extirpated from much of its range in Maryland at the turn of the 20th century due to market hunting and habitat destruction. Protection and restocking efforts during the early 1900s enabled

NANCY POWELL

White-tailed deer are common on Assateague Island.

white-tailed deer to make a dramatic recovery, and today they are one of Maryland's most abundant game species.

While many view their recovery as a success, the near-exponential growth of the white-tailed deer population during the 1980s and 1990s has resulted in overpopulation. Unknown on Assateague Island up until the late 1950s,[61] the white-tailed deer is now a prominent member of the island's mammals. As a keystone herbivore, browsing damage to agricultural crops and forest habitats that affects regeneration and forest-dwelling bird populations are two of the more prominent problems associated with white-tailed deer in the Coastal Bays region and elsewhere.



MARYLAND DEPARTMENT OF NATURAL RESOURCES

Significantly increasing the antlerless harvest of white-tailed deer in Worcester County has resulted in stabilization of the herd, as indicated by the antlered harvest. Hunters annually harvest between 1,500 and 2,000 sika deer in Maryland, with 8–10% coming from the Maryland portion of Assateague Island.

The Maryland Department of Natural Resources (MD DNR) currently estimates there are approximately 30 deer per square mile in the Coastal Bays region. MD DNR manages the white-tailed deer population primarily through regulated hunting and promotes the harvest of antlerless deer through liberal seasons and bag limits to curb population growth (see graph, left). This management tactic is working as the white-tailed deer population has stabilized or declined in many areas of Maryland, including the Coastal Bays region.

White-tailed deer coexist with the exotic sika deer (*Cervus nippon*) in parts of the Coastal Bays region, especially Assateague Island. Maryland sika deer originated in southern Japan and were introduced to the region on James Island (Chesapeake Bay) during the early 1900s. Charles Law of Berlin brought the deer to the Coastal Bays in 1920, and they were eventually released to Assateague Island.[19,20,62]

Like white-tailed deer, MD DNR manages the sika deer population through regulated hunting. In Dorchester County, where they are a popular big game species that helps support a local hunting economy, MD DNR management goals are to maintain the species at current population levels as indicated by the yearly stag harvest. On Assateague Island, where habitat and resources are more limited and sika deer can more easily

BRIAN EYLER

Sika deer were introduced into the Coastal Bays in the 20th century.

impact native species, their population is controlled with more aggressive hunting seasons and bag limits.

North American river otters (*Lutra canadensis*) are found throughout Maryland, with highest numbers occurring on the Delmarva Peninsula adjacent to the Coastal Bays and Chesapeake Bay. Otters in the wild act as a 'flagship' species for their wetland habitats, a yardstick by which to measure the health and vitality of the ecosystem. However, otters easily fall prey to car collisions, water pollution, and urban sprawl. They are also hunted, although their commercial harvest is regulated in Maryland. The biggest threat to these animals in the Coastal Bays is habitat loss. Once-pristine areas are converting to subdivisions, fragmenting habitat and reducing water quality. With proper planning to keep growth out of viable habitats, both otters and people should be able to live in harmony on the shore for a long time to come.

The Coastal Bays are home to two species of fox. The larger red fox (*Vulpes vulpes*) prefers mixed forests and open areas, while the smaller and more reclusive gray fox (*Urocyon cinereoargenteus*) chooses habitats with thicker vegetation cover, including disturbed areas such as recently logged woodlands and scrublands. Both species are omnivorous, including both plants and animals in their diet.[27]

Carnivores in the region include Virginia opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*), long-tailed weasel (*Mustela frenata*), mink (*Mustela vison*), striped skunk (*Mephitis mephitis*), and coyote (*Canis latrans*), which is a recent addition to the Coastal Bays region. Black bear (*Ursus americanus*), gray wolf (*Canis lupus*), and cougar (*Puma concolor*) historically occurred in the area but were eliminated from the Eastern Shore during colonial times.

The extermination of black bears, gray wolves, and cougars from the Coastal Bays has resulted in deer, raccoon, red fox, and opossum population explosions which have harmed biodiversity. While the latter three species steal eggs and young from ground-nesting birds and can decimate reptile and amphibian populations, deer

NANCY POWELL

A river otter devours a catfish in a pond off St. Martin River.


DAVE WILSON

A red fox scavanges roadkill on a Coastal Bays farm.

have grazed down much of the ground cover, adversely impacting understory birds like Kentucky warblers (*Oporornis formosus*) and flower-pollinating butterflies.

The Delmarva fox squirrel disappeared from the lower Eastern Shore prior to the late 1960s and was declared an endangered species in 1973. By the time of its listing, the occupied range of the Delmarva fox squirrel had contracted to about 10% of its historic range.[76] Habitat loss was the primary reason for this species' demise. As part of a recovery effort, several Delmarva fox squirrel populations were re-established within their historic range, including one in the Coastal Bays area.[74] A small population of this large, steel-gray squirrel occurs at E.A. Vaughn Wildlife Management Area and surrounding forestlands in the Girdletree area.

Assateague Island horses cause ecological damage

Despite legends of Spanish shipwrecks, the Assateague Island horses (*Equus caballus*) are most likely the wild descendants of livestock brought to the island in the late 17th and 18th centuries.[62] Like many coastal islands, Assateague provided free range and an opportunity to avoid mainland fencing laws and a property-based tax system.[75] Today, two herds of horses live on the island, separated by a fence at the Maryland–Virginia state line. Those in Maryland are owned by the National Park Service (NPS)

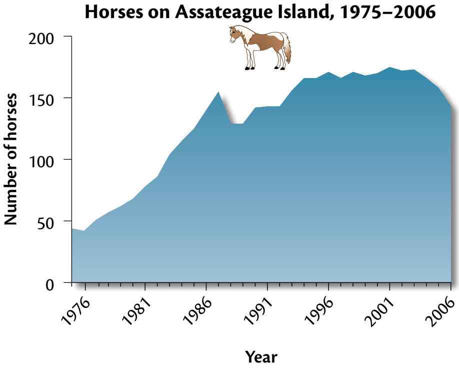

ASSATEAGUE ISLAND NATIONAL SEASHORE

The Assateague horses are an iconic symbol of the barrier island.

and managed as wildlife, while the Virginia horses are the property of the Town of Chincoteague's volunteer fire company. These are the horses made famous by Marguerite Henry's book *Misty of Chincoteague*[25] and the annual Chincoteague 'pony-penning' and auction.

When Assateague Island National Seashore was established in 1965, most of the horses had been removed from the Maryland portion of Assateague and confined to Chincoteague National Wildlife Refuge. The exception was a small, free-ranging herd belonging to a Maryland landowner who had purchased nine "Chincoteague ponies" for private enjoyment in 1961. By 1968, when NPS acquired ownership of the horses, the population consisted of 28 horses. In subsequent years the herd grew by more than 10% annually and by the late 1970s, park managers began to observe increasing evidence of resource damage caused by the horses.

Recognizing the need for population control, the park initiated research in 1985 to develop and test contraceptives. The result of that effort—a contraceptive vaccine—has been used to manage the population since 1994.[3] Reaching a high of 176 at one point, the horse population has now been reduced to 143 in 2006 due to these management efforts. Administered by dart gun, the once-a-year vaccine prevents pregnancy by causing the horses' immunological system to produce antibodies which block sperm receptor sites on the female's egg cell. The treated horses cycle naturally, mate, and exhibit all of the normal behaviors associated with estrus, but do not become pregnant. Initially developed at Assateague Island, the vaccine is now being used around the world in managing a variety of wildlife populations.



ASSATEAGUE ISLAND NATIONAL SEASHORE

The horse population of Assateague Island has been managed by the contraceptive vaccine since 1994, with a current population of 143 horses in 2006.

While the use of contraceptives has successfully lowered reproductive rates and reduced the size of the horse population, continued reliance upon contraception as the sole management strategy does not appear to be sufficient to reverse the declining ecological health of the island or protect the long-term health of the horse population. Review of survey data conducted in the late 1990s showed that horses can significantly affect dune formation and vegetation.[14] From April to September, when insect populations flourish in the salt marshes and inland areas of the island, the horses migrate toward the beach to avoid the infestations. During these months, horses feed intensively on American beachgrass (*Ammophila breviligulata*) growing near the ocean shoreline which limits the ability of the beachgrass to stabilize the dunes and prevent erosion. NPS is currently evaluating several management strategies to reduce the population to between 80 and 100 horses—a size that should achieve an appropriate balance between protecting the horses and minimizing the ecological problems they create.[3]

Marine mammals seen near the Coastal Bays include whales, dolphins, porpoises, seals, & manatees

More than 25 species of marine mammals, including whales, dolphins, seals, and the Florida manatee, have been documented in the ocean near the Coastal Bays. Some of these species include the humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), Northern right whale (*Eubalaena glacialis*), bottlenose dolphin (*Tursiops truncatus*), harbor porpoise (*Phocoena phocoena*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), long-finned pilot whale (*Globicephala melaena*), harbor seal (*Phoca vitulina*), harp seal (*Phoca groenlandica*), and Florida manatee (*Trichechus manatus latirostris*). Marine mammals are not year-round residents in Maryland—most seasonally inhabit or visit on their annual migrations along the Atlantic coast of North America.

Two of the most common species found in Maryland are the bottlenose dolphin and harbor porpoise. The terms *dolphin* and *porpoise* are often used interchangeably, but in fact they are two different species with different ranges and life histories.

Bottlenose dolphins are widely distributed in temperate and tropical waters around the world. The majority of migratory dolphins along the Atlantic coast of the United States occur from North Carolina to New Jersey. Dolphins are typically present in Maryland waters during the warmer months from May to October and are commonly seen swimming in small groups in the Coastal Bays and riding the waves along Ocean City. They are opportunistic feeders, taking whatever suitable prey is abundant at the time, but feed primarily on fish (seatrout, croaker, spot, and mullet) and invertebrates that are plentiful in the Coastal Bays.[52,81]

The harbor porpoise is smaller, with a chunky body and a blunt head with no forehead or defined beak.[18,37] In general, they are distributed in cool temperate and subarctic waters of the Northern Hemisphere. In Maryland waters, they occur primarily in the late winter and early spring, which coincides with their seasonal movements along the Atlantic coast of the United States. As a result, their seasonal residence does not typically overlap with that of the bottlenose dolphin. They usually occur singly, in pairs, or in small groups of up to 10 individuals.[31] Harbor porpoises eat a wide variety of fish and cephalopods (cuttlefish, squid, and octopus) but seem to prefer small schooling fish such as herring, mackerel, sardines, and pollack.[37]

The Florida manatee is an endangered species that inhabits coasts, estuaries, and major rivers of Florida year round. During warmer months, they may be found along the Atlantic coast as far north as Rhode Island, although sightings north of North Carolina are rare.[77] Manatees are herbivores that feed opportunistically on a wide variety of submerged, floating, and emergent vegetation.

In the fall of 1994, a manatee was sighted in the Maryland waters of Chesapeake Bay, then considered far outside the normal winter range of manatees. The adult male, nicknamed "Chessie," was captured and returned to Florida, where he was released with a satellite tag. In 1995, Chessie began to move northward and by mid-July was again in Chesapeake Bay. He continued to move through Delaware Bay and eventually swam all the way to Rhode Island before returning to Florida waters in the fall. This marked the longest known migration for a Florida manatee at that time. Since then, there have been numerous manatee sightings in the


MIKE ROBERTSON

Harbor seals near Captains Hill (Dog and Bitch Islands), Ocean City.

northeastern United States, including two confirmed sightings in Virginia in 1996 and 2001. In July 2006, a manatee was sighted in the Coastal Bays near 26th Street in Ocean City. Photos taken of the animal and analyzed by manatee researchers confirmed that it was not Chessie but a new summer traveler. Sightings of that animal continued up the Atlantic coast of the United States throughout the summer. The manatee was last sighted in Bristol Harbor, Rhode Island on August 20, 2006.

BIRDS

Many bird species make their homes in the Coastal Bays

Over 350 species of birds have been recorded in the Coastal Bays.[28] This concentration of avian diversity stems from the intersection of a variety of high-quality habitats situated along a major migratory flyway. Even in winter, when bird populations normally reach their lowest point, the Ocean City Christmas Bird Count routinely records 150 or more species on a single day in late December, by far the largest total for any such Maryland count.


DAVE WILSON

Maryland Department of Natural Resources monitors bird populations in the Coastal Bays.

Much of this avian abundance is directly linked to the rich productivity of estuarine and near-shore habitats, and differentiates the Coastal Bays from nearby inland areas. Loons, grebes, herons, waterfowl, gulls, terns, and shorebirds find their aquatic food sources in the marshes, shallow bays, and tidal flats that comprise the aquatic environment. Maintaining water quality, aquatic vegetation, and related components of the food chain are critical to preserving the natural basis for the abundance of these species.


DAVE WILSON

Overwintering snow geese in the Coastal Bays.

During spring and fall, millions of birds migrate through the Coastal Bays. Many species use the Atlantic coastline as a migratory path, with flock after flock of waterbirds streaming north or south, parallel to the barrier islands. In the fall, migrant land birds concentrate on Assateague Island, creating an avian spectacle much sought by birders from throughout the Mid-Atlantic region. Assateague Island is also well known as a hot spot for rare vagrants that have wandered thousands of miles off course on their migratory flight.

Threats to birds

- Habitat destruction.
- Forest and marsh fragmentation.
- Loblolly pine monoculture.
- Development.
- Oil spills and other pollution.
- Over-browsing by deer.
- Gull displacement of tern colonies.
- Loss of breeding islands.
- Degradation of water quality.
- Feral and domestic animals.
- Decreasing food availability.

The Coastal Bays have diverse habitats & breeding avifauna

Birds are habitat-specific. Each species has a specialized niche that provides critical elements needed for survival and reproduction. During the breeding season, this specificity is most pronounced. Below is just a sampling of the habitats and their characteristic species.

Forests

Inland and along the coastal fringe, no species is more characteristic of the pine-dominated habitats of the Coastal Bays than the pine warbler (*Dendroica pinus*). In areas of more mature pines and in the pine hammocks that fringe the salt marsh, the yellow-throated warbler (*Dendroica dominica*) is common, as is the diminutive brown-headed nuthatch (*Sitta pusilla*), here near the extreme northern limit of its distribution along the Atlantic coast. At day's end, the loud song of chuck-will's-widow (*Caprimulgus carolinensis*) echoes through the pines. In areas of mixed pine and hardwood forests, the colorful summer tanager (*Piranga rubra*) is a characteristic breeder. Forested wetlands are home to the colorful prothonotary warbler (*Protonotaria citrea*).

MARK L. HOFFMAN

The prothonotary warbler (left) needs hardwood forests to survive, while the brown-headed nuthatch (right) prefers pine hammocks.

Agriculture & grassland

Given the historical occurrence of species such as the eastern race of the greater prairie chicken (*Tympanuchus cupido*) on the Delmarva peninsula,[68] the Coastal Bays surely supported natural grassland habitats in the past. Today such areas are generally maintained through man-induced actions. Agricultural areas provide habitat for two common neotropical migrants (a neotropical migrant breeds in temperate North America and winters primarily in Central and South America)—blue grosbeak

MARK L. HOFFMAN

The grasshopper sparrow breeds in grassland habitats.

(*Passerina caerulea*) and indigo bunting (*Passerina cyanea*). The Northern bobwhite quail (*Colinus virginianus*), a popular game bird which has decreased greatly in Maryland, is still common in many farm areas, particularly in the southern half of the region. In areas set aside for conservation, both the grasshopper sparrow (*Ammodramus savannarum*) and Eastern meadowlark (*Sturnella magna*) breed. The latter species also occurs in higher salt marsh areas.

Shrub & scrub

Often created during forest rotation, mid-sucessional stage habitats consisting of shrubs and scrub are critical to a number of species, such as prairie warbler (*Dendroica discolor*), yellow-breasted chat (*Icteria virens*), and Eastern towhee (*Pipilo erythrophthalmus*). On the fringe of the salt marsh, there is also a naturally maintained shrub–scrub fringe that hosts these species and a few pairs of willow flycatchers (*Empidonax traillii*), here at the extreme southern limit of their breeding range along the Atlantic coast.


MARK L. HOFFMAN

Willow flycatchers (left) and prairie warblers (right) are two shrub–scrub species.

Salt marsh

Marshes are home to willets (*Catoptrophorus semipalmatus*), clapper rails (*Rallus longirostris*), seaside (*Ammodramus maritimus*) and salt marsh sharp-tailed (*Ammodramus caudacutus*) sparrows—all species limited to a narrow fringe of habitat. Islands in the bays provide critical breeding habitat for colonial waterbirds.


MARK L. HOFFMAN & NANCY POWELL

Willets (left) and clapper rails (right) need marshes to breed.

Colonial waterbirds nest in the Coastal Bays

Colonial nesting waterbirds are a conspicuous and integral element of the Coastal Bays, and include herons, egrets, gulls, terns, skimmers, cormorants, and ibises. Waterbirds feed at the top of food chains and their population health is an important indicator for evaluating ecosystem condition. The North American Waterbird Conservation Plan[36] and the Partners In Flight initiative (*www.partnersinflight.org*) identify several of the waterbird species that breed in Maryland as conservation targets. Several species are listed as endangered, threatened, or in need of conservation within Maryland. Development-related habitat degradation and loss, chemical contamination, fisheries over-harvesting, and sea level rise are some of the major factors impacting waterbird population trends. Colonial nesting waterbird population trends have been monitored annually in Maryland since 1985.


MARK L. HOFFMAN

Great blue herons (left) and royal terns (right) are colonial nesting waterbirds.

Maryland Department of Natural Resources (MD DNR) monitors colonial nesting waterbirds using a hierarchical approach. Annual surveys target those species of greatest conservation concern, i.e., Rare, Threatened, or Endangered (RTE) species and special interest species, including brown pelican (*Pelecanus occidentalis*) and double-crested cormorant (*Phalacrocorax auritus*). During alternating years, all major heronries and approximately 25% of herring gull (*Larus argentatus*), great black-backed gull (*Larus marinus*), and great blue heron (*Ardea herodias*) populations are surveyed using a regionally stratified, random sample of colonies that were active during one or more of the previous five years. Every five years, MD DNR completes a comprehensive state-wide survey for all species. This monitoring approach is as follows:

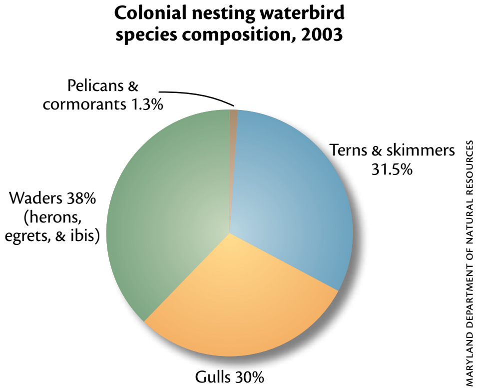
Year 1: Complete census.
Year 2: Catalog RTE and special interest species.
Year 3: Count 40% of breeding populations.
Year 4: Catalog RTE and special interest species.
Year 5: Complete census (most recently conducted in 2003).

Colonial waterbird populations are quite variable in the Coastal Bays. For example, Skimmer Island, located near the Ocean City Inlet in Isle of Wight Bay, supports a large and diverse assemblage of colonial nesting waterbirds. In 2003, it contained 12 species and 1,562 pairs, including a large mixed heronry (535 pairs), the state's largest black skimmer (*Rhynchops niger*) colony (70 pairs), and Maryland's only royal tern (*Sterna maxima*) colony (474 pairs). Skimmer Island is one of the most important colonial waterbird nesting

Species		Number of breeding pairs	Number of colonies
Double-crested cormorant (*Phalacrocorax auritus*)		68	1
Great blue heron (*Ardea herodias*)	Waders	4	1
Little blue heron (*Egretta caerulea*)		42	2
Tricolored heron (*Egretta tricolor*)		55	3
Black-crowned night heron (*Nycticorax nycticorax*)		46	6
Great egret (*Ardea alba*)		418	5
Snowy egret (*Egretta thula*)		304	4
Cattle egret (*Bubulcus ibis*)		248	3
Glossy ibis (*Plegadis falcinellus*)		807	5
Herring gull (*Larus argentatus*)	Gulls	1,223	13
Great black-backed gull (*Larus marinus*)		296	12
Common tern (*Sterna hirundo*)	Terns & skimmers	518	6
Royal tern (*Sterna maxima*)		474	1
Forster's tern (*Sterna forsteri*)		415	16
Least tern (*Sterna antillarum*)		114	3
Black skimmer (*Rynchops niger*)		96	4
Total		**5,128**	**85**

Colonial nesting waterbird results from 2003. Data are for Worcester County, Maryland. With the exception of great blue herons, all birds were found exclusively in the Coastal Bays portion of Worcester County.

MARYLAND DEPARTMENT OF NATURAL RESOURCES

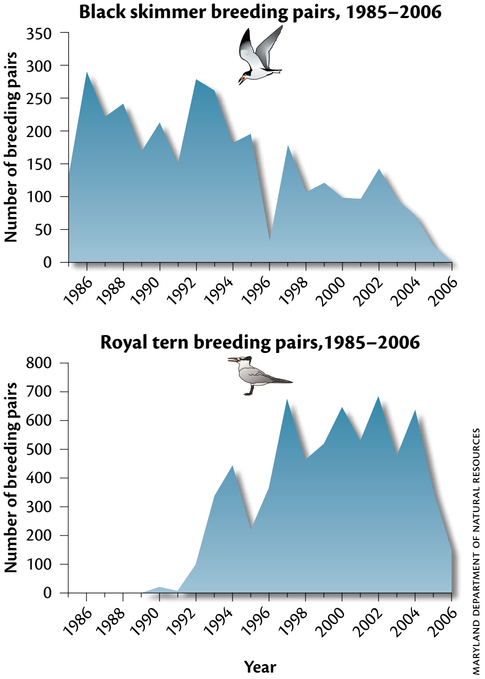


Colonial nesting waterbird species composition, 2003

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Species composition of colonial nesting waterbird populations in Worcester County, Maryland, during the 2003 breeding season.

sites in the Coastal Bays. In 2006, royal terns and black skimmers were no longer using the island for breeding because as the island stabilizes, the increased vegetation attracts nesting gulls which eat tern and skimmer chicks. However, the island still remains a valuable nesting site for wading birds such as herons, egrets, and ibises.



Black skimmer breeding pairs, 1985–2006

Royal tern breeding pairs,1985–2006

MARYLAND DEPARTMENT OF NATURAL RESOURCES

There are currently no black skimmers nesting in the Coastal Bays, and the state's only royal tern population is also declining. Data are for Worcester County.

Extirpated species (former breeders)

- Wilson's plover (*Charadrius wilsonia*).
- Roseate tern (*Sterna dougallii*).
- Red-cockaded woodpecker (*Picoides borealis*).

Waterfowl migrate along the Atlantic coast

The earliest settlers to the Coastal Bays remarked on the abundance of the region's waterfowl. Providing sustenance then, these birds today are a source of recreation to thousands of waterfowl hunters and birders each year. A conspicuous feature

Atlantic waterfowl flyway

The Atlantic waterfowl flyway is a seasonal migratory route stretching from northern Canada to the Gulf of Mexico and beyond.

along the salt marsh fringe is the duck blind, from which waterfowlers brave the frigid winter weather in hopes of bagging a black duck (*Anas rubripes*) or brant (*Branta bernicla hrota*). Chincoteague Bay also offers hunters a chance to take several species of diving ducks including scaup (*Aythya* spp.), scoter (*Melanitta* spp.), long-tailed duck (*Clangula hyemalis*), and bufflehead (*Bucephala albeola*).

MARK L. HOFFMAN

Canvasback ducks overwinter in the Coastal Bays.

Birders delight in the rocky habitat of the Ocean City Inlet, which mimics the rocky coast of New England states. Three species of ducks that were once only vagrants as far south as Maryland now occur regularly in small numbers—common (*Somateria mollissima*) and king (*Somateria spectabilis*) eiders, and harlequin duck (*Histrionicus histrionicus*). During the fall migration, tens of thousands of scoters stream past the barrier islands in their pilgrimage to wintering grounds farther south. Man-made ponds, in West Ocean City and

Species	2001	2002	2003	2004	2005	2006
American black duck (*Anas rubripes*)	12,303	6,505	6,274	9,522	6,904	3,612
American wigeon (*Anas americana*)	160	35	235	3,715	732	0
Atlantic brant (*Branta bernicla hrota*)	925	535	1,510	1,295	1,723	2,353
Bufflehead (*Bucephala clangula*)	5,500	985	1,685	1,665	3,706	1,931
Canada goose (*Branta canadensis*)	9,578	6,280	3,739	5,502	5,011	6,048
Canvasback (*Aythya valisineria*)	1,200	400	800	300	1,900	250
Common goldeneye (*Bucephala albeola*)	65	0	0	0	0	0
Gadwall (*Anas strepera*)	532	411	340	1,109	275	5
Green-winged teal (*Anas crecca*)	10	50	60	0	50	0
Long-tailed duck (*Clangula hyemalis*)	10	0	0	0	0	0
Mallard (*Anas platyrhynchos*)	4,587	2,140	1,602	2,244	2,192	1,728
Merganser (*Mergus* spp.)	10	315	100	0	151	60
Northern pintail (*Anas acuta*)	2,360	800	50	2,435	1,265	0
Northern shoveler (*Anas clypeata*)	150	0	0	0	70	0
Redhead (*Aythya americana*)	0	0	0	0	25	0
Ring-necked duck (*Aythya collaris*)	0	0	0	0	50	0
Scaup (*Aythya affinis/Aythya marila*)	0	1,350	5,300	1,050	205	700
Scoter (*Melanitta* spp.)	0	0	1,000	0	1,610	0
Snow goose (*Chen caerulescens*)	11,835	10,000	11,600	5,000	3,000	10,900
Tundra swan (*Cygnus columbianus*)	146	241	123	87	90	395
Total	**49,371**	**30,047**	**34,418**	**33,924**	**28,959**	**27,982**

U.S. FISH & WILDLIFE SERVICE

Number of waterfowl in the Coastal Bays, 2001–2005—results of the Mid-Winter Waterfowl Survey for the Coastal Bays area of Worcester County. There may be large fluctuations in numbers for birds that travel in large flocks (> 10,000 birds), such as snow goose.

Atlantic brant

Atlantic brant (*Branta bernicla hrota*) is, without question, a key waterfowl species in the Coastal Bays. Its entire wintering population is found only along the narrow coastal strip from Massachusetts to Virginia. These birds nest in remote areas of the high Arctic outside traditional waterfowl surveys areas and hence the mid-winter survey is used to monitor the population and establish hunting seasons.

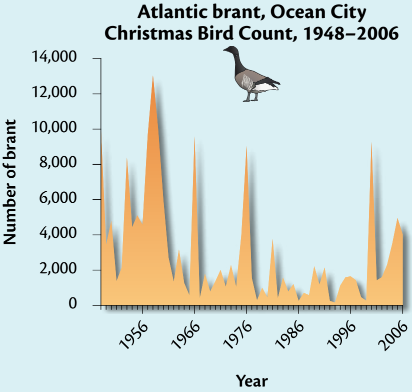
Historically, the population subsisted on submerged eelgrass (*Zostera marina*) beds. The eelgrass blight of the 1930s caused significant declines in brant population.[67] Eelgrass abundance is currently declining, and the local brant population may also decline or may switch to feeding on lawns and grassy areas. Information on the biology of brant is very limited, particularly relating to its breeding. For more information on brant and eelgrass, see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

In January 2002, the Atlantic Flyway Council launched a major initiative to obtain critical information about this important coastal species. The study's goals included clarification of brant migration routes and timing, identification of staging areas in relation to current and historical distribution of eelgrass and other submerged aquatic vegetation, defining the boundaries of the breeding range, and a search for previously unknown breeding colonies.

While brant are on the wintering grounds, wildlife agency personnel use decoys to lure brant to rocket nets for capture. Adult male brant are fitted with either a satellite transmitter or a conventional VHF radio transmitter. During January through March of 2002, 44 Atlantic brant were marked in three states. Twenty-four radio-marked brant were located during spring migration or while on the breeding grounds. For more information, see *www.state.nj.us/dep/fgw/brant03/main.htm*


MARK L. HOFFMAN

Atlantic brant migrate to the Arctic Circle and beyond.



NATIONAL AUDUBON SOCIETY/MARYLAND ORNITHOLOGICAL SOCIETY

The Ocean City Christmas Bird Count shows fluctuating numbers of Atlantic brant.

Ocean Pines, provide convenient and important wintering sites for dabbling ducks, like American wigeon (*Anas americana*)—with its otherwise-rare Eurasian counterpart (*Anas penelope*) a regular occurrence—and gadwall (*Anas strepera*), as well as divers like canvasback (*Aythya valisineria*).

Despite their benefits, waterfowl can also present management challenges. The snow goose (*Chen caerulescens*) population has increased dramatically in the Mid-Atlantic.[55] Snow geese tend to graze on roots and rhizomes of salt marsh plants, which can negatively impact coastal marshes.[66]

As part of a nation-wide waterfowl monitoring program, each January MD DNR conducts aerial surveys of Coastal Bays waterfowl populations. Although these counts are variable year-to-year and represent a single data point in dynamic populations, they establish the significance of the Coastal Bays as a wintering area for waterfowl.

Maryland's bird distribution is documented by the Breeding Bird Atlas

Conducted during a five-year period beginning in 1981 and replicated 2002–2006, the Breeding Bird Atlas project provides a basis to assess coarse changes in the distribution of Worcester County and Coastal Bays breeding avifauna over the past 20 years. The Atlas is based on determining which species breed within each 'block,' when a grid of approximately 10 km^2 (3.86 mi^2) is overlaid on Worcester County. Within these 70 blocks, field work is carried out to categorize each species as confirmed, probable, or possible breeders, based on standard criteria. Additionally, species observed within a block during breeding season, but which do not actually nest within the block (e.g., laughing gulls [*Larus atricilla*] wandering far inland from their breeding colonies to forage) are recorded as 'observed.' The Atlas is a joint project of the Maryland Ornithological Society and MD DNR, and largely relies on experienced volunteer observers (*www.mdbirds.org/atlas.html*).

Species with large differences (more than 10 blocks) between the two survey periods are listed in the table below. In general, most increasing species are compatible with man's activities and have increased throughout the Delmarva peninsula over the past 20 years (e.g., Canada goose [*Branta canadensis*] and wild turkey [*Meleagris gallopavo*]). Some changes are thought to represent increased counting effort on the present Atlas as opposed to the last (e.g., great horned [*Bubo virginianus*] and Eastern screech-owls [*Megascops asio*]). Two pine forest species (brown-headed nuthatch and chuck-will's-widow) have increased substantially, possibly as a result of the conversion of hardwood and mixed hardwood forest to loblolly pine. The grasshopper sparrow has clearly increased in part due to the enrollment of agricultural land in the Conservation Reserve Enhancement Program administered by the U.S. Department of Agriculture.

Species in decline are typically, but not exclusively, reliant on deciduous forests. Again, this points to the potential impacts of pine conversion on the suite of breeding birds.

Species	Change[1]
INCREASING	
Canada goose (*Branta canadensis*)	+57
Wild turkey (*Meleagris gallopavo*)	+44
Cedar waxwing (*Bombycilla cedrorum*)	+29
Great horned owl (*Bubo virginianus*)	+28
House finch (*Carpodacus mexicanus*)	+28
Tree swallow (*Tachycineta bicolor*)	+27
Wood duck (*Aix sponsa*)	+25
Eastern screech-owl (*Megascops asio*)	+23
Brown-headed nuthatch (*Sitta pusilla*)	+18
Red-tailed hawk (*Buteo jamaicensis*)	+16
Chuck-will's-widow (*Caprimulgus carolinensis*)	+13
Purple martin (*Progne subis*)	+13
Osprey (*Pandion haliaetus*)	+12
Grasshopper sparrow (*Ammodramus savannarum*)	+12
Orchard oriole (*Icterus spurius*)	+12
DECREASING	
Eastern phoebe (*Sayornis phoebe*)	-11
Whip-poor-will (*Caprimulgus vociferus*)	-12
Kentucky warbler (*Oporornis formosus*)	-15
Black-and-white warbler (*Mniotilta varia*)	-17

MARYLAND ORNITHOLOGICAL SOCIETY

Breeding Bird Atlas results for the whole of Worcester County. Because there are more data points used in the present Atlas as opposed to the last, only species with large differences (more than 10 blocks) are shown.

[1] Number of block differences between the 2002–2006 Atlas and the 1981–1985 Atlas.

Migrating shorebirds depend on Coastal Bays resources

Most species of shorebirds are long-distance migrants, breeding in the taiga or tundra areas of northern Canada and Alaska, and wintering from the southern United States through South America. Only in recent years has the importance of migratory stop-over areas to these species become apparent. Here they refuel for their incredibly energy-demanding migration, and the Coastal Bays are a very important area in this regard. The high productivity of the ocean beach, tidal flats, and salt marsh all provide foraging habitat for shorebirds during both the spring and fall migrations. In the spring, horseshoe crab eggs are a particularly important food source.

MARK L. HOFFMAN

American oystercatchers (left) and purple sandpipers (right) forage along the edge of the Coastal Bays.

Assateague Island is a component of the Western Hemisphere Shorebird Reserve Network's Maryland–Virginia Barrier Island site. The site is designated as an area of international importance, meaning it hosts at least 100,000 shorebirds annually, or at least 10% of the biogeographic population for a species. The peak counts table on the following page demonstrates the number of birds passing through the Coastal Bays.

Saw-whet owls are winter visitors

The Northern saw-whet owl (*Aegolius acadicus*), the smallest owl in eastern North America, is an annual winter visitor to the Coastal Bays.[6] Saw-whet owls breed during spring in forests across southern

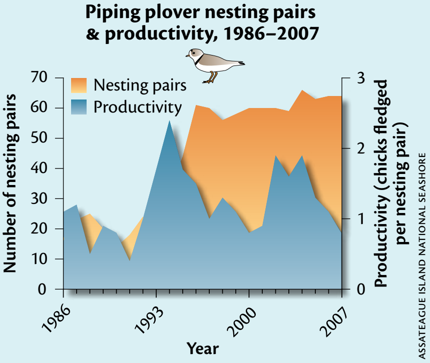
Piping plover

In 1986, piping plover (*Charadrius melodus*) was designated a threatened species by the U.S. Fish and Wildlife Service. Assateague Island, particularly the northern end, was known to host a substantial breeding population due to increased forage habitat as a result of island overwash. In the intervening years, the National Park Service has spent considerable resources to assess and manage the population. Assateague Island now has about 60 breeding pairs—about 4% of the Atlantic Coast breeding population.

Research indicates the plovers are most successful when broods have access to the bayside for foraging. The natural succession of Assateague Island is a potential threat to this species as over-washed areas become vegetated and lose value as plover habitat. An absence of strong storms since 1998 and the new storm berm has led to a gradual decline in reproductive success, a trend that will likely continue until future storms re-create the open, sparsely vegetated conditions favored by piping plovers.

MARK L. HOFFMAN

Assateague Island is home to a breeding population of piping plovers.



Piping plover nesting pairs & productivity, 1986–2007

ASSATEAGUE ISLAND NATIONAL SEASHORE

Productivity of piping plovers on Assateague Island has declined, despite increased numbers of nesting pairs.

Species	Number	Date
American avocet (*Recurvirostra americana*)	6	03/27/03
American golden plover (*Pluvialis dominica*)	34	10/18/81
American oystercatcher (*Haematopus palliatus*)	106	08/09/92
American woodcock (*Scolopax minor*)	38	12/29/76
Black-bellied plover (*Pluvialis squatarola*)	2,635	05/14/78
Black-necked stilt (*Himantopus mexicanus*)	11	05/11/02
Dunlin (*Calidris alpine*)	3,195	12/28/85
Greater yellowlegs (*Tringa melanoleuca*)	150	08/15/94
Hudsonian godwit (*Limosa haemastica*)	6	07/22/79
Killdeer (*Charadrius vociferus*)	618	12/29/75
Least sandpiper (*Calidris minutilla*)	610	05/06/78
Lesser yellowlegs (*Tringa flavipes*)	183	07/22/76
Long-billed dowitcher (*Limnodromus scolopaceus*)	41	12/28/99
Marbled godwit (*Limosa fedoa*)	5	12/07/80 & 10/19/85
Pectoral sandpiper (*Calidris melanotos*)	114	08/03/76
Piping plover (*Charadrius melodus*)	138	05/05/73
Purple sandpiper (*Calidris maritima*)	265	12/29/75
Red knot (*Calidris canutus*)	450	09/04/71
Red-necked phalarope (*Phalaropus lobatus*)	939	05/09/76
Red phalarope (*Phalaropus fulicaria*)	4,665	04/29/78
Ruddy turnstone (*Arenaria interpres*)	930	05/14/78
Sanderling (*Calidris alba*)	8,000	09/06/71
Semipalmated plover (*Charadrius semipalmatus*)	2,500	09/06/71
Semipalmated sandpiper (*Calidris pusilla*)	6,000	05/06/91 & 05/22/91
Short-billed dowitcher (*Limnodromus griseus*)	2,805	05/14/78
Solitary sandpiper (*Tringa solitaria*)	20	05/03/86
Spotted sandpiper (*Actitis macularia*)	50	07/16/80
Stilt sandpiper (*Calidris himantopus*)	70	08/05/78
Upland sandpiper (*Bartramia longicauda*)	10	08/06/94
Western sandpiper (*Calidris mauri*)	300	08/05/78 & 07/16/94
Whimbrel (*Numenius phaeopus*)	277	07/22/76
White-rumped sandpiper (*Calidris fuscicollis*)	412	05/08/78
Willet (*Catoptrophorus semipalmatus*)	1,500	04/20/75
Wilson's phalarope (*Phalaropus tricolor*)	9	08/29/87
Wilson's plover (*Charadrius wilsonia*)	20	07/25/72
Wilson's snipe (*Gallinago delicata*)	79	12/29/76

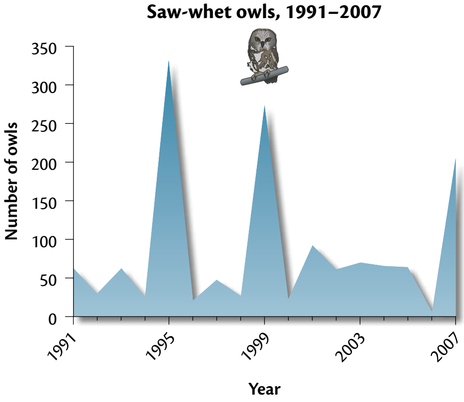
Peak counts of shorebirds in the Coastal Bays. The peak count number represents the maximum number of a species recorded in the Maryland portion of the Coastal Bays between 1970–2006.

Canada and northern United States and southward in both the Appalachian and Rocky Mountains. Their nests are usually made in tree cavities excavated by woodpeckers.

Autumn migrations begin as prey (mice, voles, shrews, and occasionally songbirds and large insects) becomes scarce with the onset of cold weather.[7] Two major migration corridors in eastern North America are along the Atlantic Coastal Plain and down the Appalachian Mountains. Much of what is known about the migration patterns of this nocturnal predator has been gleaned from banding records at over 100 sites, including Assateague Island, throughout the owl's range (for more information, see *www.projectowlnet.org*). Despite consistent trapping efforts at the banding station at Assateague, there has been a large variation in the annual number of owls captured (six to 332). Large numbers were observed in 1995 and 1999, when capture rates were three to 10 times higher than in low population years. Numbers had been relatively stable at Assateague from 2002–2005, then abruptly dropped in 2006 when only six individuals were netted. Results were similar throughout much of the East Coast south of New York.

JEFF METTER

The saw-whet owl can be found in the Coastal Bays in winter.



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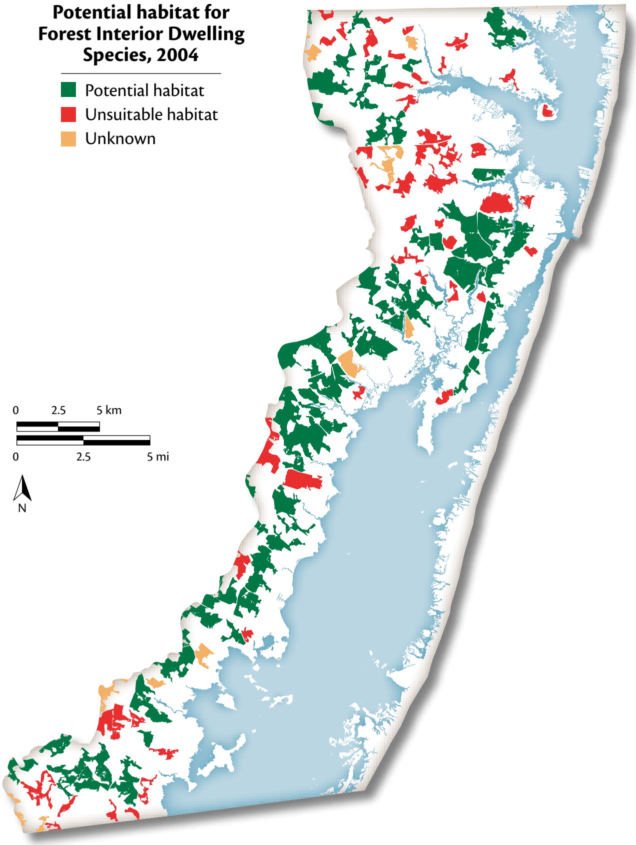
Large numbers of saw-whet owls were observed in 1995 and 1999, while 2006 had the lowest numbers recorded.

Large fluctuations in numbers of migrating owls is due to a number of factors including variability of the owl's food sources.[84] During autumn 2006, the pine cone crop was very large and synchronized for all cone-bearing trees in eastern Canada's forests—from where most of the saw-whet owls in the Coastal Bays originate. Such synchrony is unusual for pine species. Good seed crops translated into many mice and no great need for owls to migrate south. One presumption is that owls remained north because food conditions were excellent. Such conditions may lead to healthier females producing large clutches in the spring. However, pines have unpredictable seed pulses and two good crops in sequential years is highly unlikely. This was demonstrated by the relatively large number of owls observed in 2007 as they moved further south to find food.

Forest Interior Dwelling Species are sensitive to forest fragmentation

Among the many birds breeding in the Coastal Bays, a select group of species known as Forest Interior Dwelling Species (FIDS) have been targeted for conservation efforts. FIDS require large forest areas to breed successfully and maintain viable populations. This diverse group includes colorful and diminutive songbirds such as tanagers, warblers, and vireos that breed in North America and winter in the Caribbean and Central and South America. It also includes residents and short-distance migrants such as woodpeckers, hawks, and owls. Research has demonstrated that these species have declined in numbers and are very sensitive to forest fragmentation, which happens when large blocks of contiguous forest are broken into smaller parcels by development and agricultural or forestry practices.[43,64]

FIDS habitat has been defined to consist of forests that are at least 20 ha (50 acres) in size, with at least 4 ha (10 acres) of forest interior habitat. The majority of forest tracts should be dominated by pole-sized or larger trees (13 cm [5 in] or more in diameter at breast height) or have a closed canopy; or areas that are riparian (stream-side) forests that are at least 20 ha (50 acres) in size with an average total width of at least 90 m (300 ft). The stream within the riparian forest should be perennial, based on field surveys or as indicated on the most recent 7.5-minute USGS topographic maps.[34]



MARYLAND DEPARTMENT OF NATURAL RESOURCES

Potential habitat for Forest Interior Dwelling Species.

REPTILES & AMPHIBIANS

Worcester County has the greatest diversity of reptiles & amphibians in Maryland

Worcester County and the Coastal Bays watershed have the greatest diversity of reptiles and amphibians in Maryland. At least 58 of the state's 93 species can be found here, including 68% of Maryland's turtle species, 80% of frogs and toads, 63% of snake species, and 67% of lizard species.[49,50] Salamander diversity is low (seven of the state's 21 species) due to characteristics of Coastal Plain soils and historic replacement of native mixed hardwood–pine forests with loblolly pine monocultures. The climate is also warmer than the mountains of western Maryland where salamander diversity is highest.[49]

State-listed rare, threatened, or endangered species in the watershed include Eastern narrow-mouthed toad (*Gastrophryne carolinensis*), carpenter frog (*Rana virgatipes*),

A southern Coastal Plain species, the red-bellied watersnake is at its northernmost distribution in Delmarva locations only in Dorchester, Wicomico, and Worcester Counties (Maryland), and Sussex County (Delaware).[85] In Worcester County, the snake was thought to occur only in the Pocomoke River watershed, but was found in the Coastal Bays watershed in 2000 in a wooded area east of Berlin and was subsequently found during the Great Worcester County Herp Search in May, 2000 on Sinepuxent Road.

and red-bellied watersnake (*Nerodia erythrogaster erythrogaster*)—the latter two species are found nowhere else in the state except the Eastern Shore.[49] Unbroken natural lands in the watershed host numerous species, like box (*Terrapene carolina carolina*) and spotted turtles (*Clemmys guttata*), red-bellied cooter (*Pseudemys rubriventris*), broad-headed skink (*Eumeces laticeps*), and a number of frog species. The Coastal Bays are also a stronghold for diamond-backed terrapin (*Malaclemys terrapin terrapin*).

Reptiles and amphibians are generally secretive, but annual mating behaviors

What are reptiles & amphibians?

Reptiles and amphibians are collectively known as *herpetofauna* or *herptiles* (or 'herps' for short). Reptiles (such as turtles, lizards, and snakes) typically have dry, scaly skin, while amphibians (such as frogs, toads, and salamanders) have smooth, moist skin. Amphibians undergo metamorphosis from water-breathing larvae (tadpoles) into air-breathing adults. Reptiles lay eggs, usually on land, and are entirely air-breathing throughout their life.

The Eastern box turtle is found in the Coastal Bays.


DAVE WILSON

The red-bellied cooter can often be seen sunning itself on logs in warm weather.

and seasonal movements make them quite noticeable and vulnerable. The early spring chorus of frogs in wet woods signals warming weather as male frogs advertise their desire for a mate. Earliest chorus members are spring peepers (*Pseudacris crucifer*), New Jersey chorus frog (*Pseudacris feriarum kalmi*), and Eastern cricket frog (*Acris crepitans crepitans*). Also, box turtles, terrapins, snapping turtles (*Chelydra serpentina*), and red-bellied cooters are inconspicuous most of the year but become extremely vulnerable when their desire to find suitable locations for laying their eggs takes them across heavily traveled roads in early summer.

The Maryland Coastal Bays Program has helped to educate area residents about local amphibians and reptiles by holding an annual Great Worcester County Herp Search to let volunteers comb the watershed's forests and farm fields with experts to help document species. With adequate forest protection, the Coastal Bays watershed should continue to support a diverse herpetofauna.


RACHELLE DAIGNEAULT

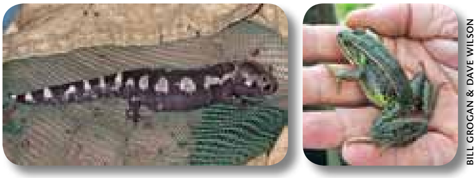
The broad-headed skink is found in forests of the Coastal Bays.

Pine plantations & herps

Natural forests typically consist of multiple plant species with trees of varying ages which provide a wide array of microhabitats for amphibians and reptiles as well as birds and mammals. Clear-cutting these forests and planting trees such as loblolly pine severely reduces the complexity of the forest and the microhabitats that are found there.

For example, a thin layer of pine needles laid down by a young but quickly growing crop of pine trees has far less habitat value than rotting logs, piles of leaves and branches, and rain-filled depressions that would be common in a more mature and diverse forest. Eastern narrow-mouthed toads require damp soils near bodies of water, or under vegetative debris. Redbacked salamanders (*Plethodon cinereus*) lay their eggs under woody debris in forests. Eastern box turtles utilize areas with high soil moisture content to look for worms and insects.

Successful forest management should be sensitive to larger ecosystem health, and techniques such as selective cutting, decreased fragmentation, and minimal use of herbicides should be emphasized.


BILL GROGAN & DAVE WILSON

Marbled salamander (*Ambystoma opacum*) and Southern leopard frog (*Rana sphenocephala*) are two amphibian species in the Coastal Bays.

There has been a global decline in amphibian biodiversity

Scientists are concerned by the rapid decline in amphibian populations worldwide. A recent assessment indicated that almost one-third of the world's amphibian population (over 1,800 species) is threatened. A number of causes have been cited for the decline, including habitat destruction, alteration, and fragmentation, introduced species, over-exploitation, climate change, ultraviolet radiation, chemical contaminants, disease, and deformities. Creative detective work by scientists paid off when a trematode (parasitic flatworm) was discovered to be responsible for many of the deformities observed in frogs in the United States.[33] Diseases and deformities have not been observed in Coastal Bays populations, but habitat destruction, alteration, and fragmentation, along with nutrient enrichment, are threats to amphibians.

A new harvesting ban will benefit terrapins

The Northern diamondback terrapin occurs throughout Maryland's Coastal Bays and Chesapeake Bay, and ranges from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. It is the only North American turtle that lives exclusively in brackish or estuarine waters. The terrapin's preferred habitat is estuarine embayments and marshes.[8]

Female diamondback terrapins leave tidal marshes typically from late May to mid-July in search of suitable upland habitat to lay eggs.[23] Suitable habitat is any open upland area above the reach of the highest tide with areas of exposed sand or loam. The diamondback terrapin is long-lived—up to 50 years—and matures slowly (seven years for males and 12 years for females). Studies have shown that adult terrapins may remain in a rather small area (less than 100 ha or 250 acres) for most of their life.

Turtles can enter crab traps and drown before the traps are collected. Use of turtle-excluding devices (TEDS) on crab pots are encouraged in many coastal areas, and are only required by law in Maryland on recreational crab pots. TEDS are rectangular or diamond-shaped, no more than 15 cm (6 in) wide and 5 cm (2 in) high, and are attached across the opening of the crab pot at the narrow end of each funnel entrance. Studies conducted by MD DNR in the Coastal Bays indicate that few terrapins are found in commercial crab pots beyond 100–200 m (325–650 ft) from shore. Also, they are not often caught in MD DNR fish trawl surveys but frequently in beach seine

ALLISON LUETTEL

The Northern diamondback terrapin matures slowly, making it vulnerable to decline.

surveys. This indicates that terrapins take advantage of the protection of marshy embayments and rarely go far offshore. Keeping pots well away from shore may be the best way to avoid accidentally catching terrapins.

A ban on the commercial harvest of terrapins in Maryland was imposed by legislative action in 2007. The ban was imposed because of poor reproductive success and high overseas demand for the turtles. However, loss of habitat from coastal development, including conversion to bulkhead and stone riprap of bayside beaches where terrapins lay their eggs, will continue to contribute to the decline of this species.

Sea turtles travel into the Coastal Bays, but rarely come ashore

Four species of sea turtles have been found near the Coastal Bays—loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempii*), and green (*Chelonia mydas*) sea turtles. Sea turtles are highly migratory and visit Maryland waters typically from May through December, with most sightings in the summer and early fall. The loggerhead is the most common sea turtle in Maryland and has been seen on numerous occasions in the Coastal Bays through the Maryland Marine Mammal and Sea Turtle Stranding Program. This joint program between MD DNR and the National Aquarium in Baltimore monitors sea turtle populations through live and dead strandings throughout Maryland waters.

MARYLAND DEPARTMENT OF NATURAL RESOURCES

This loggerhead sea turtle stranded in the Coastal Bays, apparently due to a boat strike.

JACK KUMER, ASSATEAGUE ISLAND NATIONAL SEASHORE

This leatherback sea turtle attempted to nest on the beach at Assateague Island.

Leatherback, Kemp's ridley, and green sea turtles also seasonally inhabit the Coastal Bays but with less frequency than the loggerhead. The rich species diversity in the Coastal Bays makes an ideal foraging habitat for sea turtles, which feed on a variety of organisms including blue crabs, horseshoe crabs, jellyfish, and submerged aquatic vegetation.

Sea turtle nesting ranges vary depending on species, but typically do not occur north of Virginia for any species. However, a few nests have been confirmed as far north as New Jersey.[5] The first documented loggerhead sea turtle nest in Maryland occurred in Ocean City in July, 1972. From 1972 until 1996, there were anecdotal reports of sea turtle nests and crawls in Maryland but none were documented. In May 1996, a leatherback sea turtle was photographed on the beach at Assateague Island National Seashore. Another loggerhead was observed on the beach at Assateague in July 1998.

During the summer of 1999, two loggerhead sea turtle nests were confirmed along the Atlantic coast of Maryland. The first nest was found on the north end of Assateague Island on July 8, 1999. Due to its close proximity to the tide line, the nest was relocated to higher ground. The nest was excavated and the 118 eggs were relocated 70 m (230 ft) westward of the original nest location. A second nest was reported on August 13, 1999 at the end of 62nd street in Ocean City, approximately 6 km (3.7 mi) north of the first nest. The nest was located on a populated public beach and was subject to disturbance. Therefore, a decision was made to relocate the 104 eggs to the north end of Assateague Island. Exclosures were placed around both nests and they were monitored periodically to check for predator disturbance and hatchling success. Unfortunately, neither nest successfully hatched.

INSECTS

Insects are an important ecosystem feature

Mention insects in the Coastal Bays region and odds are that the first topic will be the area's abundant biting varieties—mosquitoes, green-head flies, and no-see-ums. These insects have an irritating bite, and an even worse, though undeserved, reputation. Human pests they may be, but important creatures nonetheless with key roles as plant pollinators and components of the food web.

RICHARD ORR

The seaside dragonlet is a common salt marsh inhabitant.

Other species fare better from a human perspective. Who could not be captivated by the annual arrival, en masse, of monarch butterflies (*Danaus plexippus*) on Assateague Island, fueling up on the

CARL ZIMMERMAN

During the fall, monarch butterflies accumulate on Assateague Island during their migration to Mexico.

nectar of fall-blooming plants during their transcontinental migration to Mexico? Or the aerial acrobatics of seaside dragonlets (*Erythrodiplax berenice*) hunting for prey in the salt marsh?[59]

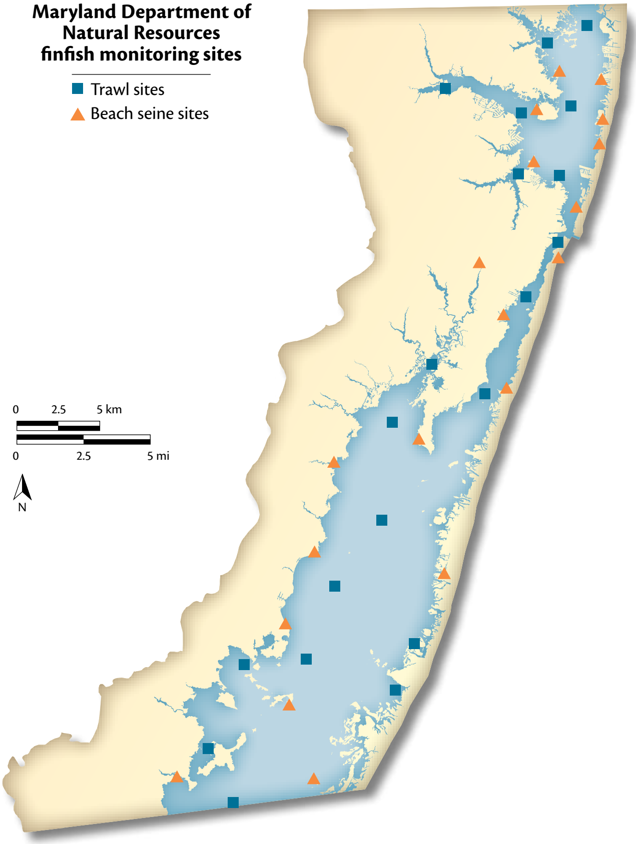

ANGEL BOLINGER

ANGEL BOLINGER

MD DNR samples finfish by beach seine netting (top) and trawling (bottom) in the Coastal Bays.

Many insects are far less visible, but no less intriguing. One of the numerous evolutionary strengths of insects is their ability to take advantage of diverse habitats. More than 19 species of grasshopper have been identified on Assateague Island, most of which are found in very specific and distinct habitat types.[60] Other specialists include the endangered white tiger beetles (*Cicindela dorsalis media* and *Cicindela lepida*). Both utilize ocean beaches, but while *Cicindela dorsalis media* occurs on the dynamic beach face at the water's edge, *Cicindela lepida* prefers the dry, loose sand of sparsely vegetated dunes.[35]

A common strategy for many insects illustrates their remarkable ability to tolerate extreme conditions. Imagine spending half your life underwater and the other half flying through the sky. Many insects do, including some dragonflies, damselflies, flies, mosquitoes, and midges. Regardless of where you look, there is always an interesting insect story, usually one illustrating the intricacy of ecological relationships or amazing adaptations found in this diverse group of organisms.



MARYLAND DEPARTMENT OF NATURAL RESOURCES

Trawl and beach seine monitoring sites in the Coastal Bays.

FISH

The Coastal Bays support a large diversity of finfish

The Coastal Bays are a dynamic aquatic system

THE COASTAL FISHERMAN

Summer flounder are a popular recreational fishing species.

that supports a wide array of finfish throughout the year. The composition of year-round residents, seasonal visitors, and juvenile finfish creates an ever-changing ecosystem among finfish populations. The Coastal Bays' location between two large biogeographic regions and proximity to the coastal Atlantic Ocean also contributes to fish diversity. These shallow waters are an ideal nursery and forage habitat for over 140 species of finfish, many of which are of commercial and recreational importance to the Ocean City area.

Through a long-term trawl and beach seine survey, MD DNR has monitored Coastal Bays finfish abundance and species composition since 1972. With human population growth, development, pollution, and fishery harvest pressures, this monitoring survey provides valuable information needed to effectively manage fish populations of the Coastal Bays.

There are spatial & seasonal trends of finfish

Results of the MD DNR annual trawl and beach seine survey indicate distinct seasonal and spatial trends in the abundance and distribution of finfish species.[58] However, the data do not indicate significant trends over comparable years of the survey (1989–2005). Fish abundances vary between embayments within the Coastal Bays due to the spatial arrangement of these embayments in relation to oceanic inlets/tidal flushing and differences in watershed use. The two northernmost embayments (Assawoman and Isle of Wight Bays) are impacted due to their location behind the resort town of Ocean City. Conversely, embayments further south (Sinepuxent and Chincoteague Bays) are relatively unimpacted due to their less developed watersheds. Additionally, the location of oceanic inlets greatly influences fish distributions as some species are transient while others are year-round residents.[44]

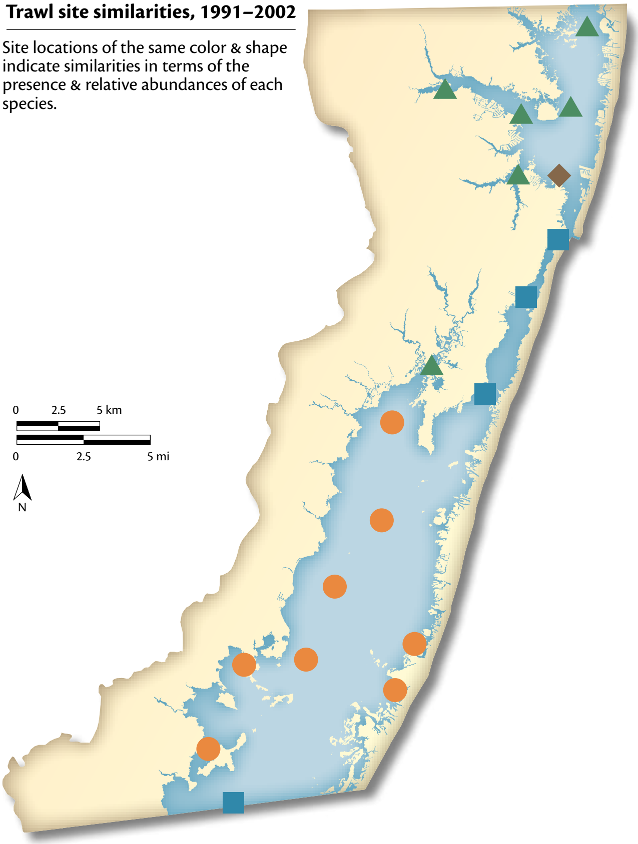
Most abundant species, from MD DNR surveys, 1991–2002

Shallow water (beach seine):

- Atlantic silverside (*Menidia menidia*).
- Atlantic menhaden (*Brevoortia tyrannus*).
- Blue crab (*Callinectes sapidus*).
- Bay anchovy (*Anchoa mitchilli*).
- Spot (*Leiostomous xanthurus*).
- Silver perch (*Bairdiella chrysoura*).
- White mullet (*Mugil cerema*).
- Mummichog (*Fundulus heteroclitus*).
- Striped killifish (*Fundulus majalis*).

Deeper water (trawl):

- Blue crab.
- Bay anchovy.
- Spot.
- Weakfish (*Cynoscion regalis*).
- Atlantic herring (*Clupea harengus*).
- Atlantic croaker (*Micropogonias undulatus*).
- Summer flounder (*Paralichthys dentatus*).
- Silver perch.



Trawl site similarities, 1991–2002

Site locations of the same color & shape indicate similarities in terms of the presence & relative abundances of each species.

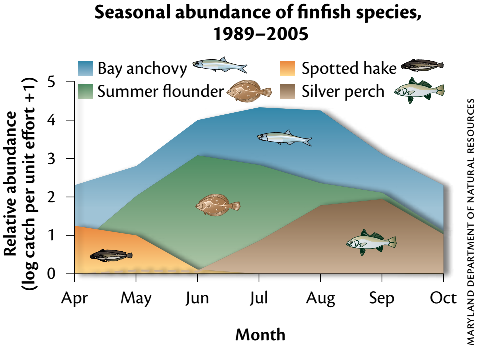
This map shows similarities between sites of trawl data in Maryland from spring through fall, 1991–2002. Of interest is the southernmost site in Chincoteague Bay, which is more similar to the Sinepuxent Bay sites than to the other Chincoteague Bay sites. The northernmost site in Newport Bay is more similar to the sites in Assawoman and Isle of Wight Bays than to the other sites in Newport and Chincoteague Bays.[58]

The trawl sites similarities map above shows the relationship between each fixed sampling location (data from spring through fall, 1991–2002), based on the presence and relative abundances of each species encountered (*relative abundance* is an estimate of actual or absolute abundance, based on trawl or beach seine samples). This shows that certain species favor one or two embayments over others, as many sites group together. Additionally, this figure demonstrates relationships between sites that are similar due to comparable environmental patterns, even though they are in separate bays. For example, the southernmost site in Chincoteague Bay (closest to the Chincoteague Inlet) is similar to sites in Sinepuxent Bay, which are also largely influenced by oceanic input from the Ocean City Inlet.[58]

Not only do the fish populations vary among the individual embayments, but they also change throughout the course of the year. Results of the MD DNR annual trawl and beach seine survey indicate that there are large seasonal fluctuations in abundance of finfish species residing within the Coastal Bays (see figure, right).

Not only do fish populations vary among the individual embayments of the Coastal Bays, but they also change throughout the course of the year. Overall, the MD DNR surveys recorded the greatest number of species and organisms caught in summer, with lower abundances in spring and fall. This is due to higher productivity (food abundance) of the Coastal Bays during summer and subsequent exploitation of food availability by marine species. These species then move out of the shallows and into offshore, deeper waters or towards southern locales to over-winter.

Species abundance fluctuates due to environmental cues, spawning behavior, and even susceptibility to sampling gear used in the surveys. Year-round residents, such as the bay anchovy (*Anchoa mitchilli*), show a steady abundance level throughout the year. Many other fish are migratory and therefore only appear at



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These four fish species utilize the Coastal Bays at different times of year.

Threats to finfish

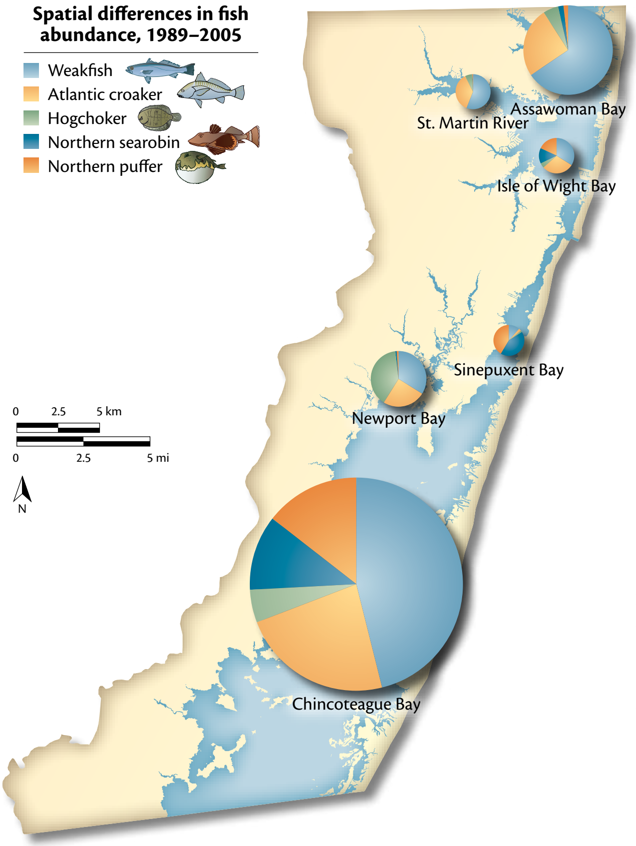
- Loss of essential fish habitat.
- Decreases in water quality.
- Commercial and recreational overfishing.

certain times of year.[56] Atlantic herring (*Clupea harengus*) is an example of a migratory species and only appears in the survey during their annual spring migration. Others inhabit the Coastal Bays intermittently, such as summer flounder (*Paralichthys dentatus*) that moves into the Coastal Bays to feed during the summer months, then returns to offshore waters to spawn through midwinter. Conversely, spotted hake (*Urophycis regia*) occupies the Coastal Bays during the winter and is only collected during spring sampling. As water temperatures rise, this cold-water species moves to deeper, cooler waters offshore and is not seen again until the following year.

Spawning behavior also plays a role in determining finfish composition.[1,22] When comparing juvenile summer flounder and silver perch (*Bairdiella chrysoura*) abundance, the timing of each species' spawn appears to directly influence its seasonal appearance in the survey. Adult summer flounder spawn in the waters of the continental shelf from late summer to early

Season	**Coastal Bay**	**Number of species**		**Number of sites**		**Number of individuals**		**Mean catch per site**	
		Trawl	**Seine**	**Trawl**	**Seine**	**Trawl**	**Seine**	**Trawl**	**Seine**
Spring	All	51	N/A	20	N/A	52,874	N/A	2,644	N/A
Early summer	All	76	72	20	18	135,385	134,165	6,769	7,454
Late summer	All	77	75	20	18	92,214	100,970	4,611	5,609
Fall	All	59	N/A	20	N/A	21,238	N/A	1,062	N/A
All	Assawoman	59	67	3	3	81,439	50,041	27,146	16,680
All	Isle of Wight	80	71	4	4	84,936	72,491	21,234	18,123
All	Sinepuxent	60	59	3	3	9,236	45,175	3,079	15,058
All	Chincoteague	83	71	10	8	126,100	67,428	12,610	8,429

Number of species, individuals, and mean catch per site for each subembayment and season by gear type.[57] Data are from Maryland only, and are from 1991–2002. Data for Isle of Wight Bay include St. Martin River, and data for Chincoteague Bay include Newport Bay. N/A means Not Applicable.



Spatial differences in fish relative abundance throughout the subembayments of the Coastal Bays (trawl data only). The size of each pie chart represents each bay's contribution to total finfish abundance, adjusted to the proportion of the each bay's size relative to the total area of the Coastal Bays. The geometric mean (a way of averaging data) of the trawl catch was used as the index of relative abundance.

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winter. By spring, juvenile summer flounder abundance is increasing and peaks during June. In comparison, silver perch spawn in the Coastal Bays during spring and juveniles are most abundant in late summer.

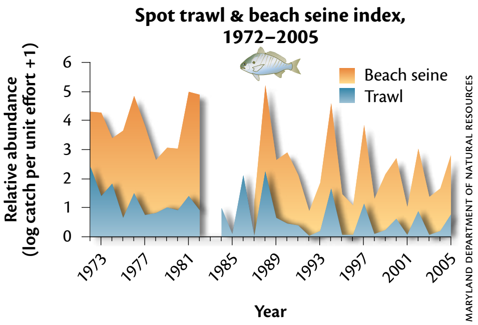
Forage fish are decreasing in abundance

Forage fish are food for larger fish species often sought for commercial and recreational purposes. Because of their position at the lower end of the food chain, forage fish are more abundant than their larger predators. Their role in the ecosystem is vital to the survival of juvenile gamefish that use the Coastal Bays as nurseries.

Found in large numbers in all areas of the Coastal Bays, bay anchovy and spot (*Leiostomus xanthurus*) are the most abundant juvenile finfish collected during the MD DNR annual surveys. Juvenile Atlantic menhaden (*Brevoortia tyrannus*) and Atlantic silverside (*Menidia menidia*) are also found in large numbers within the bays. However, these species typically inhabit only shallow waters and are collected primarily in the beach seine survey. Annual and seasonal variations in the abundance of these forage species can provide a wealth of knowledge regarding habitat utilization.

Annual indices of juvenile spot relative abundance appear to fluctuate without trend. As an offshore spawner, the abundance variation seen in the Coastal Bays could be the result of a number of factors, including offshore spawning success, ocean temperature and currents, and commercial and recreational harvest impacts.

On the other hand, bay anchovy is more of a local resident of the Coastal Bays. Adult bay anchovy reside year-round in the estuary and spawn at night throughout the spring and summer. The slightly decreasing trend in bay anchovy relative abundance since the late 1980s could be an indication of localized declining environmental conditions within the Coastal Bays watershed.



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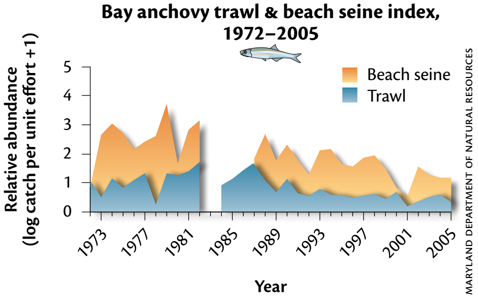
Relative abundance index for spot in Maryland. Data were removed (trawl 1983; seine 1983–1986) due to a lack of samples collected in those years. Standardization of the survey was implemented in 1989.

MARGARET MCGINTY

As juveniles, spot are an abundant forage fish species in the Coastal Bays.



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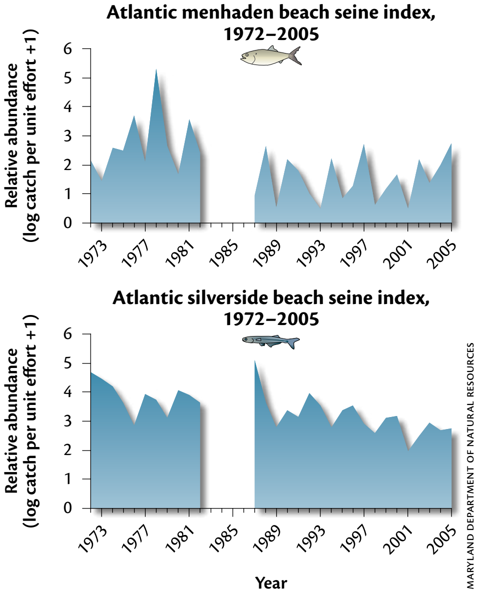
Relative abundance index for bay anchovy in Maryland. Data were removed (trawl 1983; seine 1983–1986) due to a lack of samples collected in those years. Standardization of the survey was implemented in 1989.

MARGARET MCGINTY

Bay anchovy is a year-round resident of the Coastal Bays.

Similar trends in annual relative abundance are seen in the juvenile Atlantic menhaden and Atlantic silverside beach seine indices. Like spot, menhaden are offshore spawners and variations in annual relative abundance have fluctuated without trend since the late 1980s. Factors influencing juvenile menhaden abundance in the Coastal Bays are probably similar to those mentioned for spot above. Additionally, there is a significant commercial fishery



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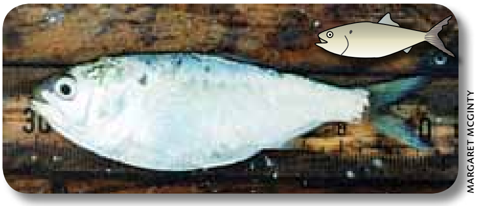
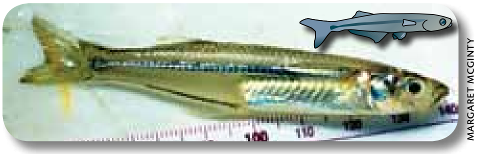
Relative abundance index for Atlantic menhaden and Atlantic silverside in Maryland. Data were removed (1983–1986) due to a lack of samples collected in those years. Standardization of the survey was implemented in 1989.



MARGARET MCGINTY

Atlantic menhaden move offshore to spawn, and so are not in the Coastal Bays year-round.



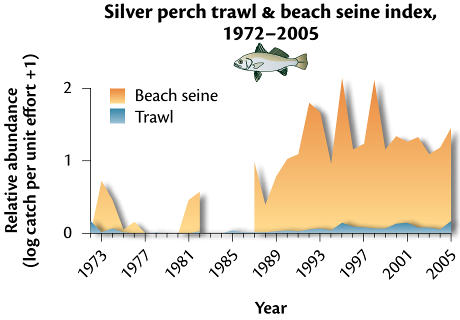
MARGARET MCGINTY

Atlantic silverside spend their entire lives in the Coastal Bays.

for Atlantic menhaden, and commercial harvest could also be a major factor determining the abundance of juveniles in the Coastal Bays.

The Atlantic silverside is another resident year-round species and its trends mimic those of the bay anchovy. The slight but consistent decline in silverside relative abundance since the late 1980s could be a result of local degradation of the Coastal Bays watershed; however, not all resident finfish exhibit this same trend.

Silver perch, another very common year-round resident species encountered in the MD DNR surveys, has shown increasing trends of relative abundance since the mid-1980s. Factors related to this trend could include increased food availability, changing environmental conditions, increased preferred habitat, and a decrease in predator species.


Silver perch trawl & beach seine index, 1972–2005

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Relative abundance index for silver perch in Maryland. Data were removed (trawl 1983; seine 1983–1986) due to a lack of samples collected in those years. Standardization of the survey was implemented in 1989.


GERRIT VELEMA

Silver perch have been increasing in the Coastal Bays.

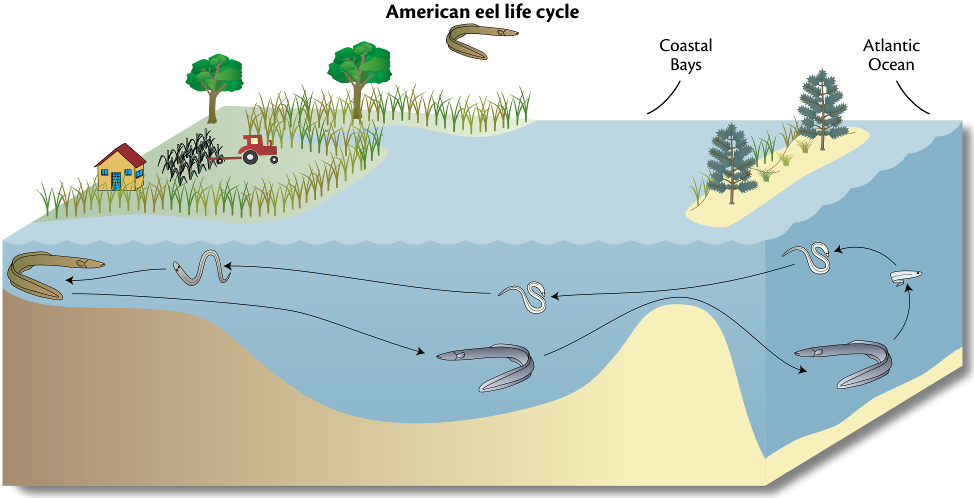
These trends in fish species diversity and abundance are important in understanding the complexities of interactions between organisms and their environment. It is important that scientists continue to monitor these trends.

Fish have differing life cycles

A common way to categorize fishes is by their life cycle and habitat. *Oceanodromous* fishes such as tunas and billfish remain in oceanic waters throughout their life and utilize Coastal Bays species such as Atlantic herring and menhaden as forage. *Anadromous* fishes, such as river herring, striped bass (*Morone saxatilis*), and hickory shad (*Alosa mediocris*), live as adults in ocean waters but spawn in productive coastal rivers for nourishment and shelter of their young. *Catadromous* fishes, such as American eel (*Anguilla rostrata*), spawn in the open ocean and migrate to estuarine waters to mature. *Coastal* fishes, such as summer flounder, seatrout, and black sea bass (*Centropristis striata*), remain in the productive coastal ocean and bays throughout their lives and make smaller movements onshore for feeding and offshore for reproduction. *Freshwater* fishes are those that spend their entire life cycle in freshwater streams and most are not able to tolerate saline water.

American eels have a complex life cycle that is still not fully understood. They spawn offshore, in the area of the Atlantic Ocean known as the Sargasso Sea, between Bermuda and the Bahamas.[65] After hatching, larvae drift on the ocean currents for up to a year before reaching estuaries along the East Coast. The American eel will remain in the estuary and, in many cases, will move even further upstream to live out its adult years. Mature adult eels continue this complex life cycle by making one last life-ending migration back to the Sargasso Sea to spawn.

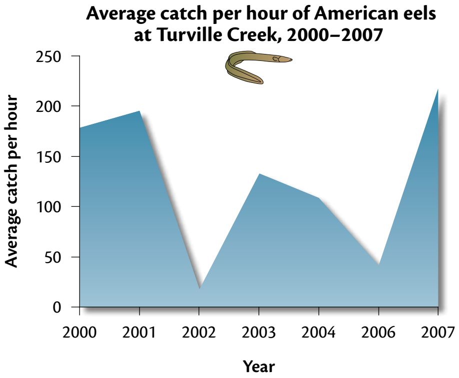
Summer flounder spawn on the continental shelf in the fall. Spawning appears to occur while the adults are



American eels begin their life when they are spawned in the Sargasso Sea in the southwest North Atlantic Ocean. They develop into transparent, willow leaf-shaped leptocephalus larvae that are carried by ocean currents to coastal inlets where they metamorphose into ‘glass’ eels. Glass eels are transparent, round, and 50–60 mm (2–2.3 in) long. In late winter and spring, the glass eels migrate into the Coastal Bays, where they soon become pigmented when they begin to feed in the estuaries. These eels are known as elvers. Both glass eels and elvers have been found at the Turville Creek fish ladder and below the Bishopville dam on St. Martin River.[82] Some elvers remain in the estuaries where they live, feed, and grow until they mature at 10–15 years of age. Others migrate varying distances upstream, overcoming seemingly impassable obstacles such as spillways and dams. When eels are fully grown and ready to migrate and mate, their coloration changes from yellow-green to silver, and they head back to the Sargasso Sea in the open ocean.

ROMAN JESIEN

American eel in the green eel stage captured in Chincoteague Bay in the fall. This is the stage prior to migration to the ocean.



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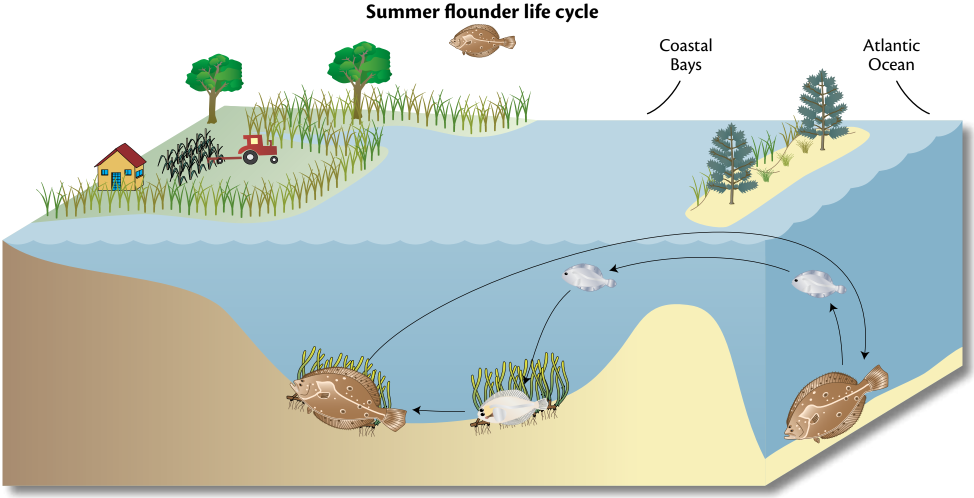
Average number of eels caught per hour in a trap deployed in Turville Creek.

migrating offshore, as the eggs are initially found nearshore and then spread to the entire continental shelf. By December and January, eggs are only found at the edge of the continental shelf.[1] Larvae ride ocean currents throughout the winter until they are deposited into estuaries in early spring. Warm water temperatures and abundant food supplies encourage fast growth. Both juveniles and adults leave the Coastal Bays in the fall.

The mummichog (*Fundulus heteroclitus*) is a common species in the Coastal Bays, with a life cycle very different from those previously discussed. Mummichogs are schooling minnows whose life cycle begins and ends in shallow estuarine waters. To reduce predation by other



Summer flounder begin their life cycle at the middle and outer continental shelf in the fall when they are spawned by adult flounder moving offshore for the winter. Eggs rise to near the surface, and the newly hatched, symmetrical larvae begin their planktonic stage of existence. In early spring, at a size of around 1 cm (0.4 inch), larvae move into the Coastal Bays where they metamorphose into juvenile flounder. The right eye migrates to the left side of the head, the body takes on the flattened appearance of the adult fish, and they settle to the bottom to begin their demersal (bottom-dwelling) stage of life, often among seagrass beds.

aquatic organisms, adult mummichogs lay their eggs on the leaves of marsh grass or the empty valves of ribbed mussels during a high tide. During periods of low water levels, eggs continue to develop while on land. Juveniles grow to adults feeding on invertebrates, including mosquito larvae, in the shallow, still waters of the marsh.[2]

Freshwater fishes are constrained by small watersheds & saltwater

Freshwater fishes are those that spend their entire life cycle in water without salt. In the Coastal Bays watershed, they are isolated in relatively small streams and are limited in their downstream movement by the saltwater barrier. Numbers are further limited by storms, which may wash fishes from streams to less hospitable locations down-river or bring saline bay waters up into streams. Human-induced changes to the landscape through agriculture, notably the common practice of ditching and channelizing (straightening streams for draining agriculture fields), have degraded habitat and limited distribution of freshwater fishes. For information on the freshwater Fish Index of Biotic Integrity (FIBI), see Chapter 15—*Habitats of the Coastal Bays & Watershed.*

Eastern mudminnow (*Umbra pygmaea)*, creek chubsucker (*Erimyzon oblongus*), and pirate perch (*Aphredoderus sayanus*) are common in the slow-moving streams that occur in the relatively flat terrain of the Coastal Bays.[51] A common fish in streams and marshes is the Eastern mosquitofish (*Gambusia holbrooki*). It bears its young live, in contrast to most fishes which lay eggs. Its cousin, the Western mosquitofish (*Gambusia affinis*), has been introduced to many parts of the world, including the Delmarva peninsula, in an effort to control mosquitoes.[32] Banded killifish (*Fundulus diaphanus*), mummichog (*Fundulus heteroclitus*), and pumpkinseed sunfish (*Lepomis gibbosus*) are tolerant of varying salinity, moderate siltation, and elevated nutrient levels in the water. The small redfin pickerel (*Esox americanus americanus*) is one of the few native predators. Largemouth bass (*Micropterus salmoides*) were introduced to the

Atlantic coast watersheds and are now top predators in a few of the larger creeks.[47,51]

Some uncommon freshwater fishes of the Coastal Bays include the blue-spotted sunfish (*Enneacanthus gloriosus*) which has a low tolerance to saltwater and requires relatively clean, clear water. Notably diminished in the Coastal Bays are darter and minnow species which are more abundant in the larger watersheds of the Chesapeake Bay drainage. For example, the tessellated darter (*Etheostoma olmstedi*), which requires sandy bottoms and can withstand low salinities, only occurs in two small watersheds.[47]

SHELLFISH

The molluscan community is diverse & abundant

The Coastal Bays ecosystem can be a hostile environment for aquatic species. Conditions can be harsh, often violently so, as when a storm blows through, churning up the bottom and dislodging the inhabitants or smothering them with sediment. Seasonal temperature extremes range from thick packs of ice scouring the shallows and shoreline to lethal summer peaks. During the summer, hypersaline conditions can prevail along with sagging dissolved oxygen levels, further stressing organisms.[26] Longer-term, gradual habitat changes, such as substrate characteristics, water quality, and biogenic structure within eelgrass beds, lead to shifts in species composition.

The most profound changes, on the scale of decades, occur from episodic events—specifically the opening and closing of inlets that radically alter the salinity regime, reshuffling the molluscan community in the process. The improvement of commercial shellfish resources was one of the primary rationales for allocating funds to construct a new inlet in the early 1930s. Just before construction was to begin, a hurricane broke through the island at the southern edge of Ocean City and the new inlet was quickly stabilized. The consequent salinity rise allowed many species to colonize formerly brackish waters, while others nearly disappeared.[10] For more information on the formation and history of the Ocean City Inlet, see Chapter 12—*Dynamic Systems at the Land–Sea Interface*.

MITCH TARNOWSKI

An example of what oysters in the Coastal Bays looked like before their demise.

There are no viable subtidal oyster populations in the Coastal Bays

The Chincoteague or Eastern oyster (*Crassostrea virginica*) has long been prized for its salty flavor, providing profitable livelihoods to generations of watermen in remote villages along the shores of the Coastal Bays. In addition to their commercial value, oysters are ecologically important as filterers and reef builders, contributing structure and hard substrate to a rich community of organisms in an otherwise soft-bottom environment.

Immediately following the Civil War, the unique conditions of the region led to the culturing of oysters,[30] an advanced practice at the time that no doubt sustained the industry much longer than it otherwise would have lasted as a wild-harvest fishery. With just Chincoteague Inlet open, oysters thrived only below South Point at the north end of Chincoteague Bay, as the waters in the bays above were not salty enough.[24] This lead to several failed schemes over the years to construct another inlet to raise salinities and expand oyster growing grounds.[24]

The eventual opening and stabilization of the Ocean City Inlet fundamentally changed the Coastal Bays ecosystem, and a surge in oyster farming was anticipated. Ironically, the resulting influx of predators, competitors, and diseases created a situation where oyster populations, whether natural or cultured—and the industry they supported—could no longer exist.[4] The demise of the Coastal Bays oyster has resulted in the loss of a critical functional component of the ecosystem and the gradual disappearance of a significant structural element.

Small, relict oyster populations still exist intertidally at a few locations throughout the Coastal Bays, with occasional spatfall (settling of larval oysters) on man-made structures such as riprap, pilings, and bridge supports.[72] Despite the long-term absence of significant oyster populations, at least three major oyster diseases are still active in the Coastal Bays (see "Oyster diseases" sidebar).

Oyster diseases

Three diseases afflict oysters in the Coastal Bays, with strikingly different patterns of infection and mortality.

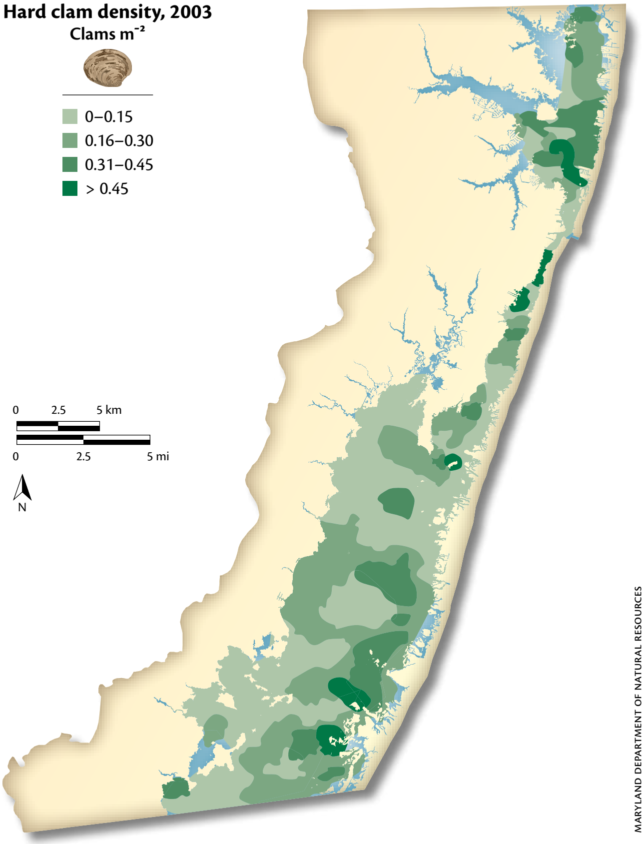
- Dermo disease, caused by the parasite *Perkinsus marinus*, can infect oysters throughout the warm months of May through October. Mortalities usually occur during the second and third years.
- MSX disease, caused by the protozoan parasite *Haplosporidium nelsoni*, is believed to have been introduced from Asia. The disease can kill oysters of any age from spat to adults.
- SSO (seaside organism) disease, caused by the closely related *Haplosporidium costalis*, is limited to salinities above 25 ppt. Infections occur during a limited time in May and June, when oysters are almost a year old, followed by a year-long incubation period before mortalities occur. Because the oysters are able to reproduce before heavy mortalities occur, this parasite is thought to be indigenous, unlike MSX disease.

Regardless of method, these diseases have had a devastating effect on oyster populations in the Coastal Bays and surrounding regions.

DAVE WILSON

Clamming is a popular recreational activity in the Coastal Bays.

Hard clam densities are lower than historical levels



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Hard clams are found throughout the Coastal Bays.

Historically, the hard clam (*Mercenaria mercenaria*) has been an important species in terms of both sustenance and commerce. In addition to being items of food for the indigenous people of the Coastal Bays, clams were highly valued as a source of purple shell for making wampum beads, the common currency of exchange among tribes along the Atlantic coast. Prior to 1933, hard clams were confined to the higher salinities in southern Chincoteague Bay. As one of the species that flourished after the Ocean City Inlet opened, new clam populations and an associated fishery quickly developed throughout the Coastal Bays. Since the 1960s, the hard clam has supplanted the oyster in commercial landings and value in the bays and is the basis of a recreational fishery for flocks of tourists that descend on the region during the warmer months.[4]

Threats to shellfish

Threats to shellfish in the Coastal Bays include:

- Shoreline development.
- Sediment and chemical runoff.
- Toxic leachates and contaminant spills at marinas.
- Navigational dredging and spoil dumping.
- Low dissolved oxygen.
- Large-scale oil spills.
- Loss of intertidal habitat.
- Erosion from boat wakes.
- Threats to seagrass habitat.
- Harmful algal blooms.
- Destructive non-indigenous species.

Current hard clam densities in all of the bays are lower than historical (1953) levels, with populations dominated by older, larger clams.[15,29,83] Recruitment is generally low and sporadic in most areas (except in parts of Sinepuxent and Isle of Wight Bays), likely because of intense predation pressure, especially from blue crabs.

Scallops have been found in most bay segments, although in low numbers

Among the more interesting of the Coastal Bays bivalves is the bay scallop (*Argopecten irradians*). They are capable swimmers for short distances, which they accomplish by jetting water through their valves, generally in response to predators. Other unusual attributes are their 18 pairs of blue eyes and hermaphroditic reproductive strategy (concurrently possessing both male and female sex organs). Bay scallops have relatively short life spans of only about one to two years, compared to the 40-year maximum life span of the hard clam. Their preferred habitat is eelgrass beds (providing the beds are not too thick), although they can also be found on other firm substrates such as shell and hard sand. Traditionally, scallops have been appreciated both for their succulent flavor and the aesthetic value of their shells.

During the 1920s, bay scallops were the objects of a modest but lucrative fishery based in Chincoteague, Virginia. Generally, however, salinities in the Coastal Bays during this period were too low to support scallops. Although the opening of the Ocean City Inlet raised salinities to suitable levels, bay scallops were unable to exploit the new areas available to them because the eelgrass beds had succumbed to 'wasting disease' during the early 1930s.

In an attempt to re-establish a population in Chincoteague Bay, the MD DNR Shellfish Program planted 1.2 million juvenile bay scallops and raised them to reproductive age during 1997 and 1998.[73] By 2002, live scallops were recorded north of the Ocean City Inlet, in both Isle of Wight and Assawoman Bays, possibly for the first time in over a century. Although low densities suggest that the long-term viability of the bay scallop population is still tenuous, the extraordinarily rapid range expansion is a major step toward re-establishment in the Coastal Bays.

ROBERT BUSSELL

The bay scallop is being re-established in the Coastal Bays.

Molluscs fill a range of ecological roles

Despite harsh conditions in the Coastal Bays, a thriving molluscan community exists, with over 100 species reported.[11,71] These are mainly opportunistic species, which are well adapted to highly variable conditions and can readily exploit environmental perturbations by rapidly colonizing disturbed areas. Adaptation to disturbance allows a particular suite of organisms to form a community within the boundaries of their habitat requirements while excluding other, less tolerant species. These communities are characterized by their resilience and persistence in the face of disturbance.

The high species diversity in the Coastal Bays is the product of a rich mosaic of habitats, the addition of marine colonizers (especially near the Ocean City Inlet), and the overlap of northern and southern species due to the proximity of a biogeographic break at Cape Hatteras, North Carolina.[71] Several recent range extensions are of southern species, suggesting a warming trend in climate. Individual embayments have pronounced differences in composition of molluscan assemblages.

The ecological significance of molluscs to the estuarine ecosystem has long been recognized. Over 125 years ago, the concept of an ecological community was developed through observations of the faunal assemblages of oyster reefs.[54] Functionally, molluscs serve as a key trophic link between primary producers (organisms that convert sunlight to energy, such as plants) and higher consumers (organisms that feed on primary producers and other consumers). Bivalves in particular are important as biogeochemical agents in benthic–pelagic coupling, cycling organic matter from the water column to the bottom. Predatory gastropods contribute to structuring prey assemblages and parasitic snails may serve as disease vectors within host populations. In addition, molluscs can have a pronounced impact on the physical structure of an ecosystem, whether by grazing, reworking the sediment, binding or securing existing substrate, or building new substrate such as oyster reefs. Below are some examples of the ecological roles molluscs play in the Coastal Bays.

Structural engineers

The ribbed mussel (*Geukensia demissa*) is the most abundant intertidal mollusc in the Coastal Bays, inhabiting a narrow band along the shoreline.[70] It is well adapted to the extremes of an intertidal existence, including the ability to breathe aerially. This ecologically important bivalve binds substrate with its web-like byssal threads, countering marsh erosion, and stimulates marsh production by fertilizing the grasses. In return, the marsh provides habitat and refuge from predation.


ROBERT BUSSELL

The ribbed mussel, along with *Spartina* salt marsh grass, stabilizes a small exposed point in Chincoteague Bay.

Grazers

The grass cerith (*Bittiolum varium*), an abundant, caraway seed-sized gastropod, grazes on epiphytic algae colonizing live eelgrass. By removing the algae, which competes with eelgrass for light and carbon intake, this tiny snail helps maintain the health of seagrass beds.


MITCH TARNOWSKI

The grass cerith is a grazing gastropod. A millimeter scale is included for size.

Deposit feeders

The elongate macoma (*Macoma tenta*) feeds on detritus by vacuuming the sediment surface with its groping, incurrent siphon. By reworking


MITCH TARNOWSKI

The bend in the shell of the elongate macoma allows the vacuuming siphon to reach the surface without kinking.

the bottom, this small bivalve can modify its habitat to the extent of excluding suspension feeders, thereby restructuring the faunal community in silty substrates.

Predators

Boring gastropods, including oyster drills and moon snails, drill holes in their victims' shells and then rasp out the meats with file-like tongues. An unusually large-sized race of the Atlantic oyster drill (*Urosalpinx cinerea*) was reported from Chincoteague Bay.

A bore hole from a moon snail in the shell of a hard clam.

Symbionts

The Atlantic awningclam (*Solemya velum*) inhabits a Y-shaped burrow, usually in the sulfide-rich sediments of seagrass beds. Chemoautotrophic bacteria living within the clam derive energy from hydrogen sulfide, which allows them to fix carbon as food for their host.

The Atlantic awningclam has symbiotic bacteria.

Suspension feeders

The coot clam (*Mulinia lateralis*) is one of the most ubiquitous molluscs in the Coastal Bays, filtering phytoplankton from the water column. It is an important food source for many waterfowl and fish.

The coot clam is a suspension feeder. A millimeter scale is included for size.

Parasites

The small, parasitic gastropod *Turbonilla interrupta* is commonly found throughout the Coastal Bays. The feeding apparatus of this family is modified for sucking blood from its hosts, and one species was shown to transmit Dermo disease among oysters. Many invertebrate species are hosts to this group of snails.

Turbonilla interrupta is a parasitic gastropod on invertebrates, including oysters. A millimeter scale is included for size.

BLUE CRABS

The blue crab life cycle is complex

The blue crab (*Callinectes sapidus*) is well known throughout Maryland as a valuable commercial and recreational living resource. The stages of the blue crab's life cycle are complex and differ between the sexes. Like many marine organisms, the recruitment of blue crabs into the Coastal Bays is driven by tides and ocean currents.[17] Fertilized eggs are released by female crabs in high salinity waters. Development of larvae (zoeae) continues in the waters of the continental shelf, where optimal conditions are typically found.[78] The second larval stage (megalopae) crabs enter the Coastal Bays on evening flood tides and disperse throughout the bays to shallow nursery habitats (seagrass and macroalgae).[45]


ROBIN ENGLISH

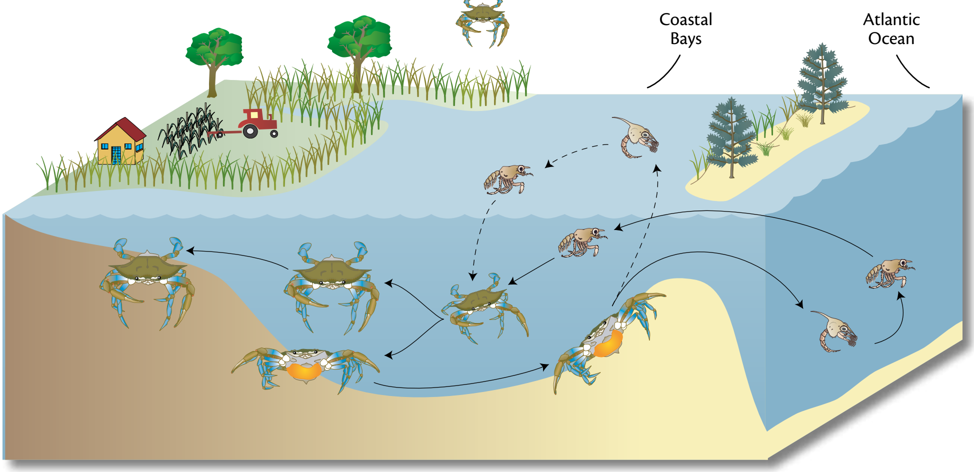
The blue crab is a familiar inhabitant of the Coastal Bays.

In contrast to Delaware and Chesapeake Bays, the viability of the Coastal Bays blue crab population is heavily reliant on successful reproduction in other estuarine systems. Although it is thought that the majority of crabs recruit to the Coastal Bays through the Ocean City and Chincoteague Inlets, reproduction of resident crabs within the Coastal Bays may also occur.

Blue crab abundance is fluctuating without trend

Survey results indicate that the abundance of blue crabs in the Coastal Bays fluctuates annually with no apparent trend. Also, the average size of crabs found in the bays shows no pattern. This suggests that blue crab fishing pressure has remained

Blue crab life cycle

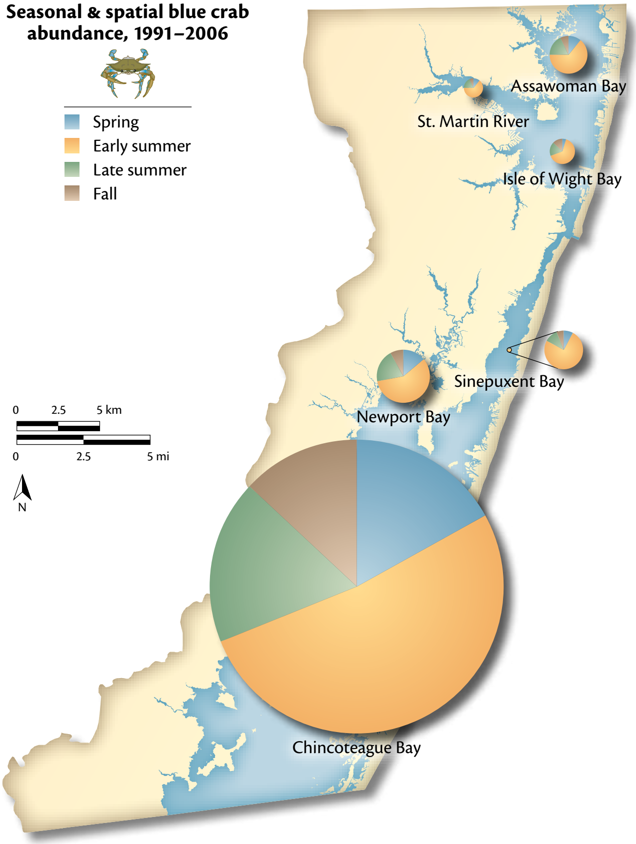


The life cycle of the blue crab is relatively complex. Mating occurs from June to October, when the females are still soft from molting. Males spend the winter in the muddy bottoms of fresher estuaries, while females migrate towards saltier waters to release fertilized eggs developing in their aprons. From May to October, the first larval stage (zoea) hatches from the eggs. Once hatched, the small zoeae are swept out to the Atlantic Ocean where, after a series of molts, the second larval form (megalopa) is produced. The megalopae can swim vertically in the water column, and ride the currents back into the Coastal Bays. After several more molts, the megalopae metamorphose into juvenile and then adult crabs.

relatively constant, with no trend up or down in relative abundance or size of crabs. Since 1990, commercial landings have also fluctuated without trend and have ranged from 227,000–800,000 kg (0.5–1.8 million lb).

Hematodinium & blue crabs

Hematodinium sp. is a parasitic dinoflagellate (a single-celled organism) that infects and kills blue crabs. In the Coastal Bays, parasite abundance follows a seasonal pattern with a sharp peak in late autumn.[53] Infections are significantly more prevalent in areas of high salinity (26–30 ppt) and in small crabs measuring less than 30 mm (1.2 in) carapace width. Chincoteague Bay has the highest prevalence, while some of the lowest numbers of infections occur north of the Ocean City Inlet and in lower salinity tributaries.



Seasonal & spatial blue crab abundance, 1991–2006

Seasonal and spatial differences in blue crab relative abundance throughout the subembayments of the Coastal Bays (trawl data only). The size of each pie chart represents each bay's contribution to total blue crab abundance, adjusted to the proportion of the each bay's size relative to the total area of the Coastal Bays. The geometric mean (a way of averaging data) of the trawl catch was used as the index of relative abundance.

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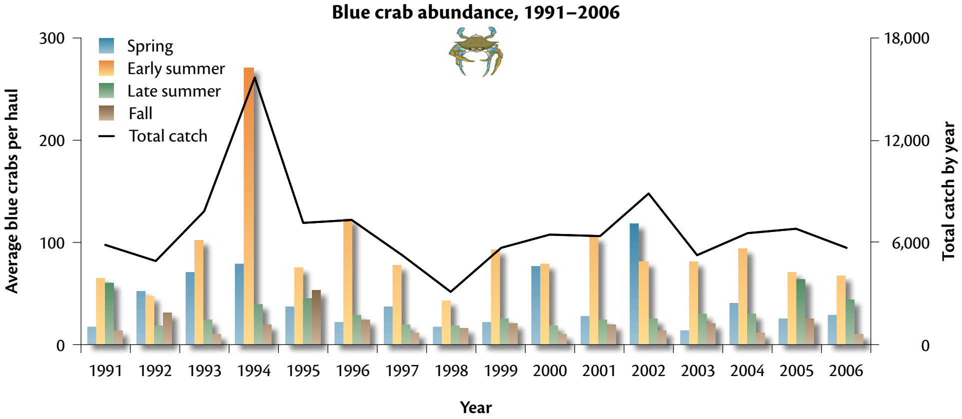


Blue crab abundance, 1991–2006

Blue crab catch (an indicator of abundance) varies per year with no apparent trend (trawl data only). Data are from Maryland only and are averaged over all the bays.

MARYLAND DEPARTMENT OF NATURAL RESOURCES

A number of factors influence crab populations in the Coastal Bays, including environmental and hydrographic conditions, especially offshore. However, a parasitic infection found in crabs in the Coastal Bays is considered to be a major influence on the population (see "*Hematodinium* and blue crabs" sidebar on facing page).

OTHER CRUSTACEANS

Many other crab species make their homes in the Coastal Bays

In addition to blue crab, MD DNR monitoring surveys conducted in the Coastal Bays have identified 23 other crab species. Occupying a variety of habitats including salt marshes, beaches, intertidal, and deep water zones, these crabs are an important component of the Coastal Bays ecology. As scavengers, cleaners, predators, and prey, each has found its ecological niche within this dynamic system.

Some species are easily seen in their semi-terrestrial habitats. Atlantic ghost crabs (*Ocypode quadrata*) are commonly spotted on the beach at Assateague Island, as well as Atlantic marsh fiddler crabs (*Uca pugnax*) in the bayside salt marsh. Spider crabs (*Libinia* spp.), ocellate lady crabs (*Ovalipes ocellatus*), and Atlantic mud crabs (*Panopeus herbstii*) are common in the Coastal Bays. However, their preference for deep water

JIM CASEY

The Japanese shore crab has been introduced into the Coastal Bays.

STEVE DOCTOR

The green crab is an exotic species introduced to the Coastal Bays for use as recreational fishing bait.

and the intertidal zone make them less likely to be seen.

The green crab (*Carcinus maenas*) and Japanese shore crab (*Hemigrapsus sanguineus*) are introduced exotic species which have become established in the intertidal zone in the Coastal Bays. Exotic species can be problematic to the ecosystem by displacing and outcompeting other native inhabitants for limited resources. Where green crabs have been introduced elsewhere, they have been destructive to native molluscan populations, including clams, oysters, and mussels.[9]

There are non-native crayfish in the Coastal Bays

The red swamp crayfish (*Procambarus clarkii*) is a non-native crayfish that has been introduced into freshwater streams in the Coastal Bays watershed. This species is large and aggressive and is likely to affect populations of native crayfishes, freshwater mussels, and amphibian species through direct competition and predation. Currently, feral populations of this species are known from Scarboro and Pawpaw Creeks, tributaries of Chincoteague Bay.

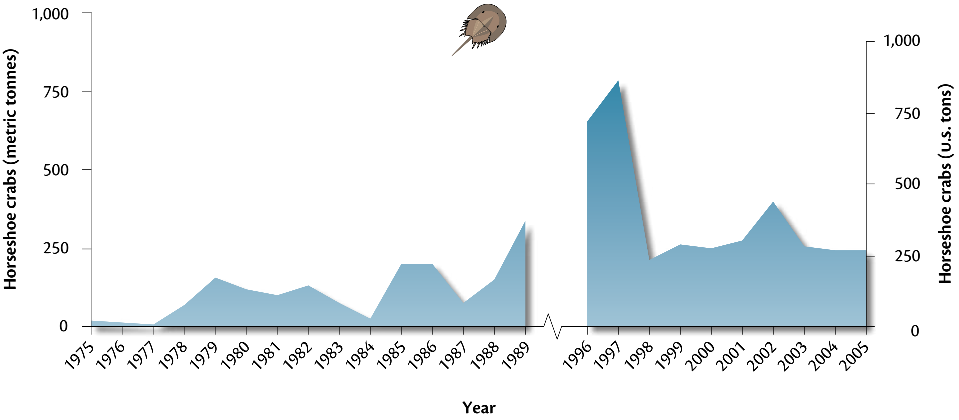
ANDREW BECKER

The red swamp crayfish is not native to the Coastal Bays watershed.

Horseshoe crabs are ecologically important

Horseshoe crabs (*Limulus polyphemus*) are not true crabs but are more closely related to spiders and other arachnids. A true ecological generalist (organisms having broad environmental tolerance ranges and relatively unspecific resource requirements), the horseshoe crab has evolved very little and endured the changing oceanic environment for over 350 million years. The range of these 'living fossils' is from Maine to the Yucatán Peninsula, Mexico, and horseshoe crabs are found in the shallow waters of Maryland's Coastal Bays throughout much of the year. Horseshoe crabs are commonly seen slowly foraging along the bottom for bivalves and marine worms, their main food source. The horseshoe crab

Maryland horseshoe crab commercial landings, 1975–2005



MARYLAND DEPARTMENT OF NATURAL RESOURCES

Commercial landings in Maryland of horseshoe crabs over the last 20 years. The data from 1975–1989 may underestimate the landings, as there was no mandatory reporting during that time.


CAROL CAIN

Horseshoe crabs mate on a bayside beach near the Oceanic Pier in Ocean City.

is ecologically important to the Coastal Bays. However, its significance extends far beyond the aquatic environment.

The spring of each year brings the environmental cues the horseshoe crab needs to begin its mating ritual. When the moon, tides, and wave action are just right, millions of horseshoe crabs in the Mid-Atlantic region make their way to spawn on the sandy beaches of the coast, including the bayside beaches of the Coastal Bays. Migrating shorebirds, such as the red knot (*Calidris canutus*), on their way from South America to their nesting grounds in the Arctic, time their arrival to the Mid-Atlantic region as horseshoe crabs are spawning. These tiny birds rely on the eggs of the horseshoe crabs as fuel to complete their 10,000-mile journey.

In addition to its ecological importance, the horseshoe crab is valued both economically and biomedically. Horseshoe crabs are commercially harvested for use as bait in the whelk (*Busycon* spp.) and American eel fisheries. A sharp rise in the harvest of horseshoe crabs in the 1990s sparked action by the Atlantic States Marine Fisheries Commission in 1998 to set limits on the number of horseshoe crabs landed commercially each year.

Horseshoe crab blood cells (amebocytes) contain a clotting substance, Limulus amebocyte lysate (LAL), which plays an important role in the health care industry.[38] LAL is used by pharmaceutical and medical device companies to test their products for bacterial contamination. Horseshoe crabs that are collected for the biomedical industry are taken to a laboratory facility where their blood is drawn, and they are returned alive to the waters where they were collected.

Historically used only for fertilizer, horseshoe crabs are now recognized as an ecologically, economically, and medically important species in the Coastal Bays ecosystem.


MIKE OATES, ANEW INC

Horseshoe crabs being bled in the laboratory to collect LAL. Horseshoe crab blood is blue because copper is the element that carries oxygen, instead of red-colored iron in mammals' blood.

Threats to horseshoe crabs

The continued threat to horseshoe crabs in the Mid-Atlantic region is the growing loss of spawning habitat due to the use of bulkheads and riprap to artificially stabilize shoreline. Optimal spawning habitat includes natural bayside beaches that have granular sediment (sand) and are protected from heavy wave action.

PLANKTON & BENTHIC COMMUNITIES

Phytoplankton are diverse & abundant

Microscopic organisms that are popularly known as algae make up a remarkable group called phytoplankton. The word *phytoplankton* comes from the Greek *phytos* (plant) and *planktos* (wanderer). Some of these organisms are very efficient at using the sun's energy to fix carbon from the water (photosynthesis) and using nutrients such as nitrogen and phosphorus to produce their own food. When involved in the photosynthetic process, these organisms act as plants do on land, by supplying oxygen to the water and forming the base of aquatic food chains.

Phytoplankton are extremely resilient and can quickly exploit changes in water quality conditions, largely because they can reproduce so rapidly. For example, under favorable conditions, some phytoplankton can divide once every 12–24 hours which can quickly lead to massive population sizes, or blooms.[63] Also, because of their small size and large surface-to-volume ratio, phytoplankton can take in nutrients and dispose of metabolic waste products very efficiently. Many of these organisms can act as consumers instead of producers if conditions are suitable, such as when sunlight is lacking or in the presence of plentiful dissolved food. Some so-called phytoplankton will actually ingest other algae. Such plankton may then save and use the chloroplasts (the cell structures used in photosynthesis) in order to produce food internally to survive in a life strategy known as kleptochloroplastidy.[39]

Several different types of phytoplankton live in the Coastal Bays, as found in surveys conducted by MD DNR. The types are classified according to photosynthetic pigments, mode of locomotion, molecular or genetic characteristics, and physical structure.

One large group of phytoplankton organisms are termed *phytoflagellates*. Phytoflagellates may obtain nutrients by photosynthesis, by absorption through the body surface, or by ingestion of food particles. These single-celled organisms propel themselves using two whip-like flagella. In the Coastal Bays, phytoflagellates are strong, consistent components of the year-round phytoplankton community, typically comprising 50% or more of the plankton in the summer season. This group make lesser but significant contributions to overall plankton abundance throughout the remainder of the year.

Another important group of phytoplankton is the *diatoms*. Diatoms are single-celled algae that have cell walls made of silicate. The construction of the cell wall, or frustule, consists of two valves that fit into each other like a little pill box. Diatoms can exist as single cells or as colonies of single cells. They are usually free-floating but some are epiphytic (found on other plant material) or benthic. In the Coastal Bays, diatoms typically achieve their greatest abundance during winter, their next greatest abundances in spring, and are less common components of the plankton community during summer and fall.

CHRIS LUCKETT

Ditylium is a diatom commonly found in the Coastal Bays phytoplankton. This photo was taken from a water sample from the Ocean City Inlet.

Dinoflagellates are another important component of the annual phytoplankton community composition. Their cell wall is composed of cellulose, a common cellular component of plants. When dissolved silica concentrations are low and limit diatom growth, dinoflagellates may outnumber diatoms and become dominant in the phytoplankton community. However, in the Coastal Bays, dinoflagellates are a minor portion of the phytoplankton. This group is very diverse—in addition to occurring in the phytoplankton community, a few dinoflagellate species can live inside the cells of aquatic animals. This can be beneficial as in the case of corals in which dinoflagellates provide food to the coral polyp; however, some species may be deleterious, as in the case of *Hematodinium* which is parasitic in blue crabs and other crustaceans (see section on blue crabs earlier in this chapter).

Although *cyanobacteria*, or blue-green algae, appear to be similar to algae in both appearance and ecological function and importance, they are actually bacteria. Most cyanobacteria are photosynthetic, and they can be found in nearly every type of habitat imaginable—freshwater, saltwater, hot springs, and underneath the ice on frozen lakes. Some species have evolved to live on land or even in the fur of animals. In the Coastal Bays, cyanobacteria are most commonly found during the winter and rarely make up more than 5% of the community in any season. In rare instances, blooms of freshwater cyanobacteria such as *Microcystis aeruginosa* may be observed at the tidal front of Coastal Bays tributaries.

Chrysophytes, or golden algae, occur commonly in phytoplankton. In the Coastal Bays, chrysophytes make their greatest contributions in the spring and can sometimes be dominant before declining through summer, fall, and winter. Some species are colorless, but the vast majority are photosynthetic. Nearly all chrysophytes become consumers in the absence of adequate light, or in the presence of plentiful dissolved food. When this occurs, the alga may turn predator, feeding on bacteria or diatoms.[80]

Pelagophytes are important because they include *Aureococcus anophagefferens*, the brown tide organism, which represents perhaps the most significant annually recurrent harmful algal bloom species in the Coastal Bays. This species caused the demise of scallop fisheries in Long Island Sound during the 1980s and has been a common, bloom-forming species in Chincoteague Bay during the last decade. It typically blooms in late spring and has frequently been recorded at concentrations that are associated with detrimental effects on living resources.[21] For more information on brown tide, see Chapter 13—*Water Quality Responses to Nutrients.*

Zooplankton feed on phytoplankton

Zooplankton are generally small animals that passively drift or weakly swim with currents. They are typically omnivorous, grazing on phytoplankton, microzooplankton, and bacteria. Zooplankton are important members of aquatic food webs, serving as the critical link between primary production (phytoplankton) and higher organisms, such as fish. Grazing by zooplankton may also play an important role in controlling algae blooms. They are the primary food source


JAMIE PIERSON

Acartia tonsa is a copepod commonly found in estuaries around the world.


JEFF BIERMANN

Some bottom-dwelling animals spend the larval parts of their life cycles in the plankton, such as this larval blue crab.

for zooplanktivorous (zooplankton-eating) fish, the larval stages of many piscivorous (fish-eating) fish, some squid, and even baleen whales (such as right whales off the coast of Assateague Island). Many fish, such as bay anchovy and Atlantic silverside, remain zooplankton feeders throughout their lives. Other species, such as menhaden, consume zooplankton as larvae and juveniles, then switch to feeding exclusively on phytoplankton as adults. The survival of piscivorous fish larvae in spawning and nursery areas is dependent upon sufficient densities of zooplankton. Availability of zooplankton food during the larval period is a critical factor in the success or failure of many species of game fish, including striped bass and white perch (*Morone americana*).

KIERA JARVIS

KIERA JARVIS

Larval fish found in the Coastal Bays include lined seahorse (*Hippocampus erectus*, top) and smallmouth flounder (*Etropus microstomus*, bottom). A millimeter scale is included for size—each major division on the rule equals one millimeter.

Zooplankton are comprised of *holoplankton* (which live permanently in the plankton community) and *meroplankton*, which spend only part of their lives in the plankton. Holoplankton range in size from microscopic crustaceans to the Portuguese man-of-war (*Physalia physalia*) with 15 m (50 ft) long tentacles, and include groups such as copepods and cladocerans (crustaceans), arrow worms, jellyfish, comb jellies, sea butterflies (molluscs), and others. Copepods are the most common constituents of estuarine zooplankton and are found in all aquatic environments. Despite their tiny size, they are the most abundant multicellular organisms on earth and constitute the largest source of protein in the oceans.[79] Meroplankton are larval forms of various organisms from just about every phylum, including blue crabs and other crustaceans, polychaete worms, molluscs, echinoderms (starfish, brittle stars, sea urchins, sand dollars, and sea cucumbers), and fishes. These larval stages allow benthic organisms to disperse and colonize new habitats.

Benthic animal communities can indicate ecosystem health

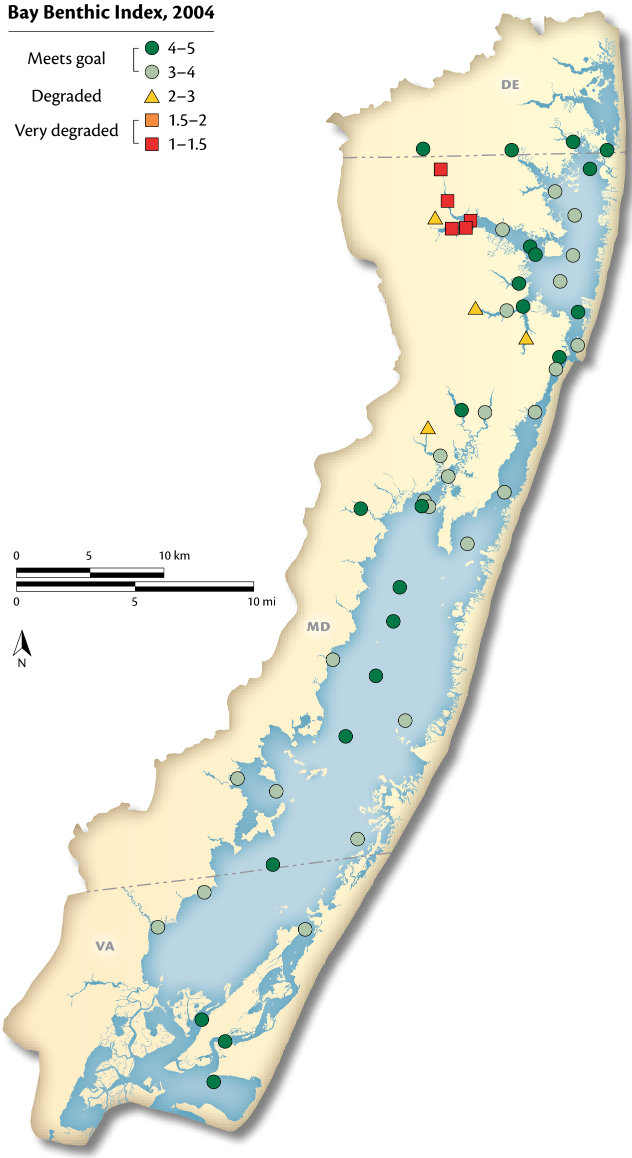
Benthic organisms typically live in the bottom sediments of creeks and bays. These worms, shellfish, snails, bugs, shrimp, scuds, and sowbugs have very specific roles to play in the ecosystem. Some of these creatures eat algae and bacteria, some are scavengers that break down larger pieces of plants or animals so bacteria can turn them back to mineral form to be used by plants, and others are carnivores that prey on the rest. These creatures process the constant stream of organic matter from land and surface waters. They are also the link between bacteria and organisms higher up the food chain, such as fish and birds.

Salinity often dictates the types of benthic organisms found at a location. In freshwater, insects dominate the benthos. Larval aquatic stages of flies, midges, mosquitoes, caddisflies, mayflies, dragonflies, and beetles are major components of the freshwater stream benthos in the Coastal Bays. As salinity increases closer to the ocean, insects are replaced by clams, crustaceans, and polychaete worms. In fact, surveys indicated that the only insects found in tidal freshwaters in the bays are non-biting midges.[41] The adult mating swarms are commonly seen by seaside dwellers in early summer.

Although various species of clams are common throughout the higher salinity bay waters, there are no freshwater clams in the Coastal Bays watershed.[12] Crustaceans are represented by a few organisms in freshwater such as crayfish, laterally compressed scuds or amphipods, and flattened sowbugs or isopods. Crustacean diversity explodes in higher salinity waters, with a rich variety of crabs, shrimps, amphipods, and isopods.

Segmented worms are conspicuous members of marine, freshwater, and terrestrial communities. They occur in a rich diversity of forms (up to 140 species in the Coastal Bays)[13] and in considerable numbers, reflecting their ecological importance.

A Bay Benthic Index has been developed to assess benthic community health and environmental quality.[42] The Bay Benthic Index includes information on pollution-tolerant and pollution-sensitive organisms. Most areas in the Coastal Bays met the goal for the Bay Benthic Index, with the exception of the upper reaches of St. Martin River and Newport, Herring, and Turville Creeks.



The Bay Benthic Index shows that most benthic areas in the Coastal Bays are in good condition, with the exception of some upstream tributaries.

U.S. ENVIRONMENTAL PROTECTION AGENCY

The common clamworm (*Nereis succinea*) is a wandering benthic predator and a widespread species. The clamworm can reach 13–15 cm (5–6 in) in length, but smaller specimens are more common.

Non-biting midges are regarded as pollution-tolerant organisms as they are hardy and able to withstand the rigors of fluctuating salinity and depressed dissolved oxygen concentrations. Also pollution-tolerant are the opportunistic paddleworm (*Eteone heteropoda*) and mudworm (*Streblospio benedicti*). Worms considered to be sensitive to polluted environments include the parchment worm (*Chaetopterus variopedatus*), which builds U-shaped parchment-like tubes in the bottom that can be up to 30 cm (1 ft) long. Each end projects a little above the surface so that the tube openings can be seen dotting the bottom. Another pollution-sensitive worm is the junk worm (*Diopatra cuprea*), which lives in long parchment-like tubes to which they attach bits of shells, pebbles, seaweed, and other 'junk.' The tubes are mostly embedded but can extend several inches above the surface of the substrate. Junk worms are bright red when alive and can grow up to 30 cm (1 ft). The blood worm (*Glycera america*), also called the beak thrower, is sensitive to pollution. They are found near the low tide level in sand and mud, as well as offshore. They can eject a large proboscis equipped with four black beaks at its tip that can nip at unsuspecting fishers trying to use them for fishing bait.[40]

The diversity of life in the Coastal Bays is unmatched in the state due to the variety of terrestrial and aquatic habitats found in the bays and their watersheds. Increasing human pressures in the Coastal Bays require that researchers and resource managers continue to monitor and preserve this crucial biodiversity.

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ACKNOWLEDGEMENTS

Many people contributed information to this chapter, in the form of hard data, graphics, personal anecdotes, and providing comments useful in the completion of this chapter. They are: Robert Colona, Dave Foreman, Bill Harvey, Larry Hindman, and Peter Tango (Maryland Department of Natural Resources), Clem Counts (Salisbury University), Jenn Dittmar (National Aquarium in Baltimore), David Kimmel (University of Maryland Center for Environmental Science), and Alice Newton (University of Algarve, Portugal).

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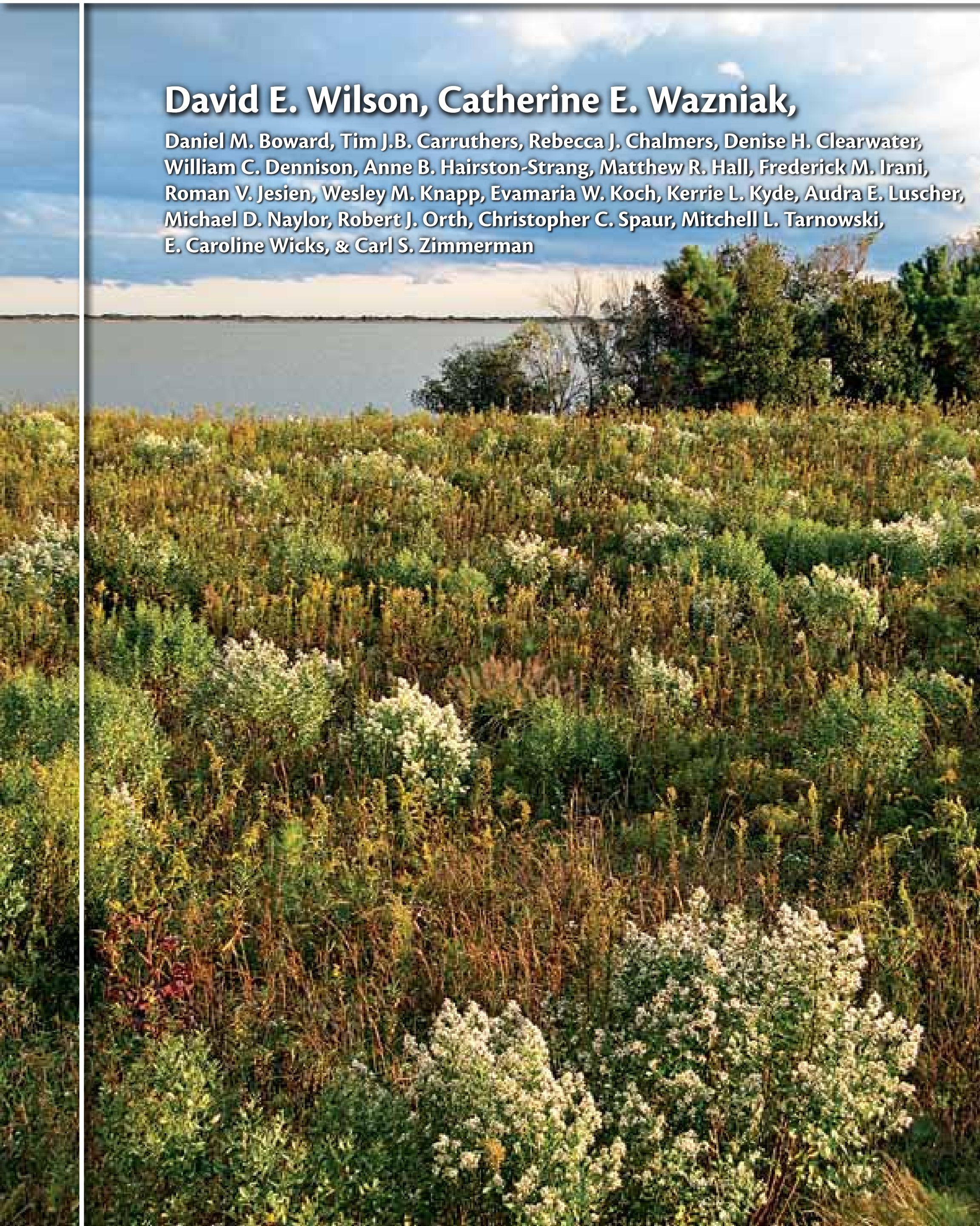
15. *Habitats of the Coastal Bays & Watershed*

David E. Wilson, Catherine E. Wazniak,

Daniel M. Boward, Tim J.B. Carruthers, Rebecca J. Chalmers, Denise H. Clearwater, William C. Dennison, Anne B. Hairston-Strang, Matthew R. Hall, Frederick M. Irani, Roman V. Jesien, Wesley M. Knapp, Evamaria W. Koch, Kerrie L. Kyde, Audra E. Luscher, Michael D. Naylor, Robert J. Orth, Christopher C. Spaur, Mitchell L. Tarnowski, E. Caroline Wicks, & Carl S. Zimmerman

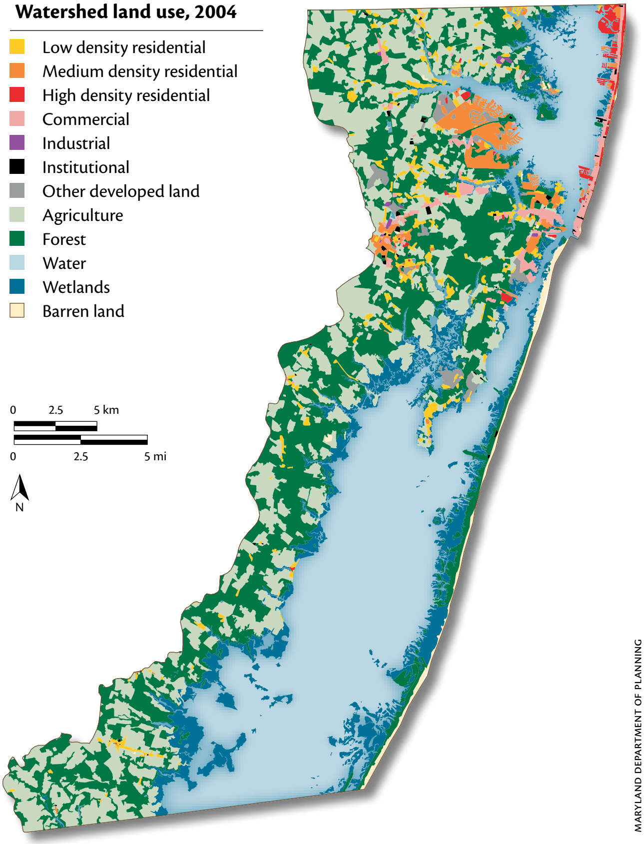


THE COASTAL BAYS AS HABITAT

The Coastal Bays support significant biological diversity

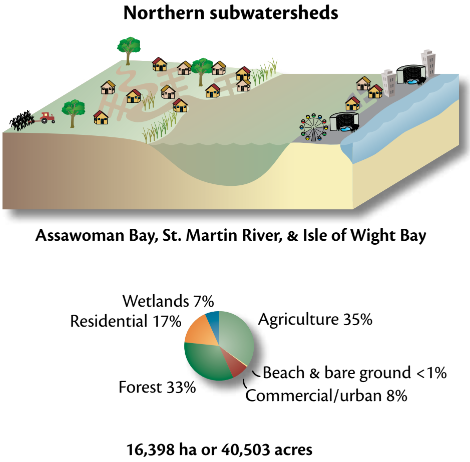
There is a reason the Coastal Bays watershed has such a large variety of wildlife—it has a diversity of habitats. With ample forests, agricultural land, wetlands, barrier islands, and bays, the relatively small watershed of Maryland's 'forgotten bays' holds thousands of species of plants and animals, including some which are unique within Maryland to the Coastal Bays region.

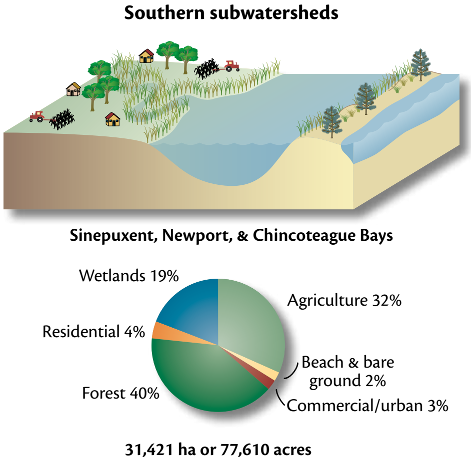
As one of the fastest-developing regions in the state, the population in the Coastal Bays is expected to continue increasing an additional 60% by 2030.[24,83] This growth has put stress on this region,



MARYLAND DEPARTMENT OF PLANNING

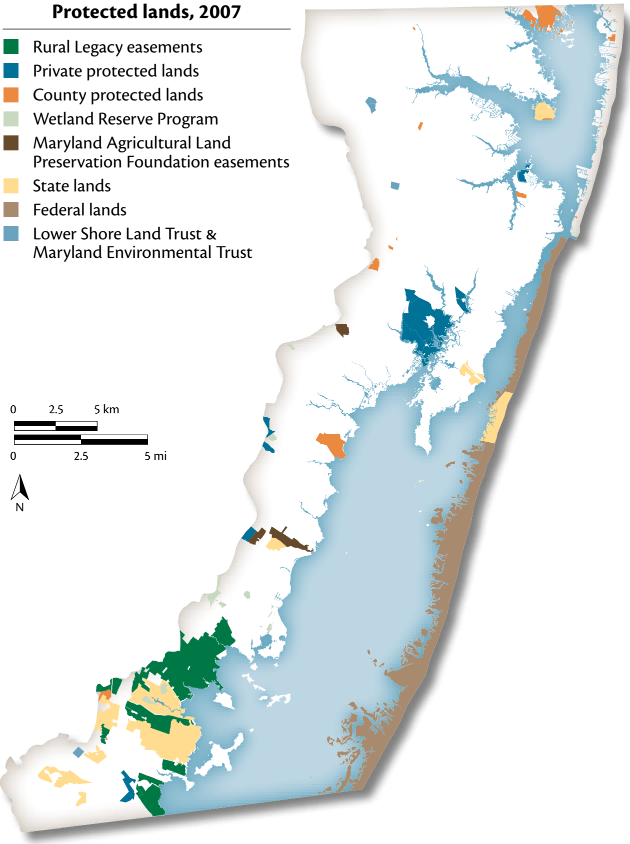
Land use in the Coastal Bays watershed is mostly forest and agriculture, with more development in the northern bays.





The northern Coastal Bays subwatersheds have more development and agriculture and consequently lower water quality, while the southern subwatersheds are less impacted. Data are for the Maryland portion of the Coastal Bays. Land use data courtesy Maryland Department of Planning.

especially north of the Ocean City Inlet. Keeping development around existing infrastructure north of Route 50 while protecting large contiguous blocks of open space to the south is a primary challenge in the race to protect important plant and animal habitats.



The protected lands of Worcester County include a combination of conservation easements, government-owned lands, and protected private lands. Map prepared by the Worcester County Department of Comprehensive Planning.

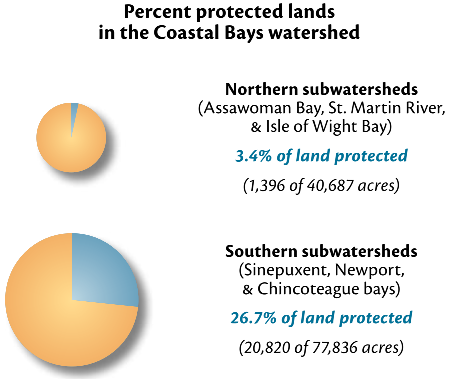
MARYLAND COASTAL BAYS PROGRAM, MARYLAND DEPARTMENT OF PLANNING, MARYLAND AGRICULTURE LAND PRESERVATION FOUNDATION, MARYLAND DEPARTMENT OF NATURAL RESOURCES, WORCESTER COUNTY DEPARTMENT OF COMPREHENSIVE PLANNING, NATURAL RESOURCES CONSERVATION SERVICE, FEDERAL WETLAND RESERVE PROGRAM, MARYLAND ENVIRONMENTAL TRUST, LOWER SHORE LAND TRUST, THE NATURE CONSERVANCY

The northern subwatersheds are more degraded than the southern subwatersheds

The Coastal Bays watershed has over 90% of its developed land north of Route 50. This has resulted in a gradual degradation of terrestrial wildlife habitat and water quality north of the Ocean City Inlet, while the southern watershed has enjoyed viable wildlife habitat protection and restoration. Ocean City (north of the inlet) and Assateague Island to the south embody this dichotomy. On the mainland, 16.2% of the land south of the Ocean City Inlet is permanently protected, compared to 3.4% north of the inlet.

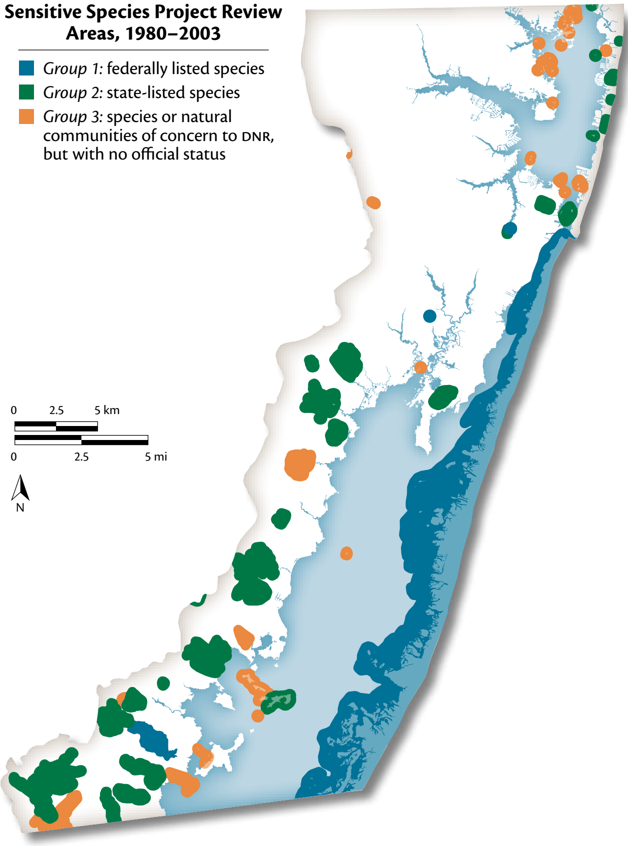
Rare, threatened, & endangered species make their home in the Coastal Bays watershed

The Coastal Bays watershed is home to a variety of rare, threatened, and endangered species. Twenty-seven animal and 95 plant species are federally or state listed as being threatened or endangered, primarily due to habitat loss or alteration (the bald eagle was removed from the threatened species list in 2007).[42]



The southern Coastal Bays subwatersheds have significantly more protected lands than the northern subwatersheds, mostly due to Assateague Island National Seashore. Data are for the Maryland parts of the Coastal Bays.

Sensitive Species Project Review Areas, 1980–2003



MARYLAND DEPARTMENT OF NATURAL RESOURCES

The Sensitive Species Project Review Areas (SSPRA) represents the general locations of documented rare, threatened, and endangered species, but does not delineate or strictly represent habitats of threatened and endangered species. It generally includes Natural Heritage Areas, Listed Species Sites, Other or Locally Significant Habitat Areas, Colonial Waterbird Sites, Waterfowl Staging and Concentration Areas, Non-Tidal Wetlands of Special State Concern, and Geographic Areas of Particular Concern.

Tributaries of Newport and Chincoteague Bays have an especially high number of rare plants. Bay and barrier islands too harbor a number of rare or declining tern, plover, skimmer, and other shorebird species. The map above shows both rare/threatened/endangered species habitat and sensitive habitats that hold species that are declining or have small Maryland or U.S. populations.

The Coastal Bays are especially rich in rare plant species due to the temperate nature of near-shore areas combined with much undeveloped forestland, especially in the south. Rare grasses and shrubs also find refuge along utility rights-of-way, where railroads or power lines keep the forest at bay and freedom from domesticated livestock or row crops provides relief. But lack of wild fires and overgrazing by white-tailed deer continue to make the watershed, and in fact the entire East Coast, inhospitable for many native grasses and shrubs.

Critical in efforts to protect and restore these habitats are both land conservation and restoration. Efforts to restore landscape features such as rare Delmarva Bays (see section later in this chapter) and controlled burns of certain areas is underway. Integral to this work is the connection and protection of large contiguous natural areas to allow gene flow and re-population of areas where local extirpations have occurred.

The Coastal Bays watershed supports some of the richest flora and fauna in the state. Ensuring its long-term survival is a key element in the work of the Maryland Coastal Bays Program and the Maryland Department of Natural Resources.

FORESTS

The Coastal Bays watershed harbors diverse forests

Forests in the Coastal Bays of Maryland cover a diverse range of sites, from dry sand ridges to swampy organic soils, with high diversity in tree species composition.

Distribution of forest cover and species in the Coastal Bays is governed primarily by moisture levels, soil texture, and salinity.

The most common forest type is mixed pine–hardwood,[21] often composed of loblolly (*Pinus taeda*) and other pines mixed with oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua*), and red maple (*Acer rubrum*). Pure pine is the next most common forest type, and is often a result of plantations—these active plantings shift species composition from mixed pine–hardwood to predominantly loblolly pine, which supports less diversity and abundance of wildlife. The wettest forests are dominated by hardwood species like sweetgum, red maple, and ash (*Fraxinus* spp.), with occasional stands of baldcypress (*Taxodium distichum*). Atlantic white-cedar (*Chamaecyparis thyoides*) is a rare freshwater wetland forest type, undocumented in the Coastal Bays but historically present on Delmarva.[33] Baldcypress swamps are usually located along freshwater streams and can grow in standing water. In drier upland habitats, oaks are more dominant. Some oak species are also adapted to wetter conditions and are often found in wetland habitats.


ANDY SERRELL

This 243-ha (600-acre) forest on the Riddle Farm at the confluence of Herring and Turville Creeks in Isle of Wight Bay subwatershed was converted to 650 homes and a golf course in 2004.

Relict sand dunes from past sea levels created sinuous sand ridges in some areas, a unique savanna habitat that tends to support some rare plants and open stands of pitch pines (*Pinus rigida*) or drought-tolerant oaks. These rare sand ridge forests are found only on the highest, driest soils.

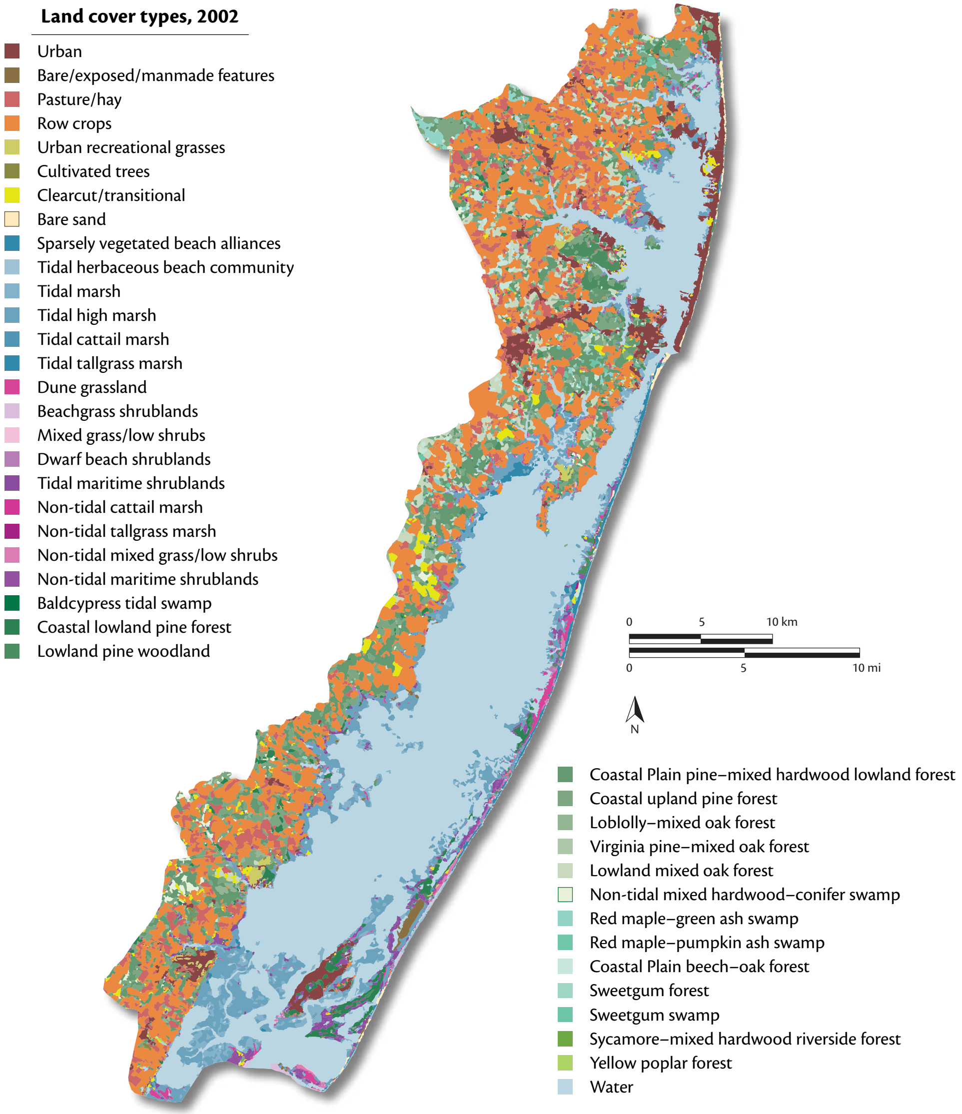

DAVE WILSON

This 36-ha (90-acre) forest, near Showell in the St. Martin River subwatershed, provides important habitat for forest interior dwelling species of birds as well as numerous plants, mammals, reptiles, and amphibians.

HABITATS

Another uncommon forest type, rich woods (so called due to their high soil fertility and subsequently rich flora) are found on uplands and usually near streams. Small pockets of rich woods can be found near Riley Creek and outside of Public Landing, both in Chincoteague Bay subwatershed.

Historically, forests covered much of the Coastal Bays watershed, providing clean water and extensive, contiguous wildlife habitat. Centuries of settlement resulted in clearing the land for farms and buildings, some of which reverted to forest through the 1970s.[35] Forest area has generally been declining since the 1980s, particularly in the northern Coastal Bays as urban development has expanded. Forests now cover an estimated 38% of the Maryland Coastal Bays watershed, compared to 41% state-wide and 55% in Worcester County.



Land cover in the Coastal Bays watershed.[40]

Watershed	Forest acres in 2000	Forest acres predicted in 2020	Predicted forest loss over 20 years (%)	Predicted watershed forested in 20 years (%)
Assawoman Bay	1,683	1,100	35	15
Isle of Wight Bay & St. Martin River	11,874	8,250	30	25
Sinepuxent Bay	2,354	1,850	20	25
Newport Bay	11,600	11,400	10	40
Chincoteague Bay	16,714	16,700	< 1	40
Coastal Bays total	**44,225**	**39,295**	**10**	**35**

MARYLAND DEPARTMENT OF NATURAL RESOURCES, BASED ON MARYLAND DEPARTMENT OF PLANNING ESTIMATES

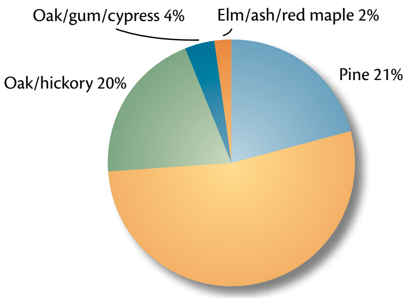
This table shows current and predicted forest cover in the subwatersheds of the Coastal Bays. Data are for the Maryland portion of the Coastal Bays. Predicted numbers are rounded to the nearest 50 acres or 5%.

Based on Maryland Department of Planning growth projections, forest cover is expected to decline to 35% in the Coastal Bays by 2020.[78]

Most Coastal Bays forests have seen multiple rounds of harvest, clearing and regrowth, changes in fire regimes, browse from a swelling deer population, invasive plants, natural droughts and floods, and insect epidemics. The forests have an inherent resilience and continue to provide key ecosystem functions, but some historic forest elements are now rare, such as fire-dependent open savanna forests, large blocks of interior forest, and the oldest stands with complex canopy structure and large nesting cavities.

The trees that have grown on old fields are often different, early successional species such as pines and yellow poplar,

Forest types



MARYLAND DEPARTMENT OF NATURAL RESOURCES, BASED ON GAP ANALYSIS PROGRAM DATA

Forest types in the Maryland portion of the Coastal Bays watershed. The 'pine' category includes planted pine forests as well as any natural pine stands with little hardwood.

Forests are the foundation of the mainland ecosystem

Key features of Coastal Bays forests:

- Forests are primarily native species, even where plantations have been established.
- Forests are the region's historic land cover in most areas.
- Forest products are part of the local economy, history, and culture.
- Forests regenerate readily following harvesting through natural succession, allowing a continuing suite of ecosystem services and economic contributions.

Ecosystem services provided by forests:

- Clean water due to abundant nutrient uptake and forest soil processes by roots.
- Moderation of water flows—infiltrating rainfall from storms and slowly releasing it as baseflow for year-round stream flow.
- Clean air—trapping particulates, producing oxygen, and sequestering carbon.
- Vertical habitat diversity for wildlife, from ground to shrubs to treetops.
- Protection of soils from erosion.
- Aquatic habitat elements, including large woody debris that shelters fish and crabs, and leaf litter that fuels the food web in small streams.

but they are the first step in rebuilding forest conditions—more porous soils, organic litter layers, moderated microclimates, and canopy habitat niches.

Species need natural hubs & corridors to survive

Many plant and animal species need large connected and undisturbed swaths of habitat to survive over the long-term. Significant areas of least-disturbed natural habitat are referred to as *green infrastructure.*

Like the infrastructure that holds together cities and towns, green infrastructure represents the best remaining habitat needed to hold together functioning ecosystems and protect thousands of species into the future.

Green infrastructure 'hubs' in Maryland are normally large blocks of forests and wetlands, and natural corridors connect them. Hubs provide adequate space and habitat to retain viable populations and diversity of species. Corridors are essential to allow for migration to hubs and avoid the isolation of species that makes them vulnerable to inbreeding, disease, natural disasters, or loss of habitat.

Connected green infrastructure is particularly important for reptiles, amphibians, plants, and many mammals. Many animals and plants cannot migrate over roads, developments, or cleared land. Forest interior birds like prothonotary warblers (*Protonotaria citrea*) and scarlet tanagers (*Piranga olivacea*) also have much better survival rates in unbroken forests.

Currently, 34% of green infrastructure in the Maryland Coastal Bays watershed is protected, leaving the remainder vulnerable to further degradation and fragmentation. When excluding the 3,200-ha (8,000-acre) Assateague Island, only 23% of these ecologically significant lands are protected on the mainland.

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Map of the green infrastructure in the Maryland Coastal Bays watershed in 2004, showing where large contiguous areas of forest and wildlife habitat still exist. Hubs were defined as contiguous areas of major ecological importance, at least 809 ha (2,000 acres) in size. These areas were identified by combining Wetlands of Special State Concern (see section later in this chapter), Sensitive Species Project Review Areas (see section earlier in this chapter), blocks of interior forest at least 202 ha (500 acres) in size plus a 152 m (500 ft) transition zone, unmodified wetlands at least 202 ha (500 acres) in size plus a 168 m (550 ft) upland buffer, and existing protected lands. Corridors are pathways of least resistance to wildlife movement, and include streams, riparian zones, and forests.[77]

Forests face many threats

Scientists believe that, historically, wildfires altered the Coastal Bays landscape every four to six years.[22] This frequency created very dynamic habitats allowing for many different forest types. Suppression of wildfire, while needed to support settled human communities, has greatly reduced historical natural disturbance. Without this disturbance, succession—the process by which forests change naturally—goes largely unchecked, creating similar habitats in the major forest types and allowing fire-sensitive species, like red maple, to become more common. Other significant natural disturbances are overwash events on Assateague Island, and wind and ice storms.

The most enduring threat to forests is a shift in land use, replacing forestland with development or other uses that cannot provide the same array of ecosystem services. Invasive exotic species pose another threat, with certain insects and diseases having the greatest potential to dramatically change forests in the Coastal Bays. Invasive plants like the common reed (*Phragmites australis*) can also threaten forest regeneration and diminish habitat value.

Long-term fire suppression and climate change may change species mixes and forest extent. Pine plantations have resulted in a shift from mixed species to loblolly pine, estimated at 21% of forestland.[25] Plantations are very useful for economic production, generating income and meeting product demand. However, intensive forestry practices limit species composition and habitat complexity, both elements that help maintain resilience of forests to major disturbances such as hurricanes. For more information on managing forests, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Invasive plants are reducing species diversity

Invasive plants are plants that can thrive and spread beyond the areas of the world in which they evolved. They reproduce quickly and prolifically and are often adapted to disturbance. They are typically introduced by people, either accidentally or intentionally.

Invasive plants can reduce species diversity because they can crowd out, shade out, and grow over less aggressive plants in the habitats they invade. They disrupt food webs because they do not provide the same feeding and nesting opportunities as plants that co-evolved with the animals in a given ecosystem. Invasive species can also change water and nutrient flows, soil pH, fire susceptibility, and light availability.[8,46]

Although many troublesome invasive plants were originally imported for ornamental or medicinal purposes, two species that are especially problematic in the Coastal Bays were accidental

Potential forest invaders

Exotic and native diseases and insects, such as gypsy moths and pine beetles, are always present and periodically damage trees. Most outbreaks generally have not caused long-term changes in forests in the Coastal Bays areas, which could change with some new exotic pests already found elsewhere in the U.S.

Invasive exotic species that have reasonable potential to be introduced in the near future include:

- *Emerald ash borer:* A beetle that kills native ash species, currently spreading in the Midwest and Canada, with pockets found in Maryland and Pennsylvania.
- *Asian long-horned beetle:* A beetle that can kill maples, poplar, willows, and others and has been found in solid wood packaging in ports on the U.S. East Coast.
- *Sudden oak death:* A disease that can kill or damage many oaks, rhododendrons, viburnums, camellias, and others. It is found in California and Oregon and is being shipped in nursery stock nation-wide despite control efforts.

introductions—the common reed and Japanese stiltgrass (*Microstegium vimineum*). Another Coastal Bays invader, Japanese knotweed (*Polygonum cuspidatum*), was an ornamental introduction.

The common reed (often colloquially referred to as "Phrag") has actually existed on the East Coast of the United States for over 4,000 years. In its historic Maryland form, it occurred in mixed stands with other tidal wetland plants. During the mid-19th century, commercial sailing ships accidentally brought a European strain of the plant, genetically different from those already here, to U.S. shores in their ballast water. The European reed was much more aggressive than the American variety, and by the 1940s had virtually replaced the historically occurring grass.[55]

The common reed can form large monocultures along Coastal Bays shorelines, taking over space normally occupied by other plants. Most marsh inhabitants cannot use it for food or shelter. The tall stalks blow over during the winter, forming a heavy layer among their own roots, changing the marsh surface height and hydrology. It should be noted that the common reed does provide some benefits, such as shoreline stabilization and water quality maintenance.

Japanese stiltgrass, or Nepalese browntop, is an Asian annual grass that spreads rapidly along disturbance corridors like trails and creek edges. It can thrive in low light,[28] and spreads by rooting at the nodes and dispersing seeds. Japanese stiltgrass changes forest floor diversity by shading out perennials. White-tailed deer—major herbivores in forested systems—do not appear to eat Japanese stiltgrass, leaving it untouched in preference for native species.

Japanese knotweed was introduced into the U.S. from Asia in the late 1800s, for use as a garden plant and for erosion control. This plant spreads primarily by long, jointed rhizomes, which can grow for meters just under the soil surface,

JANE THOMAS

The common reed near the Assateague State Park boat ramp in Sinepuxent Bay.

KERRIE KYDE

Japanese stiltgrass is an invasive grass species.

KERRIE KYDE

Flowers of Japanese knotweed, late in the season.

and which sprout to form huge colonies. Almost any broken fragment of the plant can root and become a new individual. Knotweed infestations shade out plants that live below their canopy.

Every effort should be made to limit the spread of invasive plants in order to protect the watershed's native biological communities.

PASTURES, MEADOWS, & GRASSLANDS

Grassland areas are in need of conservation

A 30-year decline in East Coast grazing habitat and improved efficiencies in farming have spelled trouble for grassland plant and bird species coast-wide. This is evidenced by declines of species such as grasshopper sparrows and Northern bobwhite quails in Maryland (see *www.mbr-pwrc.usgs.gov/bbs*). The Coastal Bays watershed has reversed this trend with the addition of nearly 2,450 ha (6,000 acres) of State and Federal Conservation Reserve Enhancement Program (CREP) grass plantings and tree plantings (which mimic grassland habitat for the first five years), and 200 ha (500 acres) of wetlands. In addition, conversion of farmland to pasture, seen in the watershed over the past several years, will likely recoup some of these losses in the short term. This has helped restore significant wildlife habitat while extracting thousands of pounds of nutrients otherwise headed towards the Coastal Bays. However, as CREP plantings undergo succession and pastureland succumbs to development, long-term losses will persist.

DAVE WILSON

The Northern bobwhite quail (*Colinus virginianus*) inhabits the edges of grassland habitats.

Stressors to grasslands

Stressors to grasslands in the Coastal Bays include:

- Development.
- Tree succession in CREP plantings.
- Over-grazing.
- Fire suppression.
- More efficient use of farming land.

Power line rights-of-way still serve as a breeding ground for rare plants, but controlled burning at these and other sites could foster a more natural plant community. Restoration and management are needed for this habitat type.

AGRICULTURAL LANDS

Croplands can be important habitat

As early as AD 900, Native Americans farmed corn in the Coastal Bays watershed.[54] Early European settlers also

DAVE WILSON

A cattle egret (*Bubulcus ibis*) looks for insects as cattle graze on a farm on Sinepuxent Road. Land lightly to moderately grazed by horses and cattle can provide excellent grassland habitat for declining bird species.

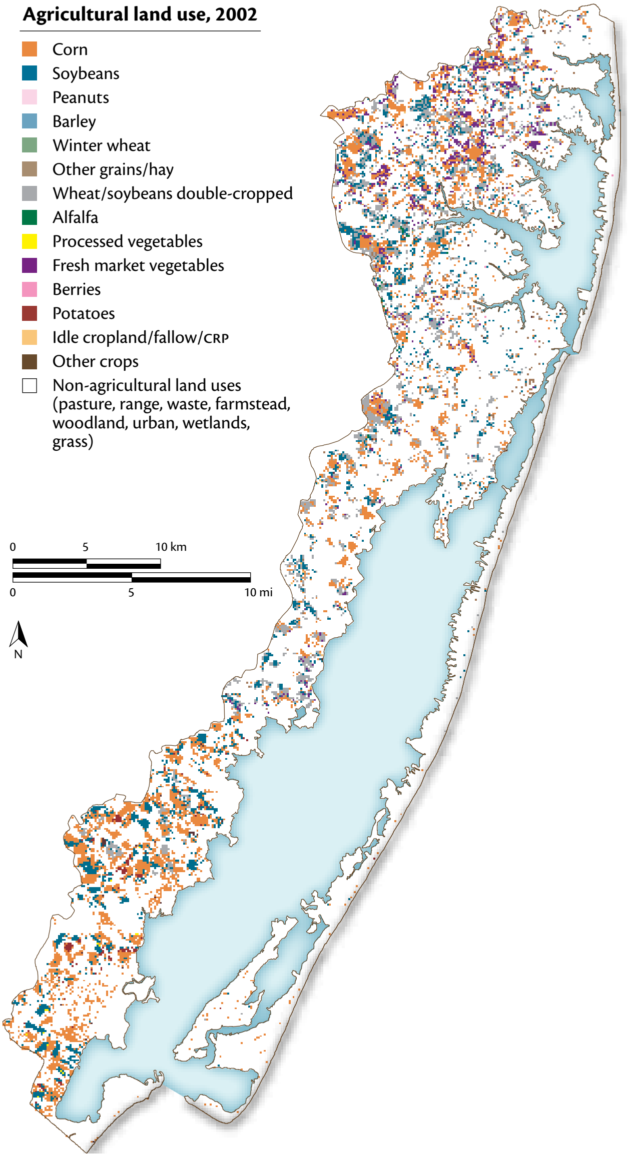
grew corn, but tobacco quickly became the most valuable crop. Initially, agriculture was confined to the nearby Pocomoke River watershed, but soon spread east as ditches were constructed to drain the wet Coastal Plain land. Concurrently, land on Assateague Island was leased to graze livestock. In the 20th century, poultry production surpassed crop farming in dominance and farmland declined by 22%.[82]


DR. RALPH ADKINS

Corn is grown as feed for poultry throughout the Coastal Bays watershed.

While croplands pale in comparison to the habitat value of pasture and forest, they do provide important wildlife habitat for white-tailed deer (*Odocoileus virginianus*), red foxes (*Vulpes vulpes*), horned larks (*Eremophila alpestris*), Eastern spadefoot toads (*Scaphiopus holbrookii*), geese, and raptors which use the fields to hunt small mammals. A variety of plants like hornworts, liverworts, and mosses also utilize this niche. Edge habitat—where fields meet forests—is a province utilized by numerous mammal and bird species, including quail and turkeys.

Over the past five years, wetland, grass, and forest restoration on the watershed's corn and soybean fields has added significant habitat and helped reduce fragmentation of some forests. Cropland management activities such as creating and maintaining field borders (areas of grasses, forbs, and shrubs), maintaining winter cover, and using crop rotations can greatly improve habitat benefits.



DEPARTMENT OF GEOGRAPHY & ENVIRONMENTAL PLANNING & THE CENTER FOR GEOGRAPHIC INFORMATION SCIENCES, TOWSON UNIVERSITY

Agricultural land use is dominated by corn and soybean production.

Stressors to agricultural lands

The primary stressor to agricultural land continues to be development. About 400 ha (1,000 acres) per year are converted to housing in the Coastal Bays watershed.[82] This has altered the habits of migratory birds of prey, ducks, and geese that use the same fields annually to hunt or graze. Development also removes the possibility of restoring the land to natural cover.

Because farmland contributes more nutrients to the bays, has suitable soils for construction, and has a lower habitat value than forests, wetlands, or grasslands, county planners have generally targeted it for development. For species living on the land, chemical pesticides and herbicides can also take their toll.

DAVE WILSON

Farmland can provide important forage areas for species like the Eastern box turtle (*Terrapene carolina carolina*).

DEVELOPED LANDS

Unchecked development can diminish wildlife diversity

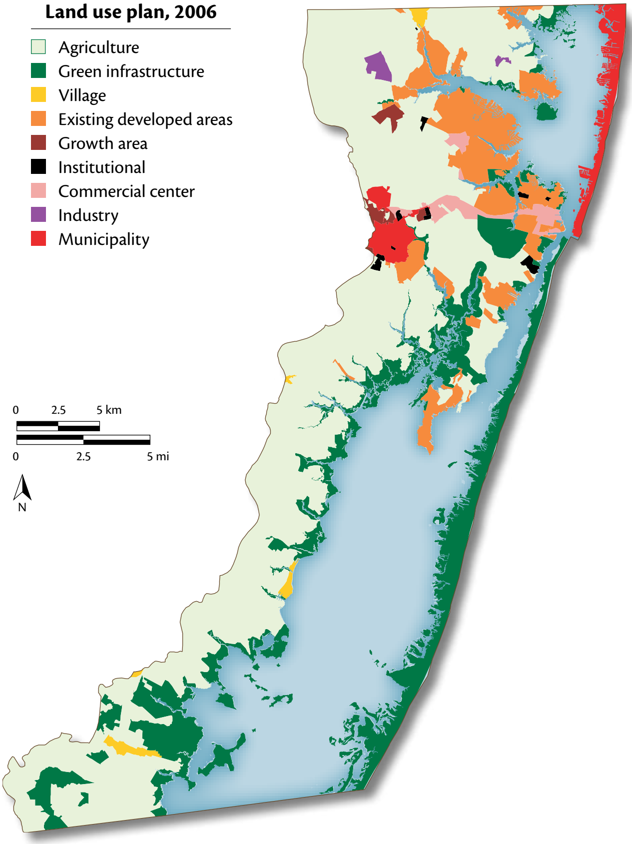
Developed land replacing natural habitat significantly reduces species diversity and is the primary cause of many species declines in the eastern United States. In addition to the loss of farmland, forests, and wetlands, development stimulates proliferation of invasive animals and plants, such as the common reed, and animals which spread problems to undeveloped lands and curtail species diversity region-wide. Golf courses, too, while 'greener' than most subdivisions, tend to only provide habitat for already common species. With the Coastal Bays watershed expected to increase in population by 60% by 2030, this problem will worsen.

Opportunities exist for improving the habitat value of developed land

Planning plays a critical role in keeping growth out of forests, wetlands, and other important habitats. While development will always transform habitats, its impact can be minimized in a variety of ways. By planning for development around existing infrastructure and not within forests and wetlands, communities can save open

SHIH-NAN CHEN

The nearly 400-ha (1,000-acre) Glen Riddle Farm development at the confluence of Turville Creek (foreground) and Herring Creek adjacent to Route 50 (background) replaced a largely forested and farming property with a marina, housing developments, and a golf course.



Worcester County's land use plan map for the future, including areas designated for future growth.

WORCESTER COUNTY

space and protect their local environment. Limiting impervious surfaces, trading turf grass for native plants, reforesting where possible, and increasing housing density to protect open space on parcels of land can save or restore wildlife habitat.

Large grass lawns are not particularly good habitat for most species. Transforming lawns to trees and native plants and reducing impervious surfaces also help aquatic habitats by limiting runoff from home sites.

WETLANDS

A diversity of wetlands is found in the Coastal Bays

The Coastal Bays watershed contains substantial wetland acreage (see table and map on the following pages). The nearly flat topography creates sluggish drainage, and poorly permeable soils are present in many areas. In addition, sea level and subsequently high water tables further increase soil wetness. Both tidal and non-tidal wetlands occur here.

Tidal wetlands

Near-ocean salinity predominates in the Coastal Bays as a result of seawater flushing through the stabilized Ocean City Inlet and comparatively small size of the mainland watershed in relation to the size of the Coastal Bays.[6] Consequently, the Coastal Bays' tidal wetlands, commonly called salt marsh, have predominantly high-salinity waters.[71] Prior to formation and stabilization of the Ocean City Inlet, when oceanic influence was less, the Coastal Bays contained substantial acreage of low salinity tidal wetlands.[58]

As a result of the limited tidal range and the processes by which these tidal wetlands develop over centuries to millennia, the majority of the tidal marshes of the Coastal Bays are flooded


DAVE WILSON

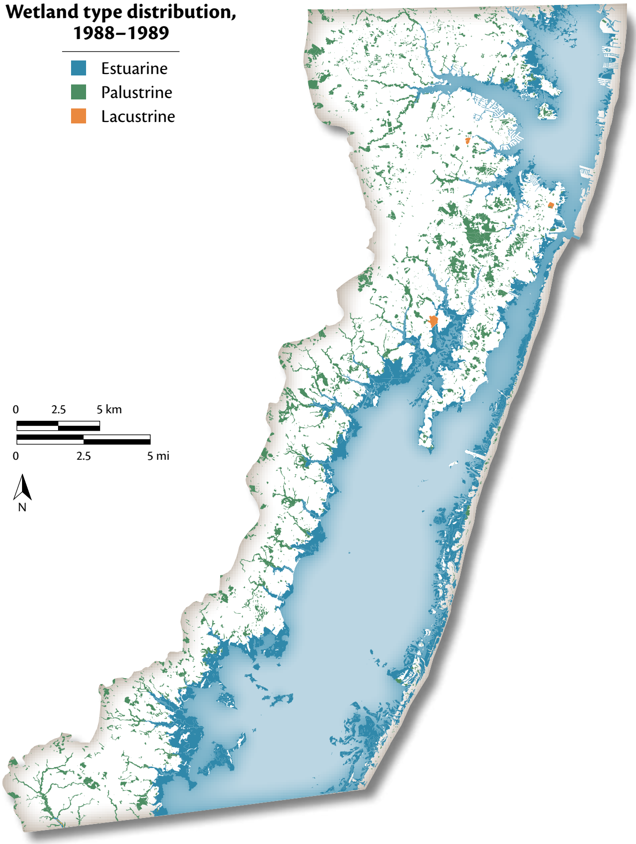
A tidal *Spartina* wetland in Sinepuxent Bay.

only irregularly during high tides (for more information on the formation of the Coastal Bays, see Chapter 12—*Dynamic Systems at the Land–Sea Interface*).[72] Wind and seasonal tides exert substantial control over marsh water levels.[65] Irregularly flooded marshes on the bay side of the barrier islands associated with historic inlets often possess creeks that are relicts from the former inlet channels.[20]

Salt marshes along the mainland shore of the Coastal Bays contain open water areas with rounded shorelines that may have developed from a geomorphic feature known as a Carolina (Delmarva) Bay (see section later in this chapter). Irregularly shaped open water areas form in the interior of tidal marshes in the process of drowning-in-place. Historic and ongoing management practices to control mosquitoes and wildlife also contribute to formation of open water areas within tidal wetlands (see "Anthropogenic stressors to wetlands" sidebar later in this section).

Grasses, grass-like plants such as rushes, and other herbaceous (i.e., non-woody) plants well-adapted to salty conditions dominate Coastal Bays salt marsh vegetation. The short-growth form of salt marsh cordgrass (*Spartina alterniflora*) predominates on the bayside edge of the marshes.[71] A band of salt-tolerant shrubs and the common reed typically occurs on the landward or higher elevation margins of salt marshes. Although an invasive variety of the common reed is a serious pest species in tidal marshes of Chesapeake and Delaware Bays, it generally occurs only on the fringe of the Coastal Bays tidal wetlands, as it cannot tolerate high salinities.

The rising sea encroaches upon former non-tidal wetland or upland forests of the mainland, forming a band of dead and dying trees along the landward margin of salt marshes. Although trees cannot reproduce in sites where brackish tidal waters invade, already-established individuals can often survive for many years before succumbing to salt stress.



MARYLAND DEPARTMENT OF NATURAL RESOURCES

This map shows wetland distribution in the Coastal Bays. Estuarine wetlands are tidally influenced and contain salt or brackish water. Palustrine wetlands are tidal and non-tidal freshwater wetlands located on floodplains associated with rivers and streams, upland depressions, and in flats between drainage systems. Lacustrine wetlands are freshwater lakes or deep ponds.

Non-tidal wetlands

Non-tidal wetlands of the Coastal Bays watershed occur predominantly in wide, flat areas of the landscape which tend to drain poorly and are somewhat detached from streams, as well as in depressions such as Delmarva Bays.[10,61,72] To a lesser extent, they also occur in floodplain areas. This distribution pattern differs from that of landscapes where greater topographic relief occurs and non-tidal wetlands concentrate along stream corridors, such as on the western shore of Chesapeake Bay. Non-tidal wetlands are typically wet to the surface during the winter and early spring, but then lack obvious water near the surface for the remainder of the year.

Coastal Bays non-tidal wetlands are predominantly forested, since trees can generally outcompete shorter plant forms in the ecological conditions occurring in these areas. These forested wetlands are often difficult to distinguish from upland areas due to the similarity of vegetation and minimal changes in elevation.[71]

Forested wetlands in the Coastal Bays watershed are dominated by two major associations: swamp chestnut oak (*Quercus bicolor*)–loblolly pine, and willow oak (*Quercus phellos*)–loblolly pine. The latter association also occurs on upland habitats. Areas of wetland forests classified as river birch (*Betula nigra*)–sycamore (*Platanus occidentalis*) and baldcypress occur along streams within the watershed.[9] Larger areas of baldcypress swamp formerly occurred along the tributaries

Vegetated wetland type	Assawoman Bay	Chincoteague Bay	Isle of Wight Bay	Newport Bay	Sinepuxent Bay	Total
Salt marsh	1,669	8,709	1,391	3,553	2,017	17,339
Salt scrub–shrub	34	294	77	23	149	577
Salt forested	0	55	0	0	0	55
Tidal freshwater marsh	6	6	0	0	0	12
Tidal freshwater scrub–shrub	44	44	63	10	2	163
Tidal freshwater forested	41	103	21	35	17	217
Non-tidal freshwater marsh	28	573	219	335	59	1,214
Non-tidal freshwater scrub–shrub	1	1,794	665	786	22	3,268
Non-tidal freshwater forested	402	4,361	4,861	3,792	741	14,157
Total	**2,225**	**15,939**	**7,297**	**8,534**	**3,007**	**37,002**

Acres of vegetated wetlands by type and major subwatershed. Data do not include wetlands established around recent man-made ponds. Data extracted from GIS data.[72] Data are for the Maryland portion of the Coastal Bays watershed.


SCOTT SMITH

Non-tidal wetlands in the upper reaches of Coastal Bays creeks support a variety of rare species while filtering nutrient runoff to the bays.

of St. Martin River in the vicinity of the Great Cypress Swamp.[3] Atlantic white-cedar swamp most likely occurred on the margins of the Coastal Bays, and is being included in restoration plantings.

Herbaceous plants and shrubs dominate in areas chronically too wet for trees, which occur in low spots in and along natural and constructed depressions, ponds, and drainage ways. This vegetation also predominates in recently-formed wetlands, such as disturbed or managed areas, including logged sites and power-line rights-of-way. Historically, fire, nutrient-poor soils, and beaver activity were probably locally important factors limiting tree cover in some non-tidal wetlands in the region.[22,41]

Wetlands perform valuable functions

The Coastal Bays wetlands naturally perform numerous functions that greatly benefit people and other living things. Services performed by wetlands can include shoreline and flood protection, water quality improvement, and provision of habitat to fish and wildlife.

A number of functions performed by wetlands are critical to maintenance of good environmental quality, which, in turn, maintains the character of the area as a desirable place to live and Ocean City as a thriving tourist destination. The magnitude of the beneficial functions performed by wetland ecosystems is dependent upon their area, landscape and landform location, waterflow pathways,[72] and position with respect to other natural habitats and pollutant sources.

Wetlands that are flooded by bay or stream waters and/or that receive runoff can improve water quality by intercepting and then transforming or storing pollutants. Vegetation and topography slow water velocities, allowing suspended materials and pollutants to be processed in the wetland. At the same time, non-tidal wetlands adjacent to rivers and streams help control flooding by temporarily storing runoff and deluge waters. Depressional wetlands also help control flooding by storing water that would otherwise contribute to runoff. In turn, the stored water helps recharge groundwater.

Salt marshes serve as nurseries for juveniles of many commercial and recreational species, such as fish and crabs, and provide habitat for wildlife such as waterfowl. The bayside edge of salt marshes features many small coves which supply valuable habitat to aquatic life. Salt marshes can provide storm protection and erosion control by reducing storm waves that reach land. They are also one of the most productive ecosystems on earth. They produce a tremendous amount of organic material (primarily salt marsh plant detritus) that, when exported from the marsh, supports the Coastal Bays food web.

Forested wetlands provide habitat for a variety of plant and animal species dependent upon wetland conditions that upland habitats do not provide. Many of the functions of this habitat are severely impaired when they are ditched and drained.

Tidal and non-tidal wetlands can sequester substantial quantities of carbon in their soils in the form of poorly decomposed plant remains. This function is increasingly recognized to be of global importance in regulating the earth's atmospheric carbon dioxide content.[4,11]

Anthropogenic stressors to wetlands

Tidal and non-tidal wetlands:

- Development.
- Exotic species out-competing native plants.
- Fragmentation through loss of adjacent natural upland habitats.
- Reduction in fire frequency.
- Excess nutrient loading.
- Excess herbivory by native species whose population densities are anthropogenically altered, e.g., white-tailed deer.

Tidal wetlands:

- Mosquito ditches.

Non-tidal wetlands:

- Drainage ditches.
- Farming.
- Logging.
- Conversion to loblolly pine plantations.

Various laws protect wetlands

Because of the high value afforded wetlands by society, wetlands are protected by federal and state law under the regulatory programs of the U.S. Army Corps of Engineers (USACE) and Maryland Department of the Environment (MDE). Regulations require that a permit be obtained to fill wetlands, and numerous other activities in wetlands are also regulated. Permitted wetlands losses are required to be mitigated (i.e., created, restored, or enhanced) to avoid net wetland losses. MDE has recommended priority areas for restoration and mitigation in the Coastal Bays watershed to guide compensatory mitigation efforts.[41]

MDE routinely tracks permitted wetland impacts. The table on the facing page presents a summary of permitted non-tidal wetlands impacts between 1991 and 2006. It is noteworthy that Isle of Wight Bay watershed led the state of Maryland in net permitted losses of non-tidal wetlands over this period. In contrast, permitted tidal wetlands losses are believed to be insubstantial in recent years on an annual basis and effectively mitigated.

At this time, aggregate success on the ground of wetlands restored or created as compensatory mitigation in the Coastal Bays is not known. MDE anticipates evaluating the success of compensatory mitigation projects by the end of 2007. For more information on managing wetlands, see Chapter 3—*Management of the Coastal Bays & Watershed.*

Human impacts on wetlands have been substantial

Two similar estimates of historic wetland losses from direct anthropogenic causes have been determined for the Coastal Bays. A USACE/Natural Resources Conservation Service study estimated that 730 ha (1,810 acres) of salt marsh and 10,000 ha (24,800 acres) of forested non-tidal wetlands were destroyed in the 20th century, for a total of 10,730 ha (26,610 acres) of direct losses.[61] The U.S. Fish and Wildlife Service (USFWS) estimated that 10,409 ha (25,721 acres) of vegetated and non-vegetated wetlands, or about 41% of the historic wetlands, have been lost and converted to other uses.[72]

	Assawoman Bay	Isle of Wight Bay	Sinepuxent Bay	Newport Bay	Chincoteague Bay	Unknown	Total
NON-TIDAL WETLANDS (1991–2006)							
Impacts							
Permitted impacts	-0.77	-73.04	-5.24	-5.96	-2.05		-87.06
Mitigation							
Permittee[1]	—	+50.02	+4.09	+3.45	—		+57.56
Programmatic[2]	—	+5	+3	+0.5	+16.7		+25.2
Other gains	—	+1.16	+0.09	+0.9	+3.92		+6.07
Net change	**-0.77**	**-16.86**	**+1.94**	**-1.11**	**+18.57**		**+1.77**
TIDAL WETLANDS (1996–2006)							
Impacts							
Permitted impacts	-0.02	-0.15	—	—	—		-0.17
Mitigation							
Permittee[1]	+0.11	+0.45	—	—	—		+0.56
Programmatic[2]	+0.09	+0.71	—	+0.12	—		+0.92
Net change	**+0.18**	**+1.00**	**—**	**+0.12**	**—**		**+1.31**
OTHER GAINS							
Voluntary restoration (1998–2006)[3]	+93.6	+146.4	+74.1	+215.1	+1,110.1	+325.33	+1,964.63
Phragmites (2005)[4]	—	—	—	—	—	+70	+70
Tidal wetland creation (2005)[5]	+0.01	+0.10	—	—	—		+0.11
Total	**+93.02**	**+130.65**	**+76.04**	**+214.11**	**+1,128.67**	**+395.33**	**+2,037.82**

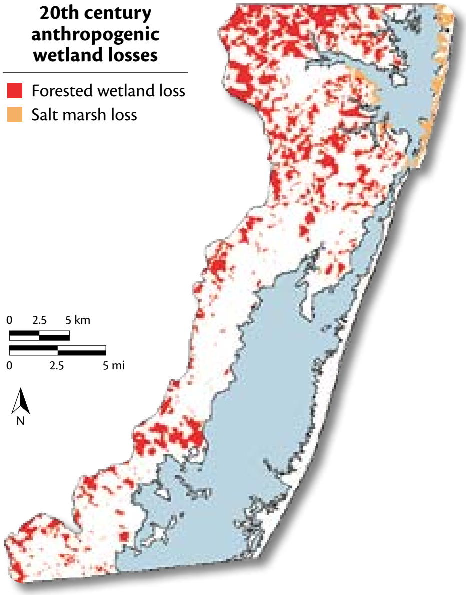
Summary of acres of permitted impacts and mitigation and other gains to non-tidal and tidal wetlands. However, this table does not account for illegal filling of wetlands which has been substantial in the Coastal Bays watershed over the past two decades, nor does it account for loss of function of natural wetland systems.

1. Permittee mitigation refers to mitigation projects undertaken by the permittee to compensate for their permitted impacts.
2. Programmatic gains refer to mitigation projects undertaken by MDE to compensate for cumulative impacts of permitted small losses which are exempt from permittee mitigation.
3. Voluntary restoration includes voluntary wetland restoration/creation projects. Records may be incomplete.
4. *Phragmites* gains refer to the treatment of 70 acres of the invasive *Phragmites* by Maryland Department of Natural Resources.
5. Tidal wetland creation refers to Natural Resources Conservation Service gains, from MDE permit records.

MARYLAND DEPARTMENT OF THE ENVIRONMENT

Salt marsh losses from direct human impacts occurred primarily from canal construction and filling for development in the northern bays. In contrast, direct losses of non-tidal wetlands occurred primarily as a consequence of drainage and conversion of these lands to agricultural use. However, more recent permitted losses are due to development. Non-tidal wetlands losses have occurred throughout the Coastal Bays watershed, and concentrated losses have taken place in the St. Martin River, Turville and Herring Creeks, and Newport Bay subwatersheds.

Salt marshes that have been filled or converted to open water cannot self-restore. For non-tidal wetlands, maintenance of the artificial drainage network prevents natural restoration that might otherwise occur. The water table in many areas has been lowered by extensive ditching—these areas can revert to wetlands if artificial drainage is removed. Continued tilling of cropped wetlands prevents natural re-establishment of wetlands vegetation.



U.S. ARMY CORPS OF ENGINEERS

This map shows general areas of estimated loss of wetlands to development and agriculture.[61]

The future viability of tidal wetlands is uncertain

Anthropogenic environmental alterations interact with natural processes that create, maintain, and destroy tidal wetlands. Historically on Fenwick Island, overwash and inlet migration created sand deposits upon which tidal wetlands formed. Coastal engineering measures that now protect Ocean City and the inlet unintentionally prevent formation of new salt marshes.[73] On the mainland of the northern Coastal Bays, structures and fill along the landward margin of salt marshes prevents marsh landward migration that would otherwise accompany rising sea level.

In contrast, erosion of marsh shorelines that accompanies sea level rise continues. Consequently, in spite of the success of the regulatory program, tidal wetlands are undergoing an indirect net loss induced by human interruption of natural processes in the northern bays that could be tens of acres per year.[61,75] Naturally steep slopes landward of existing tidal wetlands—relict features of ancient shorelines—do not favor large-scale natural tidal wetlands formation over the next several centuries to millennia. Consequently, the Coastal Bays would likely experience a net natural loss of salt marsh in the near future even in the absence of anthropogenic environmental alterations.[27]

Of greater concern, the rate of sea level rise is forecast to accelerate in accompaniment with ongoing global warming. The pattern of large areas of interior open water apparent in many mainland-fringe and island salt marshes of the Coastal Bays indicates that these tidal wetlands are already drowning and converting to open water. Based on comparison to Chesapeake and Delaware Bays tidal marshes,[29] the average 20th century rate of sea level rise on Delmarva of about 3–4 mm (0.12–0.16 in) per year [47,84] is probably at or exceeds the rate at which natural sediment and plant material accumulation can maintain existing Coastal Bays tidal wetland surfaces over the longer-term. If the long-term average rate of sea level rise accelerates, the majority of the Coastal Bays salt marshes could well drown-in-place and erode away within a period of decades. For more information on sea level rise and wetlands, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*

Wetlands important for biodiversity dot the Coastal Bays watershed

USFWS identified several wetland types in the Coastal Bays of particular importance to conservation of biodiversity within the Coastal Bays watershed and state of Maryland.[72] The salt marshes of the Coastal Bays were viewed as important because tidal wetlands of comparably high salinities do not occur elsewhere in Maryland. Large, intact, non-tidal wetland complexes provide interior habitat for wildlife that is otherwise lacking in the fragmented landscape. Additionally, several wetland types were identified by virtue of their being uncommon within the Coastal Bays watershed, although they may be more common elsewhere in the state. These types include non-tidal wetlands occurring between the swales of Assateague Island's dunes, fresh tidal wetlands, semi-permanently flooded marsh and scrub–shrub, and seasonally flooded marsh and shrub. Several notable non-tidal wetland types considered to be of regional ecological significance because of a concentrated presence of rare plant communities are described below.[37]

Delmarva Bays

Found from New Jersey to Florida, Delmarva or Carolina Bays are circular wetland depressions that pool water for part of the year before usually drying out in the heat of summer. Unlike tidal marshes, they are fed by rain, snowmelt,


WES KNAPP

A Delmarva Bay in the Assawoman Bay watershed after drying out in late summer.

and groundwater only—there is no natural drainage into or out of them. They are found in one of three types: forested, shrubby, or herbaceous. The herbaceous type is uncommon and can support many rare plant and animal species.

There are many myths surrounding the creation of Delmarva Bays, including UFO landing areas, meteorite impact zones, and whale wallows exposed after the retreat of the oceans. The truth is that Delmarva Bays formed during the last Ice Age, about 20,000 years ago, when the climate of the Coastal Bays was very cold. At that time, the landscape was only sparsely vegetated and strong prevailing winds created erosional depressions on the landscape that filled with water.

Vernal pools

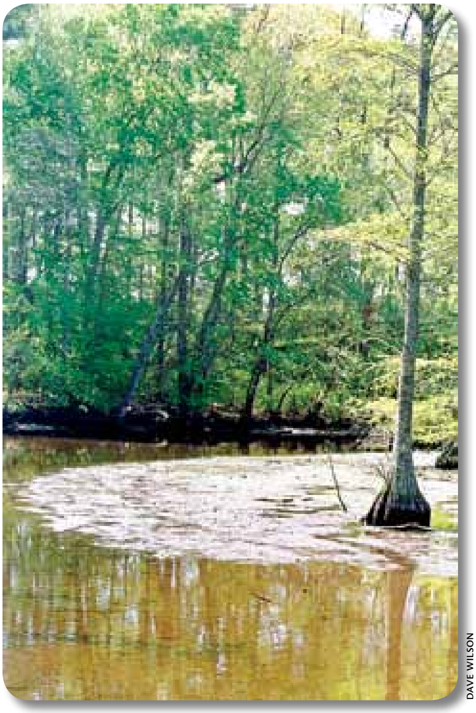
Vernal pools are small, non-tidal wetlands, typically in forests or floodplains, that fill with water when the water table rises in fall and winter, and also after snowmelt in spring. They often dry out by summer. Vernal pools often overlie an impermeable soil layer that impedes drainage. These wetlands are extremely important habitat for many species, particularly amphibians. Fish, a major predator on amphibian larvae, cannot survive in these habitats due to their ephemeral nature, and many species of frogs and salamanders have evolved to reproduce in these temporary, fish-free wetlands.

WES KNAPP

This vernal pool is located on Sinepuxent Neck, between Sinepuxent and Newport Bays.

Baldcypress swamps

Baldcypress is a beautiful tree typically found growing in and along streams and in large floodplains. Baldcypress swamp is considered to be of regional ecological significance.[36] The tree reaches the northern limit of its natural range just a few miles north of the Maryland–Delaware state line, and its occurrence here is of geographic interest. Baldcypress was formerly a much more common species in the Coastal Bays watershed. Prized for its rot-resistant wood for shipbuilding, logging from the 1700s through the early 20th century greatly reduced baldcypress swamp acreage.[5]



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A baldcypress tree in Shingle Landing Prong, a tributary of St. Martin River.

Sea-level fens

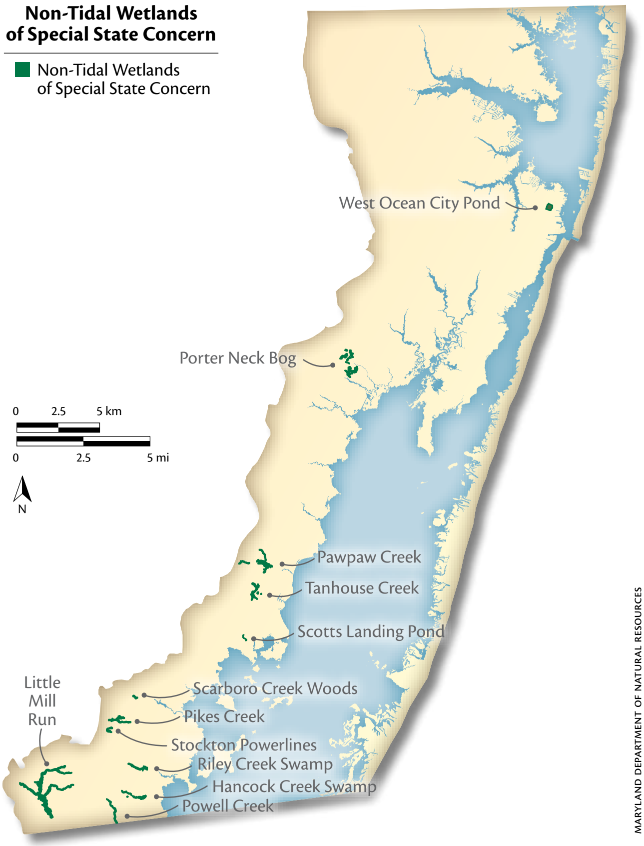
The Coastal Bays historically possessed substantial areas of herbaceous and shrubby bog-like non-tidal wetlands at groundwater seeps along the landward margins of the Coastal Bays.[58] These seepage wetlands are today known as sea-level fens.[34] Unfortunately, only small remnants survive.[41]

Interdunal swale wetlands

Found only on Assateague Island in the Coastal Bays, interdunal swale wetlands are freshwater non-tidal wetlands that occur in shallow depressions between dunes. These wetlands possess sandy soils but remain seasonally wet because of groundwater. Shifting sand dunes, salt spray, and periodic overwash and storm disturbance enable herbaceous species to outcompete shrubs and trees. Consequently, these wetlands support numerous rare herbaceous plant species.[70] Comparable wetlands may have formerly occurred on Fenwick Island.

The Coastal Bays contain non-tidal wetlands of special status

Wetlands designated as 'Non-Tidal Wetlands of Special State Concern' include many of the best examples of these wetlands in Maryland. Non-Tidal Wetlands of Special State Concern are designated for special protection under state regulations. These sites have exceptional ecological and educational value and offer landowners opportunities to observe and safeguard the beauty and natural diversity of Maryland's best remaining wetlands. Many of these special wetlands contain populations of rare and endangered native plants and animals. Other Non-Tidal Wetlands of Special State Concern represent examples of unique wetland types and collective habitats for species that thrive in specialized environments. There are 12 sites designated as Non-Tidal Wetlands of Special State Concern in the Coastal Bays: West Ocean City Pond, Porter Neck Bog, Pawpaw Creek, Tanhouse Creek, Scotts Landing Pond, Scarboro Creek Woods, Pikes Creek, Stockton Powerlines, Riley Creek Swamp, Hancock Creek Swamp, Powell Creek, and Little Mill Run. Several additional sites containing remnant sea-level fens may qualify for designation as Non-Tidal Wetlands of Special State Concern.[41] The map below shows Non-Tidal Wetlands of Special State Concern in Maryland. Many of these sites require active management if their outstanding ecological character is to be maintained.



Non-Tidal Wetlands of Special State Concern in the Maryland Coastal Bays watershed.

STREAMS

Streams connect forests & wetlands to the Coastal Bays

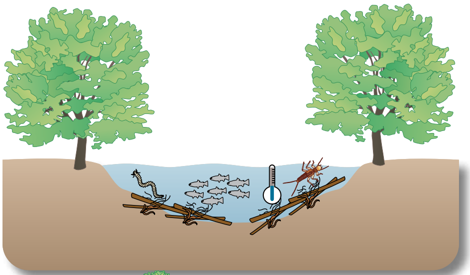
Streams carry nutrients, sediments, and pollution from the landscape and groundwater to estuaries. Thus, ecological integrity of streams is critical to maintaining the ecological quality of the Coastal Bays. Streams are but one part of complex ecosystems called *stream corridors*. A stream corridor consists of a *stream channel* with water flowing at least part of the year, a *floodplain* which is the area around the stream that is periodically flooded, and the *riparian zone*, which is the area parallel to the stream that provides shade, contributes detritus, and provides woody debris to the stream. The riparian corridor includes areas vulnerable to stream flooding as well as areas that never flood. It can contain both natural habitats and fabricated environments.

A stream corridor can contain features such as wetlands, forest, and shrubland. Patches within a stream might include woody debris and aquatic plant beds. These features and patches provide places to live for plants and animals that are responsible for transferring energy and recycling nutrients.

Ditching & channelization remove habitat

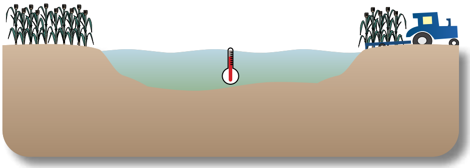
Disruption of a corridor reduces the ability of these organisms to serve in nutrient storage and transformation. For example, the flow of streams changes as sites are cleared for development

Stream



Shaded by trees and other stream-side vegetation, stream waters are cooler . Woody debris in the stream provides habitat for fish and invertebrate animals .

Ditch

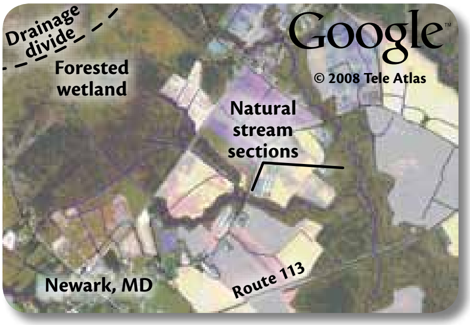


Lack of trees and other stream-side vegetation makes ditch waters warmer and shallower, with little habitat diversity for stream-dwelling animals.

ROMAN JESIEN

ROMAN JESIEN

Natural channels (left) have a much wider variety of habitats than ditched streams (right), including habitat for organisms such as algae, bacteria, insects, crustaceans, and fishes that process nutrients in the stream. In addition, the riparian (stream-side) zone provides areas for storage of water and sediments.



Massey Branch (a branch of Marshall Creek, which drains into Newport Bay) is one of just two stream sections in the Coastal Bays with natural channels.

and natural vegetation is replaced by impervious surfaces such as roof tops, roadways, parking lots, sidewalks, and driveways. Agricultural areas are typically drained by shallow constructed ditches that improve drainage efficiency. Consequently, more of the stream's annual flow is delivered as stormwater runoff rather than base flow. Excessively high flow during storms can harm organisms by preventing upstream movement and increase erosion of stream banks.

Only two sections of streams within the watershed are considered natural channels—Massey Branch (Newport Bay) and Little Mill Creek (Chincoteague Bay), totalling only 7.2 km (4.5 mi) out of 265.9 km (165.2 mi) of streams.[72] Fish passage structures have been installed at Turville Creek and Middle Branch of Shingle Landing Prong in St. Martin River to provide avenues for up and downstream movement. A large project to restore stream passage in Buntings Branch in upper St. Martin River is expected to begin construction by fall 2009. For more information, see Chapter 5—*St. Martin River.*


ROMAN JESIEN

Stream bank erosion can occur when there is a lack of riparian buffers and excessive impervious surfaces.

Streams in the Coastal Bays have the most channelization of any tributary basin in Maryland—ditching is present in 65% of stream miles. Overall, the watershed contains 722.1 km (448.7 mi) of mapped ditches or 1.5 km per km^2 (2.4 mi per mi^2). Ditches were historically created to convert forested wetlands to upland for agricultural use, but development potential of the created uplands is a current factor driving ditch maintenance. Maintenance of Public Drainage Association designated ditches is also required under law in primarily agricultural areas.

Ditched streams generally have less habitat diversity and lower flows than minimally-altered streams that retain a more natural wetland character. Ditches may partially or completely drain swamps and other wetlands that provide services including flood control, water filtration, and fish and wildlife habitat. Removal of woody debris from stream channels and overshading trees from the riparian zones causes channelized streams to be warm and shallow, with little diversity of habitats for fish and other organisms. Channelization may increase the speed of water transport, more rapidly transporting nutrients and other pollutants to the Coastal Bays, although this also depends on other factors, including slope, amount of discharge, and tidal influence.

Coastal Bays streams are in poor condition

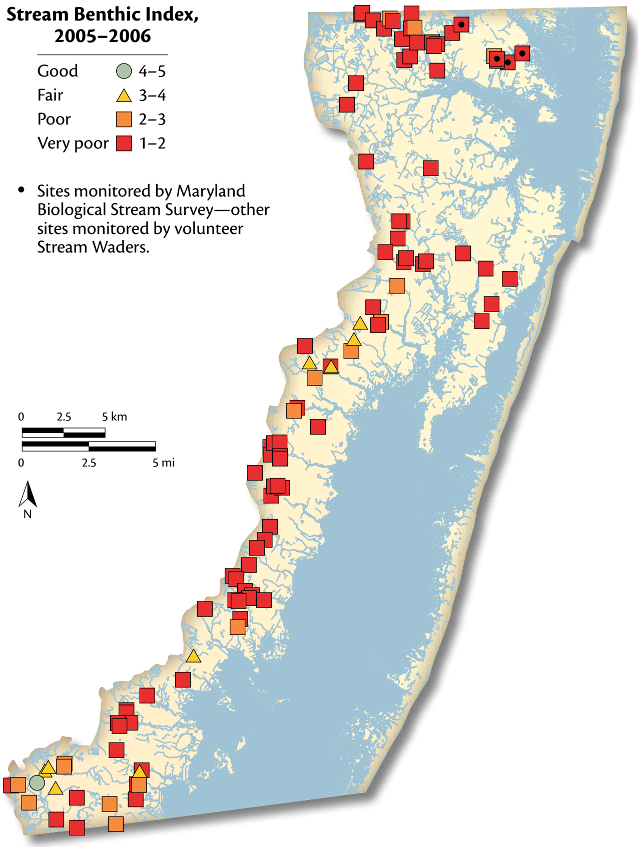
Ecological integrity of waterbodies depends on biological, chemical, and physical integrity—all three of which are important (for information on ecological integrity and its role in the Clean Water

Act, see Chapter 3—*Management of the Coastal Bays & Watershed*). Biotic integrity is particularly useful for assessment because aquatic animals are, over a period of time, exposed to most of the physical and chemical stressors present in a stream. To report overall stream health, researchers use the diversity and abundance of benthic organisms and freshwater fish. In the Coastal Bays watershed, this Index of Biological Integrity (IBI) is calculated for all sites with adequate data. These IBIs rate stream health according to the species of invertebrates or fish found there.

Most animals found in Coastal Bays watershed streams were classified as pollution-tolerant. Stream benthic index results from 110 sites rated 91% of sites as poor or very poor, while 8% of sites rated as fair. Only one site rated as good. The freshwater fish index results from eight sites rated six sites as poor or very poor, with the remaining two sites rated as fair. Impacts to the biota of Coastal Bays streams are likely the result of physical habitat modifications, such as ditching, channelization, and barriers to upstream movement of fishes.

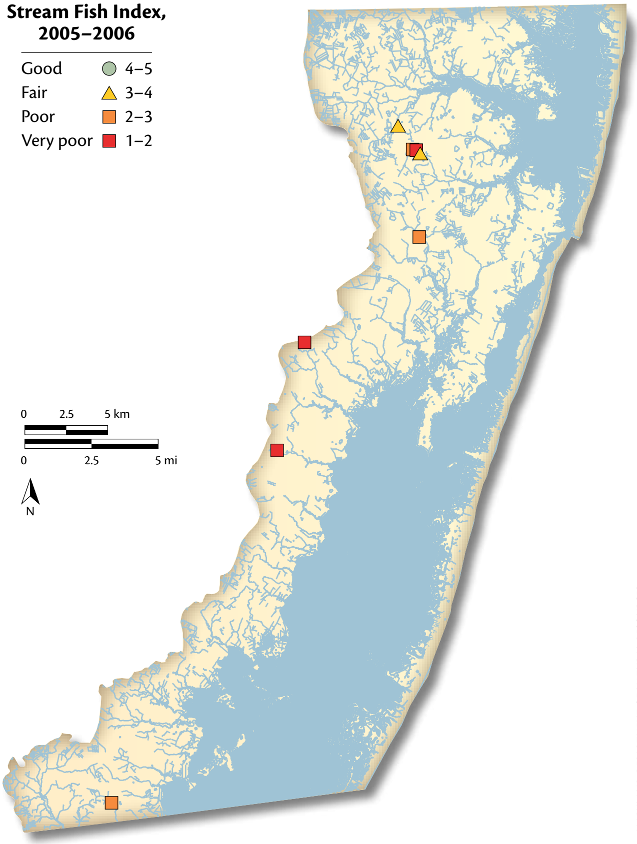
Chemical integrity of most Coastal Bays streams is poor. The streams have high nitrate and total phosphorus levels (see Chapter 13—*Water Quality Responses to Nutrients*). Coastal Bays streams are naturally acidic and many rare species (e.g., blue-spotted sunfish [*Enneacanthus gloriosus*], banded sunfish [*Enneacanthus obesus*], and swamp darter [*Etheostoma fusiforme*]) are adapted to this high acidity. Acid-tolerant native stream animals are negatively affected by practices such as liming (which artificially elevates water pH) on agricultural fields adjacent to streams. Even though most Coastal Bays streams (4.3–7.75 pH) are more acidic than state-wide water quality standards (6.5–8.5 pH)[12], streams that are acidic may be more natural and beneficial in this area.

It is not only the disruption of riparian zones that impacts streams—activities and changes in the entire watershed are important, since water flows off the watershed or as groundwater from the watershed into streams. Highly degraded watershed conditions or high pollutant inputs can overwhelm even a healthy stream corridor.



The Stream Benthic Index rated stream health according to ecological characteristics of benthic fauna found in that stream. The Stream Benthic Index indicated that most streams in the Coastal Bays were degraded.

MARYLAND DEPARTMENT OF NATURAL RESOURCES



MARYLAND DEPARTMENT OF NATURAL RESOURCES

The Stream Fish Index rated stream health according to ecological characteristics of fish found in that stream. The Stream Fish Index indicated most streams in the Coastal Bays were degraded.

THE BOTTOM & THE SHORE

Bay substrates are the foundation for aquatic life

The Coastal Bays have a diverse benthic, or bottom-dwelling, fauna, as is characteristic of shallow-water areas. These benthic communities include worms, shellfish, crustaceans, and other invertebrates. Types of bottom substrate vary from mud and clay to sand in a general west-to-east gradient. These soft substrates provide a burrowing habitat for large numbers of animals that live in the surface layer (infauna), some of which rely on the substrate as a food source (deposit feeders). Though smaller in number, some organisms dwell on the substrate surface (epifauna). Still others, mostly fish, do not live on the substrate, but rely on it for feeding (demersals). For more information on the benthic living resources of the Coastal Bays, see Chapter 14—*Diversity of Life in the Coastal Bays*.

As with all aquatic life in the Coastal Bays, salinity affects the distribution of bottom-dwellers, but sediment type also plays a role. The most diverse benthic communities occur where sediments consist of a mixture of sand, silt, and clay. The benthic community affects the physical and chemical condition of the water and sediments. Some build tubes or burrows through which they pump water. Infaunal deposit feeders, such as worms, plow through the sediments in search of food. Many benthic animals bind sediments together as fecal pellets that remain at the bottom. Predators, such

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Black-bellied plovers (*Pluvialis squatarola*) forage for food on intertidal sand and mudflats.

as adult blue crabs (*Callinectes sapidus*), scurry across the bottom searching for food. These activities stir the sediments, increasing the rate of exchange of materials into the water column. This mixing also increases diffusion of oxygen into the sediments.

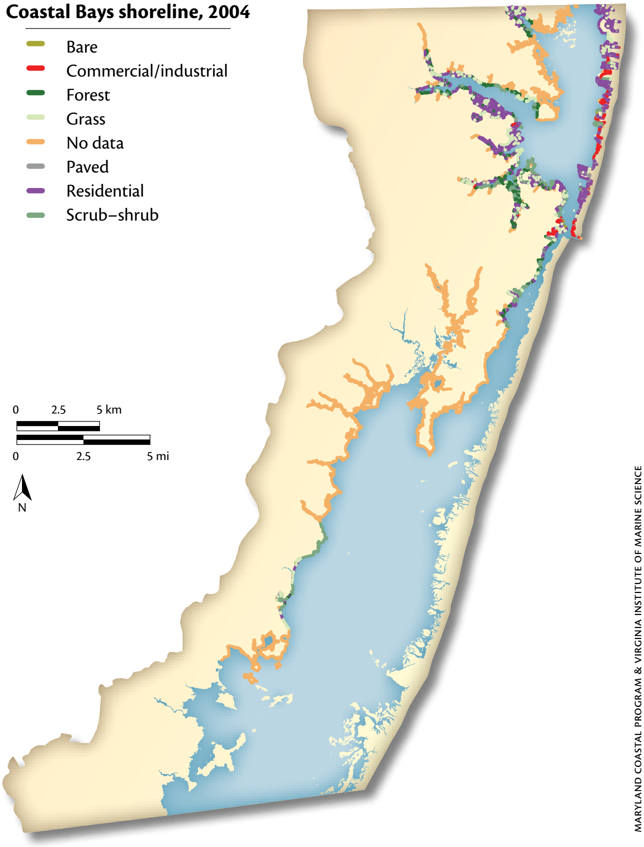
Some unvegetated bottom areas are intertidal (i.e., exposed during low tides). These areas are important feeding habitat for shorebirds since benthic organisms are either exposed directly or can be easily dug from the mud or sand.

Filter feeders like clams (*Mercenaria mercenaria*) remove suspended sediments and organic matter from the water column, helping clean the water. Direct disturbance by boating and fishing in these shallow habitats can threaten these organisms.

Superimposed on this soft-bottom environment was another ecologically important habitat with one of the most diverse communities in the Coastal Bays. Oyster bars, or reefs, provided structure and substrate for a wide variety of organisms that rely on scarce hard surfaces for attaching themselves or for refuge among the nooks and crannies of the shells. At the beginning of the 20th century, over 650 ha (1,600 acres) of oyster bars scattered throughout Chincoteague Bay were an integral part of the mosaic of bay bottom habitats. As the oysters disappeared, the bars themselves have largely been smothered by sediment.[66] The remaining bars have been maintained in part by hard clam harvesting, which prevents silt from accumulating on the oyster shells,[68] but this activity was legally mandated to end in 2008. Without a viable oyster population to add shell to the reefs, the future is not too promising for this valuable and ever-dwindling habitat. For more information on oysters, see Chapter 14—*Diversity of Life in the Coastal Bays*.

Natural shorelines are critical to the ecosystem

Maintenance and restoration of natural shoreline habitat is critical to the health of the Coastal Bays. The ribbon of marsh that grows along shorelines provides significant benefits to the aquatic ecosystem. Fringe marsh protects water quality by slowing runoff, reducing erosion, and filtering nutrients which can reduce oxygen and cause algal blooms. Native trees and



This map shows shoreline land use/land cover in the Coastal Bays.

MARYLAND COASTAL PROGRAM & VIRGINIA INSTITUTE OF MARINE SCIENCE shrubs along the water's edge shade the water and improve conditions for fish and shoreline birds, providing woody debris that offers cover for aquatic life. Natural shorelines also provide critical habitat for fisheries species, at both juvenile and adult life stages. In particular, terrapins and horseshoe crabs need natural shorelines of marsh and beach to nest and spawn. Bordering the shorelines of the Coastal Bays is 110 km (68 mi) of fringe marsh and 10 km (6 mi) of sandy beach (Atlantic coastline not included).[48]

Natural shorelines are increasingly threatened by development. Activities such as shoreline stabilization, construction, and even boat wakes adversely impact this habitat. Some property owners clear natural vegetation to increase their view of the water or

Coastal Bay	Bulkhead[1]	Riprap[1]	Wharf[1]	% of shoreline with erosion control	Total shoreline km (1989)[2]	Total km surveyed[3]
Assawoman Bay	39.4	7.4	0		152.6	69.8
% of total shoreline km	25.8%	4.8%	0%	30.6%		
Isle of Wight Bay	47.7	15.3	0.2		125.2	132.9
% of total shoreline km	38.1%	12.2%	0.2%	50.8%		
St. Martin River	36.6	5.6	0		84.8	70.8
% of total shoreline km	43.2%	6.6%	0%	50.2%		
Sinepuxent Bay	4.5	5.8	0.2		76.8	47.8
% of total shoreline km	5.9%	7.6%	0.3%	14.2%		
Newport Bay	0	0	0		58.9	6.4
% of total shoreline km	0%	0%	0%	0%		
Chincoteague Bay	1.7	1.4	0		91.7[3]	14.6
% of total shoreline km	1.9%	1.5%	0%	3.5%		
Coastal Bays total	**130.0**	**35.5**	**0.4**		**498.3**	**342.3**
% of total shoreline km	**26.1%**	**7.1%**	**0.1%**	**33.7%**		

Results from the Comprehensive Shoreline Inventory in the Coastal Bays, 2004. Results are from the Maryland portion of the Coastal Bays.

1. Length measured in kilometers. 1 km = 0.62 mi.
2. The Comprehensive Shoreline Inventory was conducted only along areas of shoreline that were developed. Large contiguous stretches of marshy coastline were not surveyed. Therefore, the total shoreline kilometers is different from the kilometers of shoreline surveyed. Kilometers of shorelines surveyed is still noted for reference. The percentages of shoreline stabilized were calculated by taking the linear extent of a particular stabilization type and dividing it by the shoreline kilometers calculated by the Maryland Geological Survey in 1989. This gives a more accurate percentage of the amount of shoreline modified in each bay. This number may be higher than the total shoreline kilometers (i.e., Isle of Wight Bay) due to discrepancies in defining bay boundaries.
3. Mainland only calculated by GIS.

to construct shoreline erosion control structures. As described in the following section, erosion control structures themselves are replacing natural shoreline.

Hardened shorelines are replacing natural shorelines

For some species, such as the ecologically important ribbed mussel (*Geukensia demissa*), the intertidal shoreline is the only habitat where they can survive. Development has increasingly encroached upon this environment, resulting in a proliferation of man-made structures constructed of a wide variety of materials that have diminished habitat value. Structures built away from the shore, such as piers, jetties, and groins, can provide scarce hard substrate for epibenthic species as a supplement, but not substitute, for existing natural intertidal shoreline.[67]

Riprap is an assemblage of stone or construction material utilized along the shoreline to dampen wave action and control erosion. Not all structures utilizing riprap are created equal. 'Living shoreline' approaches that incorporate habitat and marsh restoration into their design are preferred. The use of riprap results in the capping of the shoreline, offering less habitat benefit to the surrounding environment than natural shoreline. Use of these structures should be decided on a case-by-case basis, after an evaluation of the suitability of the site for marsh or beach creation, or a combination marsh–structural project. Of the 343 km (213 mi) of Coastal Bays shoreline assessed in 2004, 35 km (22 mi, or 7% of the total Maryland shoreline) had been modified utilizing riprap materials.[48]

Bulkheads have fallen out of favor due to wave refraction impacts resulting in scouring and deepening near the structure and leading to a loss of intertidal area and habitat. Impacts on water quality and leaching of wood preservatives are also a concern. The Maryland permitting hierarchy of preference for shoreline stabilization practices places bulkheads as the last option to address shoreline erosion. Over 130 km (81 mi, or 26% of the total Maryland shoreline) of Coastal Bays shoreline has been hardened using bulkhead treatments.[48]


BRIAN STURGIS

Bulkheads at the mouth of Pawpaw Creek at Public Landing, Chincoteague Bay.

The number of dock permit requests has greatly increased over the last decade and is the single most frequently sought permit by coastal residents.[48] Concerns about the


JANE THOMAS

Riprap along the shoreline of a new development in Sinepuxent Bay.


JANE THOMAS

Community pier at a public boat ramp in Sinepuxent Bay.

proliferation of numerous private docks relate to impacts on the environment, navigation, aesthetics, and the ability of the public to access the waterfront. A recent field survey indicates that 2,530 private docks exist in the Coastal Bays (this survey total did not assess docks along Fenwick Island).[39] To minimize the shading impacts of these structures on seagrasses and wetlands, Worcester County has limited the length of individual and community piers to 30 m (100 ft) and 150 m (500 ft), respectively. For more information on shoreline management, see Chapter 3—*Management of the Coastal Bays & Watershed.*

ISLANDS

Shifting barrier islands support rare species

Coastal barrier islands like Assateague and Fenwick Islands epitomize the interaction between land and sea. Responding to wind and waves, storms and fluctuating sea level, barrier islands are geologic juggernauts—always changing, always on the move. Witness the southern tip of Assateague Island, where the island has grown by more than 10 km (6 mi) and 570 ha (1,400 acres) since 1850.[19] Or look to the tree stumps standing at the edge of the ocean, remnants of former bay-side forests locked in place as the island slowly marches to the west. The face of change is everywhere.

Island habitats can be as dynamic as the landform itself. When storms are less frequent and less intense, highly adapted plants such as American beach grass (*Ammophilia brevigulata*) capture wind-blown sand and slowly form dunes along the ocean beach. Supported by a dense framework of roots and rhizomes, the dunes serve as a bulwark against the sea, providing habitat and protecting less-tolerant plant communities from the effects of salt spray and storm overwash.

Intense storms can, however, overwhelm the dunes, flattening the landscape and distributing sand across the island in broad, flat sheets. The habitat changes, but it still remains habitat. Despite their barren appearance, overwash flats support a suite of rare plant and animal species that find reprieve from competition and predation in newly open spaces. Many, like the piping plover (*Charadrius melodus*), a small shorebird, and the herbaceous seabeach amaranth (*Amarantus pumilus*)—both federally listed as threatened species—are habitat specialists, dependent upon the storm-created environments found only on barrier islands. Other species are equally dependent on specific habitats, and equally vulnerable when conditions change.

The ponds and non-tidal wetlands scattered throughout the island's interior provide the sole source of freshwater for aquatic and terrestrial species alike, yet are far from static. A direct extension of

Stressors to barrier islands

Despite their inherent resiliency, barrier islands can be influenced by a broad array of human activities, both directly and indirectly.

- Exotic species such as feral horses alter native plant and animal communities and can disrupt key ecological processes.
- Shore stabilization structures like groins and jetties disrupt the natural movement of sand and have increased rates of erosion in adjacent areas.
- Accelerated rates of sea level rise associated with global warming may overwhelm the island's capacity to respond and persist.
- Development limits the island's ability to migrate in response to sea level rise by preventing storm-caused overwash and inlet formation processes.
- Recreational activities like off-road vehicle use impact resident biological communities and can reduce habitat value for migratory bird species.

groundwater, the ponds and wetlands occur wherever the land surface dips below the upper surface of the shallow aquifer. As such, water levels vary dramatically depending upon rainfall and temperature-related rates of evaporation and transpiration. Water quality can also fluctuate, periodically becoming brackish from saltwater influx during major storms. Despite these challenges, biodiversity is high in freshwater pond and wetland habitats, and illustrates well the tenacity of life on a barrier island, where change is the only constant. For more information on island formation, see Chapter 12—*Dynamic Systems at the Land–Sea Interface.*

Bay islands are critical waterbird breeding grounds

The Coastal Bays contain about 50 islands that range in size from less than an acre to several hundred acres. These islands are predominantly vegetated by salt marsh, although some are also vegetated by scrub–shrub or lack vegetation over substantial portions of their area.

As a function of their isolation from human disturbance and mammalian predators such as foxes, the bay islands provide important nesting habitat for numerous waterbird species. Several bay islands are of regional significance as nesting sites for species of waterbirds that nest colonially, including gulls, terns, skimmers, egrets, herons, ibis, cormorants, and pelicans. Bay islands also provide habitat for numerous other species not dependent on islands.[7]

Degree of isolation, vegetative condition, and island size are critical factors in determining island suitability as waterbird nesting habitat. Isolation from mammalian predators is optimal when islands are well offshore, or separated from the mainland by strong currents. Some waterbird species require open sand to nest, others nest in salt marsh, and still others nest in reeds or shrubs. Colonial waterbirds

U.S. ARMY CORPS OF ENGINEERS

This aerial photo of Fenwick Island and Ocean City (foreground) and Assateague Island (background) shows how far the north end of Assateague Island has migrated landwards since the opening of the Ocean City Inlet in 1933.


DAVE WILSON

Exotic species such as horses can pose a threat to delicate barrier islands.

Overwash areas & biodiversity

Storms are a primary force shaping coastal environments, driving landscape-level changes essential to the health of the ecosystem. Storm-driven waves and high tides shape habitat, create new lands from old, and both limit and enable species diversity. Without regular disturbance, plants and animals that rely upon habitats created and maintained by storms lose out to those less tolerant of change.

Actions to stabilize coastal properties and protect infrastructure through features such as seawalls and artificial dunes have significantly reduced the influence of storms. As a result, many once-common species have become increasingly rare as suitable habitat has declined.

require sufficient space to nest in large groups. If islands become too small, there is insufficient space for colonial interactions. Waterbirds nesting on open sand shift their nesting sites from year to year to wherever conditions are suitable. Vegetation-nesting colonial waterbirds show strong fidelity to colony sites, and reuse existing sites until conditions become unsuitable.[73] *Of principal importance is the simple continued physical existence of islands.*

Nesting waterbirds are highly vulnerable to human disturbance. Inclusion of many islands in state and federal parks and wildlife management


DAVE WILSON

Trees give way to sand and water as shoreline erodes in southern Chincoteague Bay.

areas affords these habitats substantial protection. Natural vegetative succession or disturbance will change the suitability of islands as nesting habitat according to bird species nesting condition requirements. For beach-nesting species, vegetative succession effectively causes loss of nesting habitat. Island disturbance or erosion which causes vegetation loss can reduce habitat suitability for species that nest in vegetation. For more information on waterbirds, see Chapter 14—*Diversity of Life in the Coastal Bays*.

Islands of the Coastal Bays form via one of three processes:

Flood-tidal delta islands

Sand conveyed into the Coastal Bays from the ocean through inlets accumulates and forms flood-tidal delta islands. Skimmer Island is actively forming through this process today. Other islands on the bay side of Assateague and Fenwick Islands formed as flood-tidal deltas when inlets were historically located in those areas.

Islands originating as flood-tidal deltas are typically bare sand shoals when newly formed; where dunes form, these islands can support upland vegetation. Otherwise, the majority of the island is ultimately colonized by salt marsh if it remains stable for an extended period of time.

Mainland remnant islands

Islands along the mainland shoreline form as differential erosion and drowning leaves some former mainland areas surrounded by water. Spits form off the mainland


JANE THOMAS

Mills Island in Chincoteague Bay is a mainland remnant marsh island. Interior open water areas are indicative of failing marshes.

JANE THOMAS

Skimmer Island, just north of the U.S. Route 50 bridge in Isle of Wight Bay, is a flood-tidal delta island, formed when the incoming tide loses speed and deposits suspended sand inside the Coastal Bays.

where sufficient erosion occurs to provide a sand supply. These can be isolated from the mainland by erosion and form small islands.

Islands formed by erosion of the mainland possess whatever vegetation characterized the site at the time it detached. Then, a succession of vegetation types takes place, forming salt marsh and open water in accompaniment with rising sea level.

Dredge spoil islands

Additional islands form locally via historic disposal of dredged material and filling to create land. Dredged material islands are unvegetated when created, but vegetative succession gradually converts these sites to salt marsh or scrub–shrub vegetation.[73]

No new inlets through Assateague Island into Chincoteague Bay—that could form new bay flood-tidal delta islands—have occurred in many decades. At the northern end of Assateague Island, the U.S. Army Corps of Engineers and National Park Service are working to mitigate decreased sediment supply—a result of the Ocean City Inlet—through regular sand bypassing efforts. On the mainland shoreline of Chincoteague Bay, natural processes that could form islands are largely intact; however, suitable geomorphologic conditions are required for this to occur. In the northern bays, natural processes that historically formed bay islands along Fenwick Island and much of the mainland shoreline have been arrested by shoreline and property protection work. However, Skimmer Island (see photo on opposite page) and adjacent shoal areas remain suitable as sites for island growth or new island formation, and new salt marsh islands have formed on the western side of Assawoman Bay as the marshes there fail. No dredged material islands have been created for decades, and only South Point Spoils Island remains as a substantial dredged material island suitable for nesting. In contrast to the limited rate of formation of new islands, the natural forces of erosion that destroy islands continue unabated throughout the Coastal Bays.[73]


U.S. ARMY CORPS OF ENGINEERS

South Point Spoils Island in northern Chincoteague Bay.

SEAGRASSES

After impressive gains, seagrass distribution has suffered a recent decline

Seagrasses are an important part of the Coastal Bays ecosystem. Not only do seagrasses improve water quality, they also provide food and shelter for waterfowl, fish, and shellfish. Seagrass beds are used as nurseries by many species and are habitat for bay scallops (*Argopecten irradians*). For example, research has shown that the density of juvenile blue crabs is 30 times greater in seagrass beds than in unvegetated areas.[49]

Present-day distribution is well-documented (1986–2006)

There are currently two types of seagrasses found in the Maryland Coastal Bays—eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). A 'wasting


EVAMARIA KOCH

Eelgrass adjacent to Tizzard Island in Chincoteague Bay.

disease' virtually eliminated eelgrass in the early 1930s.[13,14,69] Seagrass (both eelgrass and widgeon grass) acreage throughout the Coastal Bays increased steadily for almost two decades since 1986,[30,52] with an overall 320% increase. This represents the greatest documented percent increase on the entire U.S. East Coast.

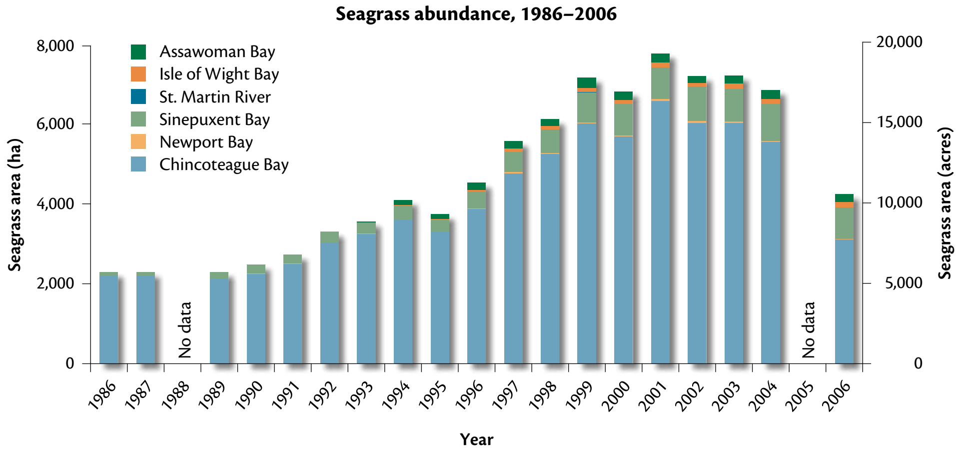
Stressors to seagrasses

Overall, water quality in the Coastal Bays is becoming more degraded and many areas do not meet crucial thresholds needed to maintain important living resources.

Increased nutrient inputs from point and non-point sources and sediments in the water column can lead to decreased sunlight reaching seagrasses and are considered the primary threat to seagrass health. Increasing water temperatures from global warming will stress seagrasses, such as eelgrass, that prefer cooler temperatures.

Seagrasses in the Coastal Bays may also be damaged by **excessive macroalgae, brown tide,** and **recreational and commercial boating activity**. Natural factors, such as sediment type and tidal currents, also influence the health and location of seagrass beds.

The dispersal characteristics of eelgrass—which spreads by seed from detached and floating flowering shoots that contain viable seeds—may have limited eelgrass recovery initially in the northern bays. Once re-established, increases in seagrass abundance in the 1990s may have been related to improving water column nutrient trends in some areas.[76] Since 1999, seagrass acreage has leveled off or declined,[30,51,52] coincident with degrading water quality trends (also see Chapter 13—*Water Quality Responses to Nutrients*),[76] and suffered a significant decline in 2005 that did not rebound in 2006 or 2007. Corroborative anecdotal evidence suggests that eelgrass was reduced in many areas along the Mid-Atlantic coast at about this time, while other areas improved (Isle of Wight and Assawoman Bays and the Coastal Bays of Virginia).[74] A multitude of different theories have been advanced to account for the declines, yet none have been conclusively demonstrated to be the cause, nor is it believed that the large-scale declines were the result of a single factor. One factor observed in Johnson Bay (Chincoteague Bay) and Chesapeake Bay was elevated water temperatures in the summer and fall of 2005. Field observations by Maryland Department of Natural Resources suggest some declines happened over the winter of 2004–2005 in the Coastal Bays and seagrasses were already impacted in some areas by May 2005. Some scientists suggested the decline



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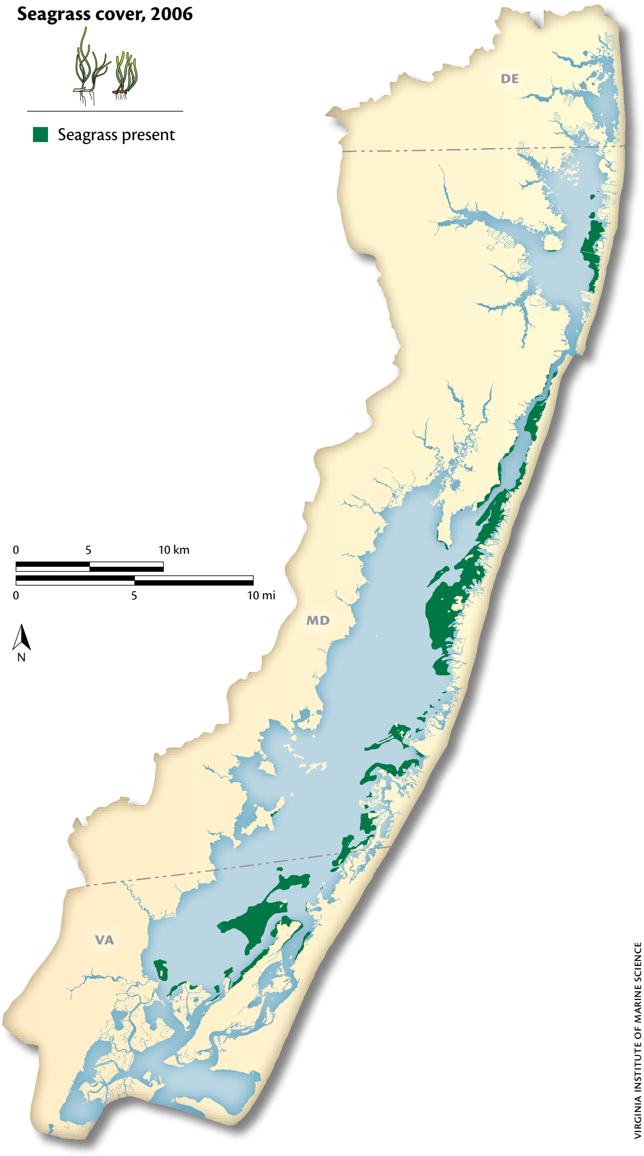
Seagrass coverage in the Coastal Bays increased until 2001, after which it has been declining. Graph includes the Virginia portion of Chincoteague Bay.

in New Jersey may have been due to brown tide blooms. It is hypothesized that areas where plants were already stressed (due to poor water quality, limited flushing, and/or brown tide) succumbed to additional pressures, which explains why areas within Chesapeake Bay, the Virginia Coastal Bays, the northern Coastal Bays of Maryland were able to remain productive.



In 2006, seagrass was mostly found along the eastern side of the Coastal Bays, with a higher occurrence in the southern bays.

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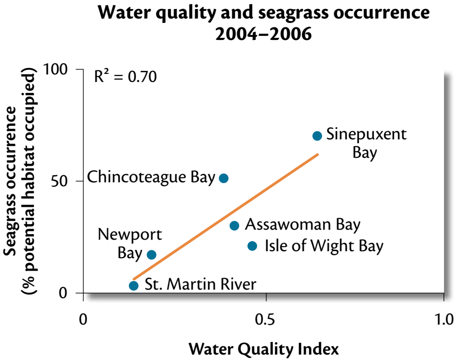
Seagrass coverage follows water quality trends

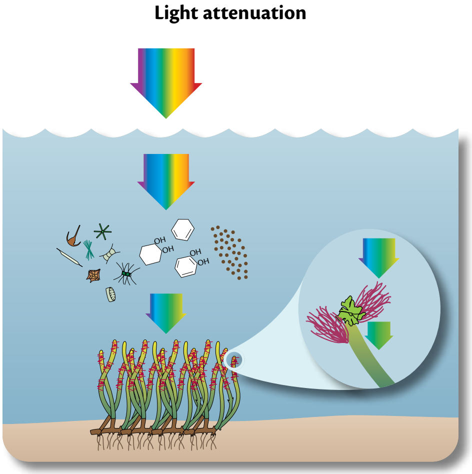
While historic losses of seagrass are largely attributable to disease, salinity alterations, and other factors (e.g., storms), water quality conditions play a critical role in the current seagrass distribution. Water quality is determined by the amount of total nitrogen, total phosphorus, dissolved oxygen, chlorophyll *a*, and suspended sediment in the water column. If nutrient (nitrogen and phosphorus) concentrations in the water are too high, algal blooms (measured by chlorophyll *a*) and epiphyte growth occur and block the light needed for seagrass growth.

Water quality trend analyses reveal significant trend reversals (from improving to degrading water quality) in the late 1990s (for more information, see Chapter 13—*Water Quality Responses to Nutrients*). Increases in seagrass area plateaued around the same time. Additionally, reports of smothering of seagrass by macroalgae were documented in some areas during 1999–2000.[52]

Although seagrasses are found in four major segments of Maryland's Coastal Bays, they are not distributed evenly, due to differences in water quality and sediment characteristics.



Seagrass occurrence is related to water quality.



Various factors influence how much light is absorbed in the water column before reaching seagrasses on the bottom. These include phytoplankton , humics (organic matter) , suspended sediment , and epiphytes growing on the seagrass leaves . The quality (color) of light also changes from white to blue-green as different wavelengths are absorbed.

In general, water and sediment quality are worse in the tributaries than in the open bays, although water quality is deteriorating even in these areas. Seagrass coverage seems to follow the same pattern, with less coverage in the tributaries (low water quality) and more coverage in open bay areas (high water quality).

Historical occurrence is less well-known (1900s–1970s)

Historical references of seagrass in the Coastal Bays prior to 1986—when the Virginia Institute of Marine Science started annual aerial monitoring in the region—are patchy and sometimes vague or conflicting. The following is the best comprehensive summary of scientific literature relating to the occurrence of seagrass or other vegetation over the past century.

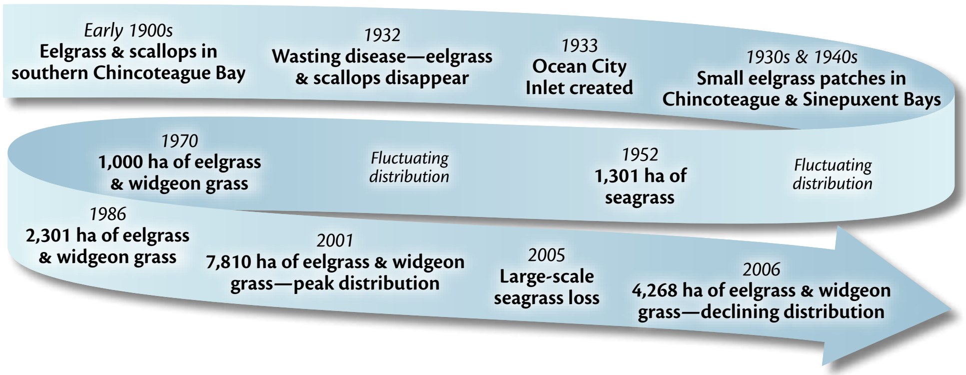
During the later 19th century, eelgrass scarcity was noted in this region but had recovered by the early 1900s, where salinity was appropriate.[26] Eelgrass was the major aquatic vegetation found in the bays and was primarily restricted to the southern portion of Chincoteague Bay where salinities were highest.[13,14,18] Scallop landings in this area peaked in 1930.[52] Areas north of South Point (the northern end of Chincoteague Bay) were primarily brackish[23,62] during this period and there are no known records of seagrass in the upper part of the lagoons at that time, although one study states that the bottom was covered in "vegetable growth."[62] It is presumed these areas would have been prime habitat for widgeon grass, yet the presence of widgeon grass was not officially documented until 1970.[2]

As a result of the wasting disease that led to catastrophic declines in eelgrass populations throughout the Atlantic Ocean (North America and Europe), eelgrass disappeared from the Coastal Bays by 1932, and with it, bay scallops.[13,14] The opening and stabilization of the Ocean City Inlet in 1933 permanently increased salinity in the Coastal Bays. The New Jersey and Delmarva Coastal Bays were among the last to rebound from the eelgrass blight; however, small patches of eelgrass were present within Chincoteague and Sinepuxent Bays in the late 1930s and early 1940s.[15,16,17] In 1941, eelgrass showed a marked improvement in the bays, although coverage was still much lower than before the wasting disease. However, by 1944, only three small plots of eelgrass were documented, each only 3 m (10 ft) in diameter.[17] Atlantic brant (*Branta bernicla* *hrota*) may have played an important role in limiting its spread.[16] In 1947, heavy mats of drifting algae were documented in Chincoteague Bay and were believed to be related to oyster losses that year.[38] Overall, setbacks to eelgrass recovery along the Atlantic coast occurred prior to 1945 and recovery took 30–40 years.[53]

Around the Atlantic, eelgrass made a slow recovery with recurrences of wasting disease and it is believed recolonization occurred largely between 1950–1970, although data are limited during this period and sometimes seemingly conflicting.[69] An analysis of historical agriculture photos taken in 1952 showed an estimated 1,302 ha (3,217 acres) of seagrass in the Maryland portion of the Coastal Bays (missing a small portion of upper Assawoman Bay; see table on following page).[43] This historical analysis suggests approximately 4% of the bottom was covered by seagrass and agrees with observations that most of the bays' bottom was barren during this time—in Chincoteague Bay, less than 1% of the bottom was covered.[59] However, a different study stated that Chincoteague Bay and the Virginia Coastal Bays were "almost totally devoid of plant life" in 1953.[18,60] Another study stated that eelgrass had not made a return to the Coastal Bays by the mid-1950s; however, other vegetation was present, including large mats of macroalgae.[80] Vegetation was documented at 11 sites; [80] however, many sites were not in the mapped shallow seagrass areas (see map on following page).[43] Presumably much of this acreage was widgeon grass, not eelgrass; however, it is hard to say if eelgrass was present in small patches as was reported in the 1940s.[17]

One study made no reference to seagrass in Chincoteague or Sinepuxent Bays in 1959, but did state "the shallowness permits abundant growths of bryozoans, *Ulva*, and the red algae, *Agardhiella*." [56] This study consisted of monthly trawl surveys during 1959, some beach seines (mostly on the western portion of Chincoteague Bay), and other methods in many areas not believed to have seagrass. In 1964, it was reported that "Dense *Zostera* and *Agardhiella* beds are common in the sandy portion" of Assawoman Bay.[57] While eelgrass was abundant in northeast Assawoman Bay, macroalgae was abundant throughout the bay, including *Enteromorpha*, *Chaetomorpha*, *Ceramium*, and *Gracilaria*, whereas *Ulva* was documented floating in the channel and inlet areas. In 1962, *Ulva*, eelgrass, corn, and some invertebrates were reported to be the principal diet of waterfowl collected in the Coastal Bays.[64] However, brant in the Chincoteague region during the

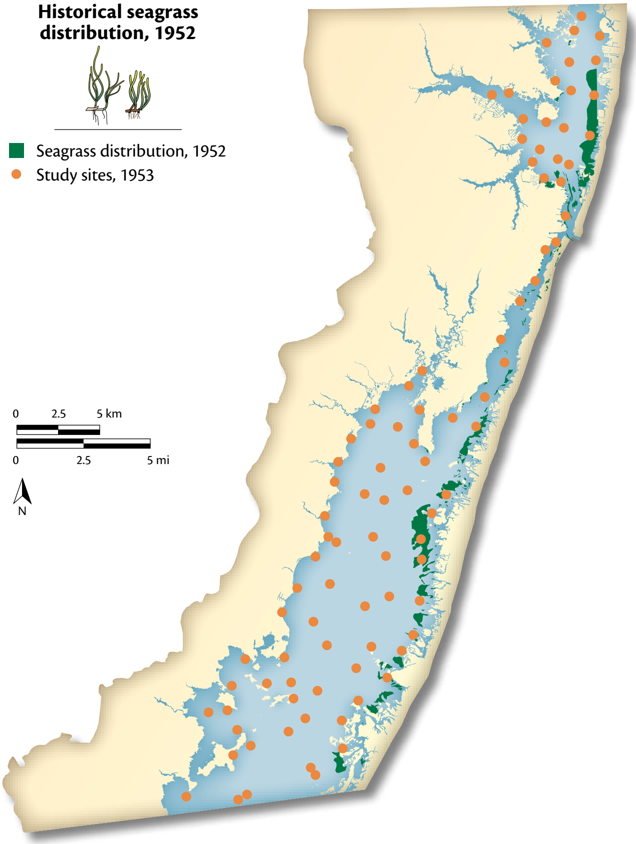
Timeline of seagrass in the Coastal Bays



A timeline of seagrass distribution in the Coastal Bays.

winters of 1955–1958 fed almost entirely on *Ulva*.[43]

The Assateague ecological study in 1970 showed only 1,000 ha (2,471 acres) of seagrass (both eelgrass and widgeon grass) in Chincoteague Bay, mostly in the areas of Popes Bay and Tingles Island.[2] Seagrass was also present in Assawoman and Isle of Wight Bays in the early 1970s (eelgrass was dominant in Assawoman Bay).[1] Degrading water quality and shoreline development/sand borrowing (especially in the northern bays) are hypothesized factors limiting seagrass distribution during this period.[1,44] There are no known references of seagrass abundance between 1970 and 1986, when the Virginia Institute of Marine Science started their annual submerged aquatic vegetation survey in the region. By then, seagrass in Chincoteague and Sinepuxent Bays had expanded to 2,301 ha (5,687 acres); however, no seagrass was present in Isle of Wight or Assawoman Bays. This is believed to have been the highest acreage ever documented in the bays up to that time.



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A retrospective analysis of aerial photos shows approximately 1,302 ha (3,217 acres) of seagrass in the Maryland portion of the Coastal Bays in 1952.[43] Surveys at the study sites in 1953 documented "vegetation" at 11 of the sites.[79]

Watershed	**1952**	**2003**
Assawoman Bay	174	201
Isle of Wight Bay & St. Martin River	311	139
Sinepuxent Bay	161	822
Newport Bay	2.2	36
Chincoteague Bay	654	3,438
Coastal Bays total	**1,302**	**4,636**

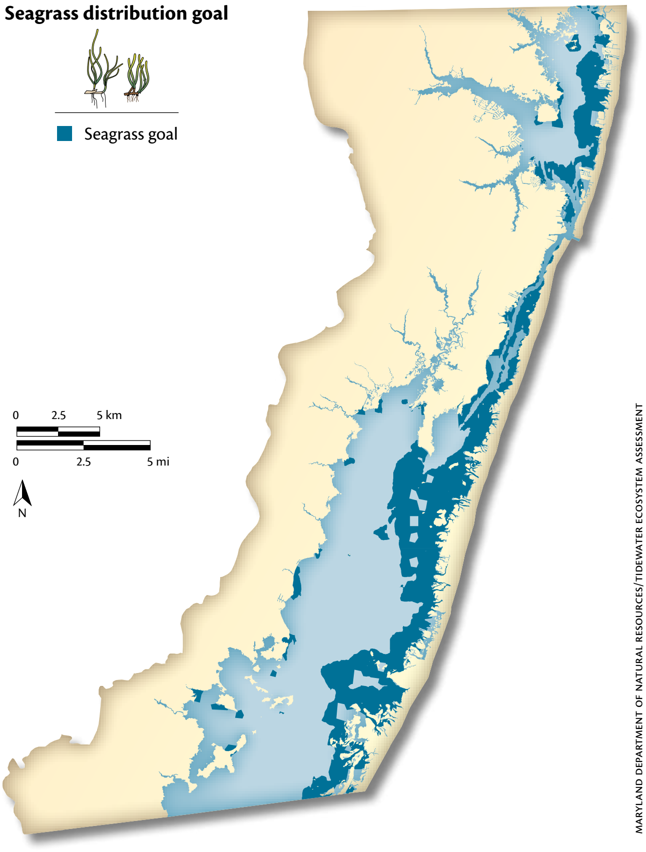
Hectares of seagrass in the Maryland portion of the Coastal Bays in 1952 and 2003.[43,51,52]

Sediment suitability is a key factor in seagrass distribution

Recent studies have shown that sediment composition plays a key role in seagrass distribution.[31,63,81] Seagrasses are usually found in areas that have sediments with 35% or less silt and clay, i.e., in sandy areas.[31] For example, large areas of bay bottom adjacent to Assateague Island in Chincoteague Bay are colonized by seagrasses and characterized by sandy sediments. In contrast, seagrasses do not colonize areas adjacent to retreating marshes on the western shore of the Coastal Bays unless there is a layer of sand overlaying the fine-grained, compacted sediment (ancient marsh) that remains in the seagrass habitat after the marsh has retreated.[81]

The seagrass goal is not being met

A seagrass goal was developed based on potential seagrass habitat. Potential habitat was characterized by water depths less than 1.5 m—due to light availability—and sediment type.[76] Seagrass coverage in 2004–2006 (3,700 ha) was estimated to occupy 49% of the potential habitat (7,650 ha) in the Maryland portion of the Coastal Bays, with the greatest percentage of seagrass habitat occupied in Sinepuxent Bay (70%). Water quality plays a role in the goal attainment among sub-embayments. Other environmental parameters, such as water flow and waves, may resolve the remaining seagrass distribution.



The seagrass goal maps areas in the Coastal Bays that are shallower than 1.5 m deep and have sandy sediments (< 35% silt+clay).

MARYLAND DEPARTMENT OF NATURAL RESOURCES/TIDEWATER ECOSYSTEM ASSESSMENT

Global climate change is of great importance for the future direction of the Coastal Bays

The Coastal Bays are susceptible to warming water temperatures that can affect species diversity and distribution. Eelgrass is a cool-water species, and the Coastal Bays are near the southern extent of its distribution. As a result, any increase in water temperatures can impact local eelgrass populations.

In late summer 2005, a major dieback of eelgrass occurred in Chincoteague Bay, where the largest seagrass beds in the Coastal Bays are found, which may have been caused in part by unusually still, hot conditions,[32] dropping the goal attainment during 2004–2006 to only 51% in Chincoteague Bay, and 49% in the Maryland portion of the Coastal Bays overall.

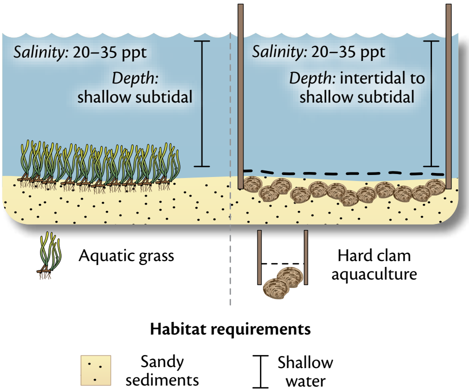
Furthermore, increased storm frequency and intensity may disturb seagrass beds through the deposition of large volumes of sand on shallow seagrass beds in barrier island overwash zones. Additionally, sea level rise is leading to shoreline retreat which is changing sediment characteristics in seagrass habitats, limiting their distribution.[63,81]

These types of changes can leave impressions for decades. Because these impacts accumulate slowly over time, it will be a challenge to manage them and their impacts on seagrass habitat in the Coastal Bays.

Habitat for clam aquaculture is similar to seagrass

With approximately 50% of the seagrass goal attained, other issues may further decrease the likelihood of meeting the Maryland Coastal Bays Program's goal. Historically, hydraulic dredging of clams has been a large industry in the Coastal Bays. However, due to the impact of dredging on seagrass beds, dredging was prohibited in existing seagrass beds in 2001 by the Maryland legislature,[50] and clam dredging of any kind will be banned beginning October 1, 2008. The feasibility of clam aquaculture has been explored and facilities are beginning to develop. Concern has arisen because clam aquaculture requirements overlap with seagrass habitat requirements since both prefer sandy sediments and shallow depths. Much of this suitable habitat is located within the protected boundaries of Assateague Island National Seashore—where aquaculture activities are unwelcomed—and also in sandy 'pockets' on the western shore. At this time, potential impacts from aquaculture—positive (e.g., improved water quality) or

Seagrass & hard clam habitat requirements



Habitat requirements for both seagrasses and clam aquaculture include sandy sediments and shallow water.

JANE THOMAS

Aerial photo showing seagrass beds growing into previously established clam aquaculture plots near Chincoteague Island in Chincoteague Bay, Virginia.

negative (e.g., disturbing seagrasses)—are still undetermined in the Coastal Bays.

Seagrass loss affects more than aquatic life

In addition to aquatic species, ducks and geese use the grasses for sustenance during migration. Additionally, the vegetation removes nutrients from the water, and traps sediments that cloud the bays. Large gains and losses in seagrass thus tend to compound themselves. Following the eelgrass die-off in 2005, Atlantic brant in the Coastal Bays exhibited very unusual behavior for a mild winter. Winter 2005 data suggest many brant in the Maryland portion of the Coastal Bays were field-feeding due to the decrease of aquatic grass.

Both on land and in the shallow waters of the Coastal Bays, wildlife continues to thrive in places least touched by humankind. In the next century, the challenge to wildlife and the biodiversity it brings will lie in striking a balance between the desires of people and the needs of the living things that make the Coastal Bays the rich estuary that locals and visitors have come to know.

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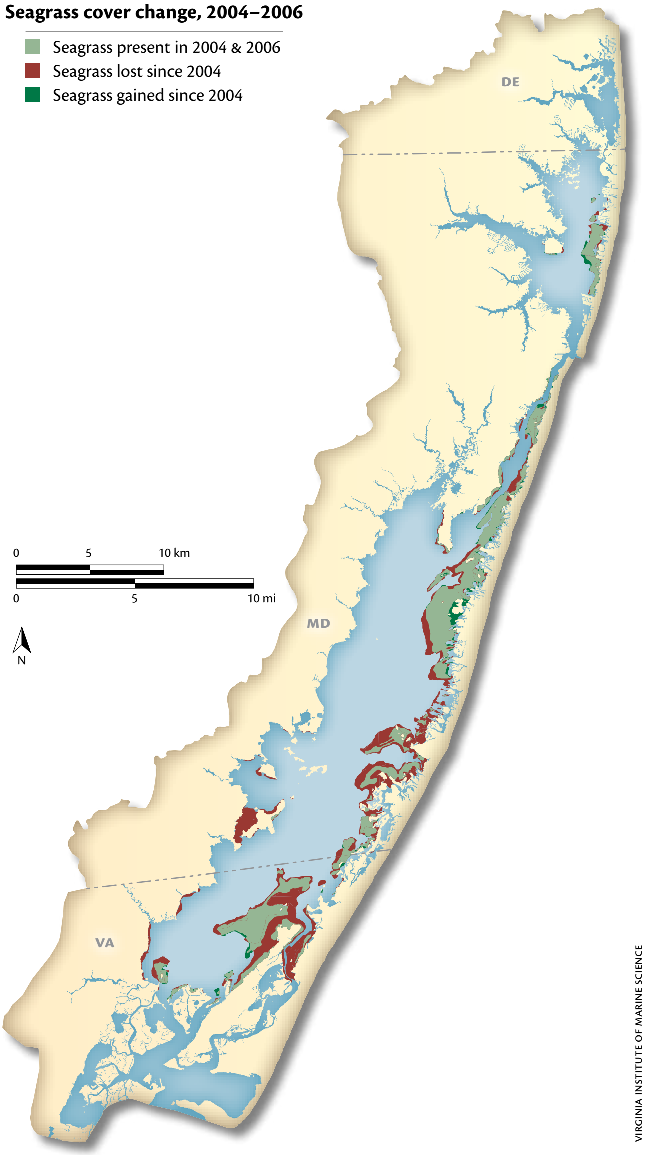

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Significant losses of seagrasses were sustained between 2004 and 2006—2,625 ha (6,487 acres), mostly in the southern bays.

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FURTHER READING

Maryland Department of the Environment: *http://www.mde.state.md.us/programs/waterprograms/wetlands_waterways/documents_information/mdwetlands.asp*

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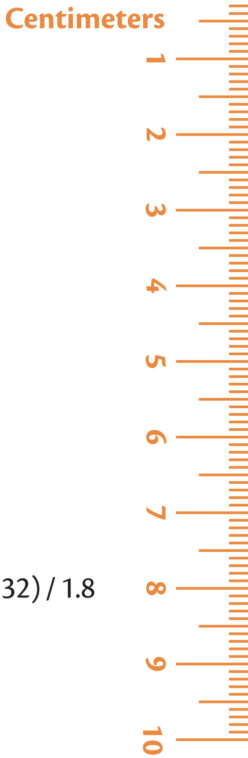
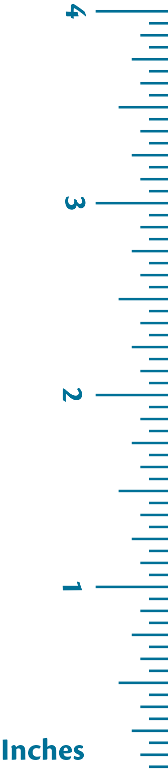


Unit conversions

1 in = 2.54 cm
1 ft = 0.3 m
1 mi = 1.61 km
1 acre = 0.4 ha
1 mi^2 = 2.6 km^2
1 gal = 3.79 L
1 lb = 0.45 kg
T°Fahrenheit = (T°Celsius * 1.8) + 32

1 cm = 0.39 in
1 m = 3.28 ft
1 km = 0.62 mi
1 ha = 2.47 acre
1 km^2 = 0.39 mi^2
1 L = 0.26 gal
1 kg = 2.2 lb
T°Celsius = (T°Fahrenheit - 32) / 1.8



The title of this book—*Shifting Sands*—refers to both the dynamic nature of the barrier islands forming the coastal lagoons of Maryland's Atlantic Ocean coastline and also the changing cultural landscape as more and more people discover these once-forgotten bays. The subtitle of the book—*Environmental and cultural change in Maryland's Coastal Bays*—reflects the way the book integrates natural and human influences.

Shifting Sands is a richly illustrated, multi-authored introduction to Assawoman Bay, Isle of Wight Bay, St. Martin River, Sinepuxent Bay, Newport Bay, and Chincoteague Bay. This book leads the reader on a voyage of discovery, providing a user-friendly guide to the history, setting, context, and ecology of these waterways nestled behind Assateague, Fenwick, and Chincoteague Islands. Photographs, conceptual diagrams, maps, and graphs are used to showcase the key features of and major threats to these magnificent bays, watersheds, and islands, with recommendations for how to preserve them for future generations.

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