The Hudson River Estuary Habitat Restoration Plan

Hudson River Estuary

NEIWPCC
New England Interstate Water Pollution Control Commission

The New NY WORKS for the Environment

Hudson River Estuary Program
New York State Department of Environmental Conservation
Andrew M. Cuomo, Governor
Joe Martens, Commissioner

The NYSDEC Hudson River Estuary Program, the Hudson River National Estuarine Research Reserve and the NEIWPCC

The Hudson River Estuary Program mission is to help people enjoy, protect and revitalize the tidal Hudson and its watershed through public and private partnerships which mobilize resources and people to achieve regional goals. The program is grounded in science to improve the stewardship of the estuary in ways that sustain the benefits a vital ecosystem provides:

- Clean water
- Access for recreation, education and inspiration
- Restored fish, wildlife and habitats
- Resilient, revitalized waterfront communities
- Beautiful natural scenery

The program is coordinated by the NYS Department of Environmental Conservation and extends from the Troy dam to the Verrazano Bridge, including the upper New York harbor. It is guided by an *Action Agenda*–a forward-looking plan developed through significant community participation. The Hudson River Estuary Program achieves real progress through extensive outreach, coordination with state and federal agencies, and development of networks that enable people to work together towards a shared vision. This collaborative approach includes: grants and restoration projects; education, research, and training; natural resource conservation and protection; and community planning assistance. The program is supported through the NYS Environmental Protection Fund. For more information about the Hudson River Estuary Program, visit: www.dec.ny.gov/lands/4920.html

The Hudson River National Estuarine Research Reserve (HRNERR) is a state-federal partnership program that manages four federally designated and state-protected sites along 100 miles of the Hudson River estuary: Piermont Marsh, Iona Island, Tivoli Bays and Stockport Flats. The HRNERR's mission is to improve the health and vitality of the Hudson River estuary by protecting estuarine habitats through integrated education, training, stewardship and restoration, and monitoring and research programs. This program is operated as a partnership between New York State and the National Oceanic and Atmospheric Administration (NOAA).

The New England Interstate Water Pollution Control Commission (NEIWPCC) is a not-for-profit organization, established by Congress in 1947 to serve and assist its member states individually and collectively by providing coordination, research, public education, training and leadership in the management and protection of water quality in the New England states and New York State. NEIWPCC strives to coordinate activities and forums that encourage cooperation among the states, educate the public about key water quality issues, support research projects, train environmental professionals, and provide overall leadership in the management and protection of water quality. Through a partnership with NYSDEC, NEIWPCC supports the Hudson River Estuary Program by providing technical assistance, water resource expertise and project support.

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EXECUTIVE SUMMARY

The Hudson River plays a vital role in the lives of the people of New York State and the nation. An important environmental resource, the river provides drinking water and recreational opportunities, and serves as habitat for a variety of fish, wildlife, and plant species, including some that are globally rare.[1] Coastal migratory fish, such as striped bass, river herring, American shad, Atlantic sturgeon, and Atlantic tomcod, rely on the Hudson River estuary for spawning, nursery, and forage habitat. Long valued as a transportation corridor for the region's agricultural and industrial goods, the Hudson also supports economically significant recreation and tourism industries. The Hudson is an integral part of New York's identity. Its history and scenic beauty have inspired generations of artists, naturalists, and philosophers.

The American Bald Eagle has been reintroduced to the Hudson River and is often seen perching, feeding and raising young along its banks. (Photo: NYSDEC)

The Plan

As with many of our nation's estuaries, the Hudson River is an irreplaceable natural resource that will require a substantial amount of effort, funding and dedication to restore. To be successful, restoration of the Hudson River will require many state and federal agencies, local municipalities, non-governmental organizations and commercial interests to work together to plan and implement restoration activities. This plan identifies priority habitats vital to the health and resiliency of the estuary and actions for restoring them. The plan is a basis for coordinating funding, planning, research and implementation of resources toward a single, focused goal: The enduring health and well being of the Hudson River estuary, its inhabitants and the people of the Hudson River Valley and New York State.

Why Restore?

Despite recent improvements in the Hudson, there remains a profound need for habitat restoration. Between 1800 and 1972, shorelines and wetlands were extensively altered, relocated and eliminated along the 152-mile length of the estuary. The river channel has been narrowed and straightened between Catskill and Troy, and over a third of the surface area of the river in this same reach—over 3,300 acres—was filled with sediments dredged from the federal navigation channel. Hundreds of dams have been built in tributaries leading to the Hudson, fragmenting habitats, degrading water quality, and preventing migratory fish movement. Invasive plant and animal species have taken up residence in the

[1] Robert Naczi, The New York Botanical Garden and David Werier, Botanical and Ecological Consultant, pers. comm.

estuary. As a result of these and other factors, many populations of native fish, wildlife, and plant species have declined, and several have been listed as threatened or endangered. While we cannot restore the river to its original condition, we can take action to improve and restore remaining habitats, while also continuing the Hudson's current function as a navigable river and a transportation corridor.

Habitat restoration and protection will preserve the many critical functions that habitats in the estuary provide, including fish spawning, nursery and foraging habitat, and improved water quality. Furthermore, restoration will improve the resiliency of the Hudson's shoreline communities, and help them adapt to future extreme weather events and sea-level rise.

Restoration Actions

Restoration is possible today due to improved conditions in the Hudson River as result of a variety of laws, including the Clean Water Act (1972) and other environmental efforts by New York State, the federal and local governments, and a host of non-governmental organizations. Section IV of this plan describes additional actions that will be undertaken to restore four priority habitat types: intertidal habitats, shallow water habitats, shorelines and tributary stream habitats. Each of these four habitats plays an important role in maintaining ecosystem health, and all have been degraded or destroyed on a large scale by human actions. Most important, many feasible opportunities exist to restore or revitalize these habitats.

The five restoration actions intended to restore the four priority Hudson River habitats are:

- *Protect and conserve existing estuary habitat,* including protection of adjacent shore lands
- *Restore side channels,* including tidal wetlands, vegetated shallow waters, back waters and intertidal habitats
- *Promote and implement construction of fish passage structures, dam removal and culvert right-sizing and placement* in tributaries to the Hudson
- *Promote and implement use of ecologically enhanced shoreline treatments* where shoreline stabilization is required to protect property or other economic assets
- *Implement programs to control invasive plant species,* including preventing new introductions

Geographic Scope

The geographic scope of this plan is all tidal waters of the Hudson River estuary, from the federal dam at Troy south to the Tappan Zee Bridge in Haverstraw Bay, including the shoreline habitats in waterfront communities along the Hudson from Albany to Sleepy Hollow and the portions of its tributaries that were historically accessible to migratory fish. The plan is meant to complement the *Hudson/Raritan Estuary Comprehensive Restoration*

Plan (HRE-CRP), which has been developed for the southern portion of the estuary from the Tappan Zee Bridge south to lower New York bay.[2]

Restoration Science and Adaptive Management

This restoration plan is the culmination of two decades of research, monitoring and management planning. NYSDEC, the New York State Department of State and the United States Army Corps of Engineers began to research and develop restoration feasibility studies for key habitats of the Hudson in the mid 1990s. In 2005, the Hudson River Estuary Program adopted as one of its primary goals to: "Conserve, protect and enhance river and shoreline habitats to assure that life cycles of key species are supported for human enjoyment and to sustain a healthy ecosystem."

As a result, scientists and resource managers have created a wealth of information that can be used to effectively design and implement the restoration actions identified in this plan. However, restoration, like all sciences, is always evolving. This plan identifies broad research needs that will continue to develop our understanding of Hudson River habitats and how to restore them. Individual projects implemented under this plan will be monitored and evaluated to determine success. Information from independent research and monitoring of active restoration sites will be used to adaptively manage restoration projects from a site-by-site basis to an ecosystem scale.

[2] http://www.nan.usace.army.mil/harbor/index.php?crp

I. OVERVIEW OF THE HABITAT RESTORATION PLAN

PURPOSE OF THE PLAN

This Habitat Restoration Plan provides the foundation for achieving the estuary's management goals of restoring tidal wetlands, natural shorelines, and shallows and of facilitating fish passage up the Hudson's tributaries.

The plan identifies priority habitats and actions for restoration. These priorities, along with other existing management documents, including the Hudson River Estuary Action Agenda, will become the basis of future restoration planning and implementation efforts by New York State and others.

Students learning about and enjoying the Hudson River aboard the sloop Clearwater near Beacon, NY (Photo: Dave Conover, Clearwater)

The plan is intended for use by government agencies, scientists, conservation and environmental organizations, and research institutions throughout the region to:

- Plan, prioritize, carry out, and evaluate habitat restoration projects;
- Advance the state of our knowledge about the habitat needs of priority species;
- Develop understanding of how best to carry out meaningful restoration projects;
- Guide habitat protection efforts that will support adaptation to sea-level rise and promote ecosystem resilience; and
- Coordinate and document habitat restoration and restoration science projects.

Setting Restoration Priorities and Goals

Priority habitats for restoration were identified using the following three criteria:

- Habitats important to the overall health of the ecosystem
- Habitats that have been degraded or destroyed on a large scale by human action
- Habitats for which feasible opportunities for restoration exist

These criteria resulted in a focus on four priority habitats for restoration:

- Intertidal habitats
- Shallow-water habitats
- Shoreline habitats
- Tributary habitats

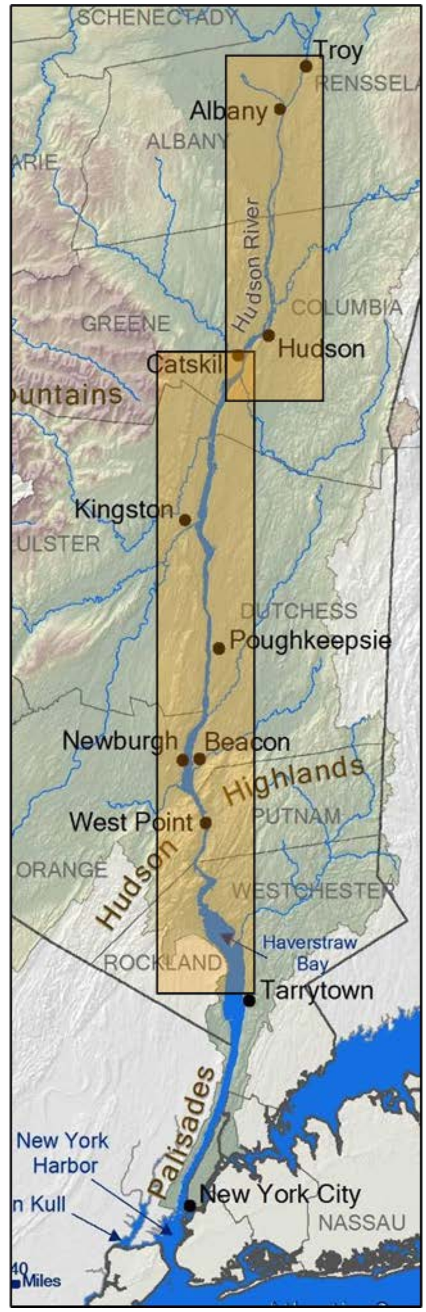
These priorities, along with other existing management documents, including the *Hudson River Estuary Action Agenda*, will become the foundation of future restoration planning and implementation efforts by New York State and others. To restore these habitats, five restoration actions were identified:

- *Protect and conserve existing estuary habitat,* including protection of adjacent shore lands
- *Restore side channels,* including tidal wetlands, vegetated shallow waters, back waters and intertidal habitats
- *Promote and implement construction of fish passage structures, dam removal and culvert right-sizing and placement, and shoreline conservation* in and along tributaries to the Hudson
- *Promote and implement use of ecologically enhanced shoreline treatments* where shoreline stabilization is required to protect property or other economic assets
- *Implement programs to control invasive plant species,* including preventing new introductions

Following the publication of this plan, NYSDEC and its Estuary Program partners will identify a series of technically feasible, appropriate and measurable objectives for restoration using a collaborative process supported by the latest scientific understanding. These objectives, known as Target Ecosystem Characteristics (TECs) are the result of a process established by the Hudson River Foundation and local partners to develop the *Hudson-Raritan Estuary Comprehensive Restoration Plan* for the area south of the Tappan Zee Bridge. For more on the process for developing Target Ecosystem Characteristics, please see: "Restoration Goals (Target Ecosystem Characteristics)" on page 36. The TECs will form the basis for site-specific restoration projects.

Hudson River Estuary Educator
Chris Bowser measures an American eel
on Furnace Brook in Putnam County.

GEOGRAPHIC SCOPE OF THE PLAN



The geographic scope of the *Habitat Restoration Plan* includes the tidal waters of the Hudson River estuary and the portions of its tributaries that were historically accessible to migratory fish, from the federal dam at Troy (river mile 152) south to the Tappan Zee Bridge (river mile 26). This plan complements the Hudson-Raritan Estuary Comprehensive Restoration Plan (HRE-CRP), which identifies restoration priorities for the lower Hudson River south of the Tappan Zee Bridge and for the New York-New Jersey harbor area.[3] Together, the *Hudson River Estuary Habitat Restoration Plan* and the companion *Hudson-Raritan Estuary Comprehensive Restoration Plan* are integrated through a similar approach, shared participants and, most of all, a single water body—the Hudson River estuary.

PLAN DEVELOPMENT AND REVIEW

Early Restoration Planning

Estuary-wide habitat restoration planning began in the mid-1990s with authorization of the federal-state Hudson River Habitat Restoration Project, a partnership of the New York State Department of Environmental Conservation (NYSDEC), the New York State Department of State and the U.S. Army Corps of Engineers (USACOE). An initial "reconnaissance" phase established the historical USACOE impact to habitats and set the stage for USACOE involvement in restoration planning, required for continued federal funding.[4]

An interdisciplinary team of scientists and habitat biologists was formed to identify existing resources and relevant information about Hudson River habitats, and to guide a site selection process. The team quickly identified widespread gaps in our knowledge of habitat locations, status and trends, ecological functions and restoration needs. It recognized that substantially more information was needed to develop appropriate goals, actions, ecological targets, and suitable indicators of restoration success. Soon after, the partner agencies began studies of the feasibility of restoring habitats.

[4] U. S. Army Corps of Engineers. 1995.

This led to a series of estuary-wide habitat studies, some of which continue today. They were underwritten and/or coordinated by the Hudson River Estuary Program, the Hudson River National Estuarine Research Reserve, the Hudson River Foundation, the National Oceanic and Atmospheric Administration and others. These studies included habitat inventories (tidal wetlands and submerged aquatic vegetation); studies of habitat change over time; a river bottom, digital-mapping program; shoreline mapping and ecological assessments; and studies of the ecology and ecological functions of both submerged aquatic vegetation and Hudson River freshwater tidal marshes.

The studies provide an important foundation for restoration planning, implementation and evaluation of success. Details about these studies are provided in Appendix A: Selected Resources for Planning and Evaluating Restoration Projects in the Hudson River Estuary. Several leading academic and research institutions in the region participated in producing this work, and the NYSDEC Office of Natural Resources provided key mapping and technical input.

The Draft Plan

The *Hudson River Estuary Habitat Restoration Plan* was developed with input from state and federal regulatory agencies, scientists, natural resource managers and non-governmental organizations. Many technical resources produced by these groups were used to develop an understanding of current conditions and how they have changed over time due to human action. The author presented this information to several agencies and organizations to promote a shared understanding of historical and current conditions in the Hudson River estuary, and to gather information, ideas and suggestions from these groups, which were factored into the plan.

Review Process

Drafts of this plan were reviewed by scientists and state and federal natural resource managers, including members of NYSDEC's Hudson River Estuary Management Advisory Committee. Several meetings to introduce the plan and discuss proposed actions were held with non-governmental organizations, including conservation and environmental advocacy groups, soil and water conservation districts and sportsman's clubs, as well as public presentations in communities along the Hudson. The draft plan was released for public review following State Environmental Quality Review Act requirements, and the resulting public comments were addressed.

II. WHY RESTORE?

A commercial shad fisherman is shown on the Hudson River before the fishery was closed. (Photo: NYSDEC)

A healthy, vibrant and resilient Hudson River ecosystem has been and will continue to be an essential part of the well being of the people and communities of the Hudson River Valley. Today, the Hudson River has a vital role in the lives of the people of New York State and the nation as an environmental resource, providing drinking water and recreational opportunities and serving as habitat for plants and a wide variety of resident and migratory fish and wildlife. These include important coastal migratory fish species, such as: striped bass, river herring, American shad (*Alosa sapidissima*), Atlantic sturgeon and Atlantic tomcod (*Microgadus tomcod*). The Hudson also has been and continues to be an important economic engine providing a transportation corridor for the region's agricultural and industrial goods, providing a tourism destination and attracting businesses to the region. Finally, the Hudson is an integral part of the valley's identity. Its rich history and scenic beauty have inspired generations of artists, naturalists, philosophers, tourists and residents.

The actions proposed in this plan will restore habitats that are key to productivity and the health and resiliency of the Hudson now and into the future. Taking these actions will enable the river to continue its central role in the biological, economic and cultural health of the Hudson River Valley and all its residents.

Actions taken to conserve forest, stream, and wetland ecosystems in the watershed of the Hudson have also provided important benefits to the river. Interest in and study of the river have also greatly increased our understanding of the river's past and present conditions. This, along with improved water quality conditions, has created a unique opportunity to take the next step in recovery of the Hudson River ecosystem—restoration of habitats vital to supporting the biological and economic health of the Hudson and its surrounding community.

Restoration Will Increase the Estuary's Vitality and Productivity

Estuaries—tidal areas where the freshwater of a river meets the saltwater of the sea—are among Earth's most important and productive ecosystems. They support abundant wildlife, and they function as reproductive, refuge and forage habitat for many resident and migratory species of fish, birds, reptiles, amphibians, invertebrates and mammals. Estuaries are home to an unequalled diversity of plant and animal species, many of which do not or cannot exist elsewhere.[5] Nationally, 75 percent of commercially harvested fish and shellfish depend on estuaries and nearby coastal waters for some part of their life-cycle.[6] Estuaries also provide food, erosion control, floodwater storage, and water purification by wetlands. In addition, they provide transportation routes and sites for industry and recreation.

Habitat restoration will help preserve the biological integrity and productivity of the Hudson River estuary. Successful habitat restoration in the Hudson will increase the health and diversity of the river, preserve the natural scenic beauty of the river and valley, increase recreational opportunities, and increase ecosystem resilience of the river and surrounding communities during a period of climate change and sea-level rise. Commercial and sport fishing industries within the valley and along the Atlantic coast will benefit from a more productive, restored estuary. Several studies have shown the economic benefits of coastal restoration, including job creation, improvement to recreation and tourism industries, increased food production, and ecosystem services.[7],[8]

Restoration Will Help Compensate for Historic Losses of Habitat

The Hudson River estuary has been transformed by human actions, significantly altering and reducing habitats needed to support a productive, diverse and resilient ecosystem. Hudson River habitats have been lost due to two large-scale transportation developments: construction of the federal navigation channel filled wetlands, shallows and intertidal areas, including side channels; and construction of railroads on both shores isolated wetlands and altered shorelines. Dumping of municipal and household or construction waste into shoreline wetlands, as well as thousands of smaller habitat losses also took place over hundreds of years.

From the early 1800s through the mid-1900s, the U.S. Army Corps of Engineers deepened the river for commercial navigation. Maintenance of the channel continues today. Early attempts to deepen the Hudson's navigation channel for shipping included construction of dikes in the upper third of the estuary (Catskill to Troy) in an attempt to constrict the main channel, thereby increasing flow. Later projects included dredging the main channel, then depositing the dredged material in shallows behind the dikes to eliminate side channels, connect islands, and further concentrate the flow of water to inside the main channel. While beneficial for shipping, these actions resulted in the loss of nearly 4,000 acres of shallow-water habitat, including the near complete elimination of side channels in the upper third of the estuary.[9]

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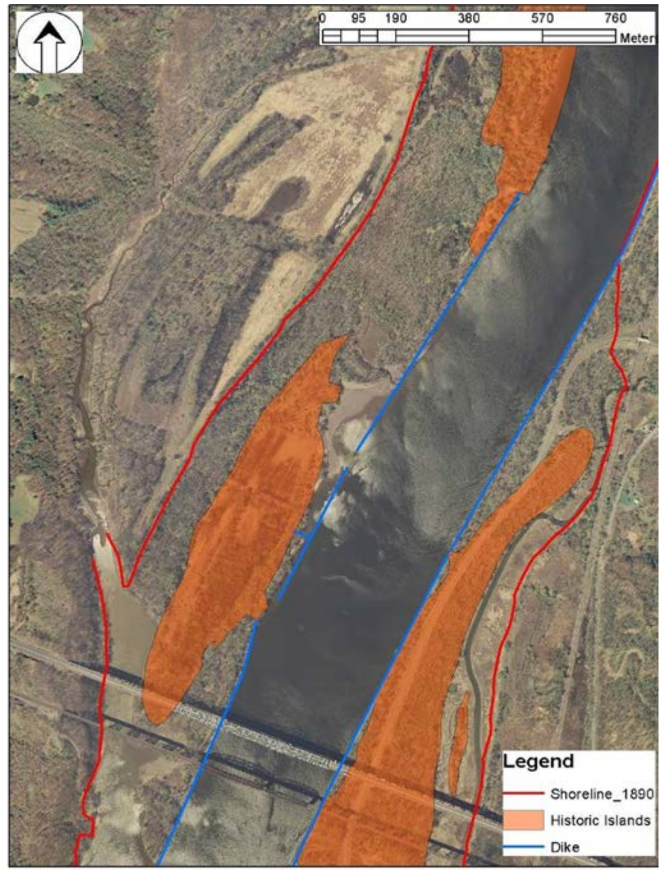
[5] *Restore America's Estuaries*, 2002.
[6] *Restore America's Estuaries*, 2002.
[7] http://www.estuaries.org/images/81103-RAE_17_FINAL_web.pdf
[8] http://www.estuaries.org/images/stories/NOAA_RAE_BRP_Estuary_Economics.pdf
[9] Miller, et al., 2006A, Collins and Miller, 2011.

Loss of shallows was not isolated to the upper estuary. From New York City to Troy, many communities, government entities and industries up and down the river discharged or deposited dredged sediment or other fill material, municipal waste, industrial chemicals and hazardous substances into the river and its shoreline. Many shallows along the banks of the Hudson were filled, then developed or dredged to create deep-water access for ships, barges and ferries. In addition to dredging and filling, wetlands and shallow coves along the edges of the estuary were filled and/or isolated when railroad causeways were constructed along the banks of the river in the 1850s.



This image of the Hudson River near Castleton, New York shows the historic shoreline (red lines), historic islands (orange) and dikes (blue lines). Areas of land inside the historic shoreline that are not historic islands are areas that were filled when the navigation channel was dredged. (Image: NYSDEC)

Agriculture, timber and manufacturing industries took advantage of the many tributaries leading to the Hudson. Many dams were constructed to provide hydropower to saw mills, grist mills, and factories, or to create reservoirs for irrigation or drinking water supply. Despite declines in demand for these uses, many dams built over the past century remain in place. These structures fragment tributary habitats, degrade water quality, block fish migrations, and interrupt natural sediment transport to the estuary.

Overall, about half of the river shoreline within our study area from the Tappan Zee to Troy was altered by human action prior to the passage of the Clean Water Act in 1972, when the public began to appreciate the value of fishable, drinkable, swimmable waters and understand the benefits that wetlands, floodplains, and other natural resources provide.

Restoration Will Help Restore Fisheries

Certain fish, bird and wildlife populations supported by the Hudson River estuary have declined to critically low levels over the past 70 years, in part due to habitat loss. Historic accounts of the Hudson River from early Europeans describe bountiful fish populations that were easily harvested without modern fishing methods. Since European settlement, several factors have contributed to the decline in the number of native fish and economically important sport and commercial fisheries. These factors include:

overfishing, pollution, degraded water quality, introduction of invasive species, fragmentation, loss of habitat and climate change.[10] Recovery of these species must address all factors; however, habitat restoration is a key element of any fisheries restoration program.

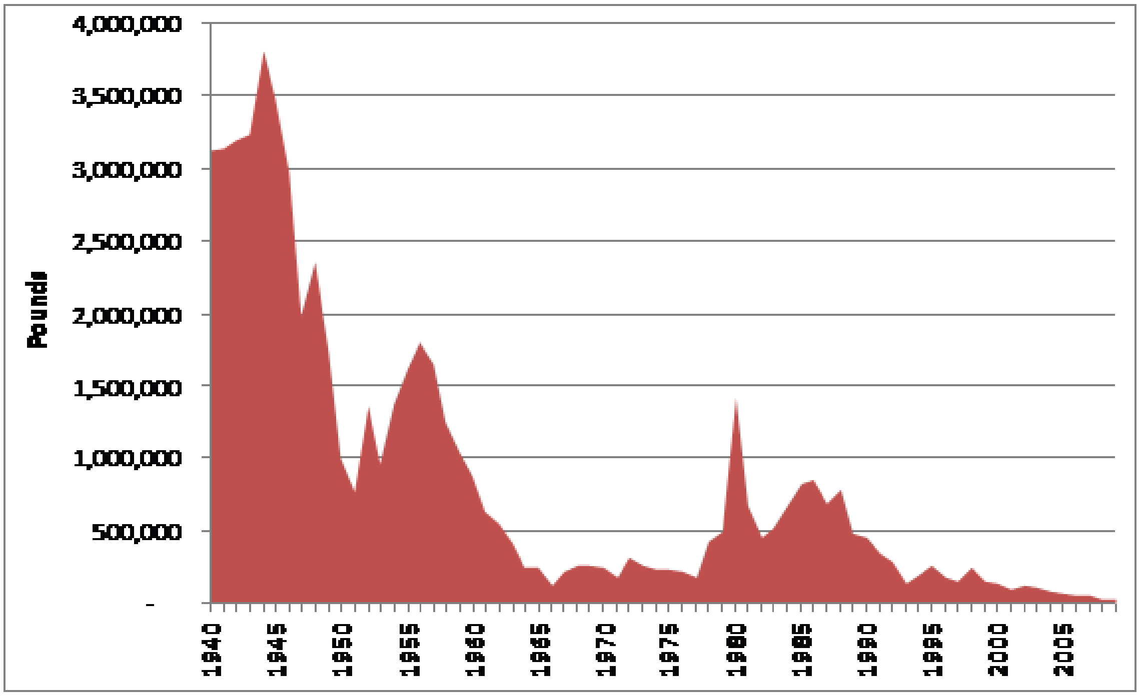


Figure 1. Landings of Hudson River American shad (*Alosa sapidissima*) declined from 1940 to 2009. Note: Fishery was closed in 2010. (Source: NYSDEC, Hudson River Fisheries Unit)

Estuarine and coastal migratory fish that spawn in the Hudson, including American shad, river herring, and Atlantic sturgeon, have declined dramatically (Figure 1). Fisheries management experts have identified several potential causes for the decline of such migratory fish species, and have sought to protect spawning fish by taking management actions to reduce commercial and sport fishing mortality. However, the recovery of these fish stocks is at least partially dependent on the Hudson's ability to produce future generations of fish. Successful restoration of high-quality spawning, nursery, and refuge habitats in the Hudson River estuary, including its tributaries, will allow greater spawning success and survival of young-of-year fish for a number of resident and migratory species. Without restoration, recovery of these economically important species may be limited. Because many coastal migratory fish are also a source of food for larger ocean fish, such as cod and bluefish, coastal commercial fisheries could benefit from restoration of Hudson River habitats.

[10] Hattala and Kahnle, 2005, Hattala, 2010.

Restoration Will Enhance Climate Resiliency

Sea level has been rising worldwide for many thousands of years. However, the rate of sea-level rise has been increasing over the last century. Mean sea level at the Battery in New York City has risen 11 inches over the last 150 years.[11] In the early 1990s, the rate of sea-level rise along the coastal United States from Cape Hatteras, North Carolina to north of Boston, Massachusetts began further accelerating, and is now rising significantly faster than the global average. This is due to a combination of changes in large Atlantic Ocean surface currents, the melting of continental ice sheets and the expansion of ocean water as it warms—all well–documented, recent trends.[12] According to some current projections, water levels along the Hudson may rise as much as 72 inches by the year 2100 and will continue rising rapidly in the centuries to come unless major steps are taken to reduce carbon in the atmosphere.[13] Additionally, in the Northeast, extreme rainfall and flooding events have become more frequent. Tropical storms Irene and Lee in 2011 produced massive rainfall and discharge from the river and deposited an estimated 1.5 million tons of sediment in the estuary. Hurricane Sandy in 2012 created a historic storm surge that traveled inland, up the length of the estuary to Troy, rising in some locations to more than nine feet above normal high tides.

Many Hudson River estuary habitats will be stressed by accelerating rates of sea-level rise and increased frequency of extreme storms, but none more than its critically productive wetlands and shallow water vegetation beds. Intertidal and shallow-water plant communities are extremely sensitive to water depth and salinity levels. Even moderately altered conditions in estuarine and coastal areas will lead to losses of these habitats along with the human benefits they provide: food, flood protection, water quality, recreation, and many others. Data on wetland sediment accretion in Hudson River tidal wetlands suggest that many marshes and other tidal habitats will be severely challenged over the coming century. At the lower, more conservative end of projected sea-level rise rates, tidal wetlands may accrete enough sediment to match rising sea level, while at the higher end of projected rates, a high proportion of habitats may be lost. In the latter scenario, shallow water habitats will be covered by more water, which gradually will become too deep for enough light to penetrate and enable plants to grow. Intertidal wetlands will become continuously submerged, to the detriment of plants not adapted to those conditions. Adjacent uplands that typically get flooded a few times a month will be inundated at high tide on a daily basis. In both scenarios, upslope migration of tidal habitats toward low-lying floodplain areas can be expected.

Habitat restoration is a key component of a forward-looking coastal adaptation strategy that can increase the Hudson River estuary ecosystem's resiliency during times of environmental stress, such as periods of extreme weather, climate change and accelerated sea-level rise. A resilient ecosystem with greater biodiversity and diversity of habitats has the capacity to withstand and bounce back from these accelerating stresses, helping to

[11] http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8518750
[12] http://www.usgs.gov/newsroom/article.asp?ID=3256&from=rss_home#.UBLu2KA9XTp
[13] NYS 2100 Commission at: http://www.rockefellerfoundation.org/news/publications/nys-2100-commission-report-building

maintain critical habitats and their functions in the estuary. Ensuring the capacity for wetland migration through habitat protection and restoration will preserve the many important functions these habitats contribute to the ecosystem, including fish spawning, nursery and forage habitats, and improved water quality.

Preserving low-lying natural areas along the estuary shoreline will allow wetlands to migrate inland and will enable more estuary shallows and wetlands to continue to exist as sea level rises. Protection of these areas also reduces risk to human communities from floods and rising sea level. Removing dams, protecting floodplains, and assuring a vegetated buffer along tributary streams of the estuary will relieve the impacts of intense storms by absorbing the destructive energy of flood waters and help to restore more balanced sediment transport in tributaries. Construction of side channels in the upper estuary will increase spawning and forage habitats for many species and provide low-flow refuge habitats for fish and wildlife during high-flow periods associated with high-discharge, extreme weather events.[14] Where shore protection is needed, designing shorelines that include features that mimic natural systems will enhance the habitat function of those shorelines, and will allow communities to protect important properties and infrastructure from erosion while preserving habitat value. In addition to these measures to enhance the health of the estuary, this plan recognizes the important links between the estuary and maintaining a healthy watershed, including the forests, fields, streams and wetlands comprising it.

For more information about the role of restoration in climate change adaptation and resiliency, please see:

http://www.estuaries.org/images/stories/RAE_Restore-Adapt-Mitigate_Climate-Chg-Report.pdf

[14] McMahon and Hartman, 1989, Bowen, et al., 2003.

III. OVERVIEW OF HUDSON RIVER ESTUARY HABITATS

INTRODUCTION TO HUDSON RIVER HABITATS

The web of life in the tidal Hudson River is complex, diverse, and important. It links to uplands, tributary streams and the Atlantic Ocean. The existence and condition of Hudson River habitats has a bearing on water quality (and for some, drinking water), resilience to storms and shoreline erosion, recreational fisheries (and any future commercial fisheries), a host of recreational pursuits, and the quality of our communities.

A great blue heron feeds in vegetated shallows near the intertidal marsh. (Photo: Carl Alderson, NOAA)

The Hudson River estuary's waters have a wide range in salinity (saltiness), from freshwater throughout the upper 85 miles of the estuary to waters much closer to the salinity of the Atlantic Ocean near New York harbor. Heavy freshwater flows from storms or snow melt dilute salinity in the lower part of the estuary, while periods of drought can result in brackish waters moving well upriver. The estuary's waters also range from shallows less than six feet deep at low tide to nearly 200 feet in the Hudson Highlands. Historically, the upper third of the estuary (from Catskill to Troy) was dominated by shallow waters. All waters of the Hudson are highly productive, supporting many ecologically important species.

Throughout the estuary, two broad habitat types—intertidal wetlands and shallow water habitats—are distinguished by elevation (height) relative to high and low tide (Figure 2). They contain richly diverse but distinct plant communities that are home to a great variety of plants and animals and are important to many ecological processes that provide food and improve water quality.

In the lower part of the estuary where water salinity is usually within the range of 15-30 parts per million, eastern oysters (*Crassostrea virginica*) once grew in vast numbers, forming extensive reefs in and around New York harbor and north to the Tappan Zee. Today, for a variety of reasons, oysters are only occasionally found in localized reefs on the bottom, where they provide habitat for a range of animals. Oysters feed by filtering microscopic plants and animals from the water and, in the process, improve water quality.

Today, small populations of oysters are found in the Hudson estuary as far north as Haverstraw Bay. The Tappan Zee Bridge, which spans the bay, is the southern boundary of this plan. Although oyster restoration in this area may be a worthwhile endeavor, the majority of locations where oyster restoration is feasible in the Hudson River/New York harbor region are outside the geographic scope of this plan. Therefore, oyster restoration is not specifically addressed. However, this plan recognizes and supports the oyster restoration goals of the *Hudson-Raritan Estuary Comprehensive Restoration Plan*, including restoration efforts in the Haverstraw Bay/Tappan Zee region.[15]

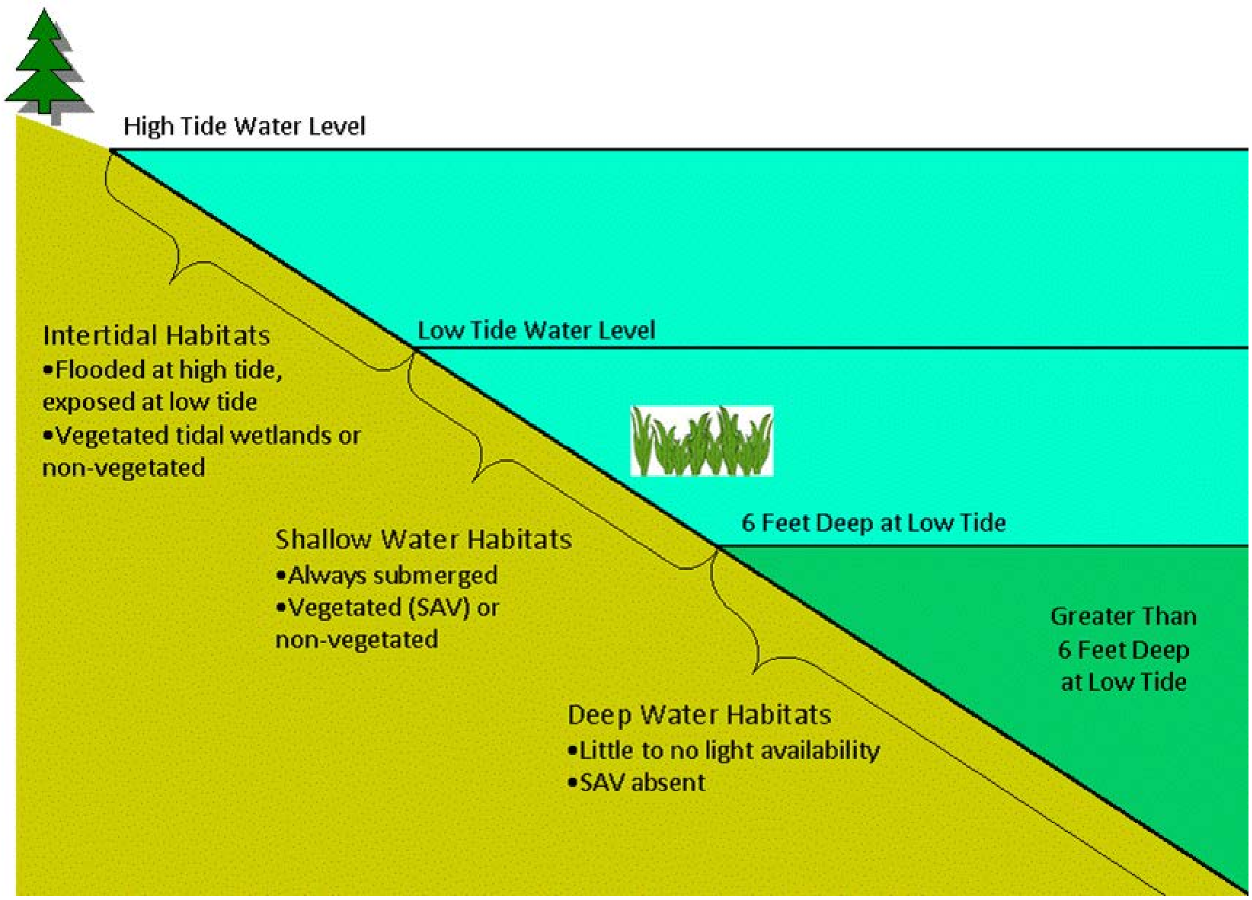


Figure 2: Intertidal, shallow and deep-water habitats of the Hudson River estuary and its tributaries

Although this plan does not directly address measures to improve water quality in the Hudson River estuary, many state and federal programs are focused on this issue. For instance, the *Hudson River Estuary Action Agenda* includes goals focused on water quality for swimming, source water, and pollution reduction, as well as tributary and watershed conservation. This plan indirectly supports such water quality improvement by identifying opportunities to restore wetlands and vegetated shorelines which filter sediments, transform nutrients and remove pollutants.

[15] http://www.nan.usace.army.mil/harbor/index.php?crp

PRIORITY HABITATS FOR RESTORATION

Restoration of strictly defined historic conditions is generally not possible, nor is it necessarily desirable under current conditions of settlement and river use. Instead, this plan identifies feasible and appropriate activities that will result in meaningful restoration that will improve the health and resiliency of the Hudson River today and into the future.

Three criteria were used to identify priority habitats for restoration:

- Habitats important to the overall health of the ecosystem
- Habitats that have been degraded or destroyed on a large scale by human action
- Habitats for which there are existing feasible opportunities for restoration

The criteria resulted in four priority habitats for restoration:

- Intertidal habitats
- Shallow-water habitats
- Shorelines
- Tributary stream habitats

Although this list does not include all habitats that have been lost or impaired, the items listed are priorities because it is feasible to restore them, and their restoration will improve the health and resiliency of the Hudson River estuary ecosystem.

Intertidal Habitats

The Hudson River estuary's more than 6,000 acres of intertidal wetlands (Tappan Zee Bridge to Troy) occur between low and high tide and are regularly flooded and drained twice a day by rising and falling tides. Intertidal wetlands are found in the main stem of the Hudson as well as in tidal mouths of tributaries. They include: brackish marshes (e.g., Iona Island, Constitution and Manitou marshes) and freshwater tidal marshes (e.g., Tivoli Bays, Ramshorn, Hudson South Bay and Mill Creek mashes). Mud and sand flats, broad-leaf emergent and graminoid-dominated marshes, and tidal shrub and tree swamps can all be found in Hudson River tidal wetlands.

The Tivoli Bays Wildlife Management Area in Dutchess County is a freshwater tidal marsh dominated by cattail (*Typha angustifolia*) and is home to a wide variety of fish, birds and mammals. (Photo: NYSDEC)

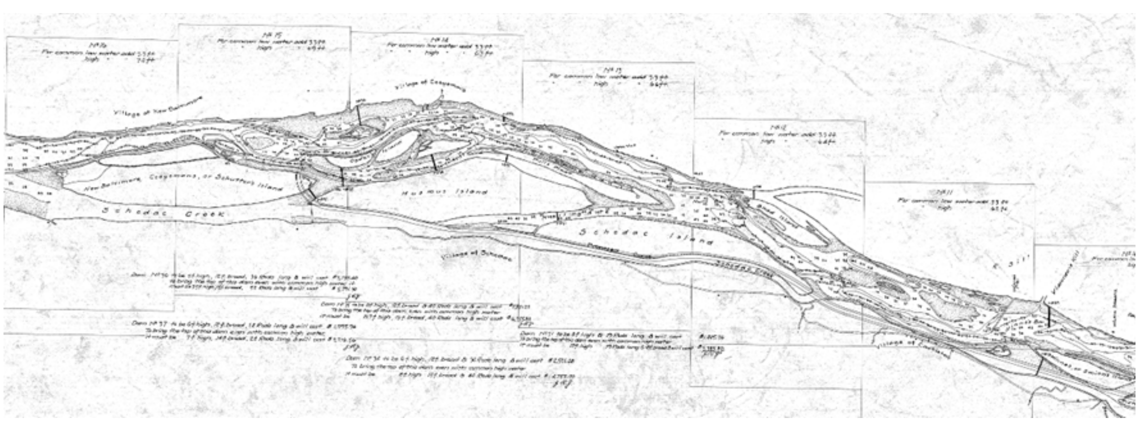
Brackish marshes, vegetated by non-woody plants that are salt tolerant, exist in the lower estuary but are uncommon.[16] Freshwater tidal marshes are common from the Bear Mountain Bridge north. They contain richly diverse wetland plant communities dominated by non-woody plants, often cattail *(Typha angustifolia)* and spatterdock *(Nuphar advena)*, with many other plant species present. Freshwater tidal swamps are highly diverse communities dominated by shrubs and/or trees, with diverse understories that can tolerate regular flooding.

Hudson River intertidal habitats also include extensive areas of non-vegetated mud and sand flats regularly inundated by water. Mudflats consist of finer grained sediments high in organic matter, giving rise to diverse invertebrate communities. Sand flats which have lower amounts of organic matter predominate in the upper estuary. Both are important feeding areas for wildlife, especially resident and migratory birds, including many species of wading birds, ducks and geese. Tidal flats also protect adjacent properties by dissipating wave energy and slowing the river's currents that can erode shorelines.

All of these intertidal habitats are vital components of the Hudson River ecosystem, providing habitat to a host of species, from diminutive plants no taller than a couple of inches, such as American water-wort (*Elatine* Americana) to small marsh fish, such as the banded killifish *(Fundulus diaphanus),* and to the largest predatory bird, the bald eagle, which thrives on fish from the Hudson.

Stresses on Intertidal Wetland Habitats

Construction of the federal navigation channel destroyed and degraded intertidal habitats in the upper estuary on a massive scale. As the main channel was deepened, dredge material was used to fill nearby shallows and intertidal areas, including side channels converting aquatic into upland habitat. As a result, the upper estuary from Catskill to Troy, NY was transformed from a shallow, braided river channel with many islands and backwaters, to a river dominated by a deep channel with far fewer intertidal wetlands and vegetated shallows.



This map from 1820 of the upper Hudson River estuary near Schodack shows many islands and side channels.

[16] Reschke, 1990.

Comparisons of historic and modern maps of the Hudson yield estimates that more than 1,300 acres of intertidal areas were lost in the upper third of the estuary alone.[17,18] Additional filling of many hundreds of acres throughout the rest of the estuary also occurred, especially along more urbanized sections of the lower estuary, where industrial and transportation infrastructure was built.

Current and future stresses on intertidal habitats include continued pressure from commercial and recreational activities, pollutant inputs from the watershed and accelerated sea-level rise associated with climate change. While several of these stresses are managed through regulations designed to protect habitats and programs to reduce pollutants, climate change and sea-level rise present new challenges for the river that will require additional efforts to protect these important habitats. As sea level rises, intertidal areas will be flooded by deepening waters. The intertidal wetlands are expected to either stay in place by building up sediments more rapidly, migrate inland and up where terrain and land use allow, or disappear into shallows that may or may not be vegetated. Scientists are studying marsh sediment cores to determine past sedimentation rates and patterns. In a few areas, scientists have begun to monitor current sedimentation rates using surface elevation tables. To minimize the net loss of remaining intertidal areas, "wetland buffers"—undeveloped areas with natural sloping shorelines—should be protected and restored to provide opportunities for intertidal habitats to migrate upland as sea level rises.

Shallow Water Habitats

Shallow-water habitats within the Hudson River estuary and tidal portions of its tributaries are defined as areas continuously submerged (or nearly so) and six feet deep or less at low tide (see figure 2). Submerged aquatic vegetation (SAV) communities are exclusively found in lower intertidal and shallow water habitats, primarily in the fresh water, northern portion of the estuary to the slightly brackish portions further south in Haverstraw Bay. Hudson River SAV beds are dominated by water celery *(Vallisneria Americana)*, a rooted, freshwater native plant.[19] Recent inventories of SAV (1997, 2002 and 2007) identified more than 5,000 acres of SAV in the estuary. SAV beds throughout the river play a vital role in improving water quality by increasing oxygen in the water[20] and producing food energy for the ecosystem. They also serve as essential feeding and refuge habitat for many species and life stages of fish, birds, turtles and invertebrate animals.[21] In addition, they play an important role in supporting the biodiversity and high densities of invertebrates in the Hudson River estuary,[22] such as worms and insects, and are thought to be the richest

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[17] Miller, et al., 2006A.
[18] Collins and Miller, 2011.
[19] Reschke, 1990.
[20] Findlay, et al., 2006, Caraco and Cole, 2002.
[21] Findlay, et al., 2006, Korschgen and Green, 1988.
[22] Strayer and Malcom, 2007.

feeding grounds in the estuary for many fish.[23] For reasons not yet understood, in some years, SAV beds disappear, returning in future years.

Stresses on Shallow Water Habitats

Submerged aquatic vegetation (SAV) is vital to the health of the estuary. It provides habitat for a host of small invertebrates and small fish which, in turn, provide forage opportunities for larger predators. The plants also play an important role in providing oxygen to estuary waters. (Photo: SAV Mapping Project)

Stresses on shallow water habitats are similar to those on intertidal habitats above. Construction of the navigation channel destroyed and degraded shallow habitats in the upper estuary on a massive scale. As the main channel was deepened, the dredge material was used to fill nearby shallows, intertidal areas and side channels. As a result, the upper estuary from Catskill to Troy, NY was transformed from a shallow, braided river channel with many islands and backwaters, to a river dominated by a deep channel with far fewer vegetated shallows.[24]

A comparison of historic maps and current conditions shows that more than 2,800 acres of shallow water areas were lost in the upper third of the estuary alone (Catskill to Troy). Additional filling of many hundreds of acres throughout the rest of the estuary also occurred, especially along more urbanized sections of the lower estuary, where industrial and transportation infrastructure was built to take advantage of navigation opportunities.

[23] Findlay, et al., 2006.
[24] Miller, et al. 2006A, Collins and Miller, 2011.

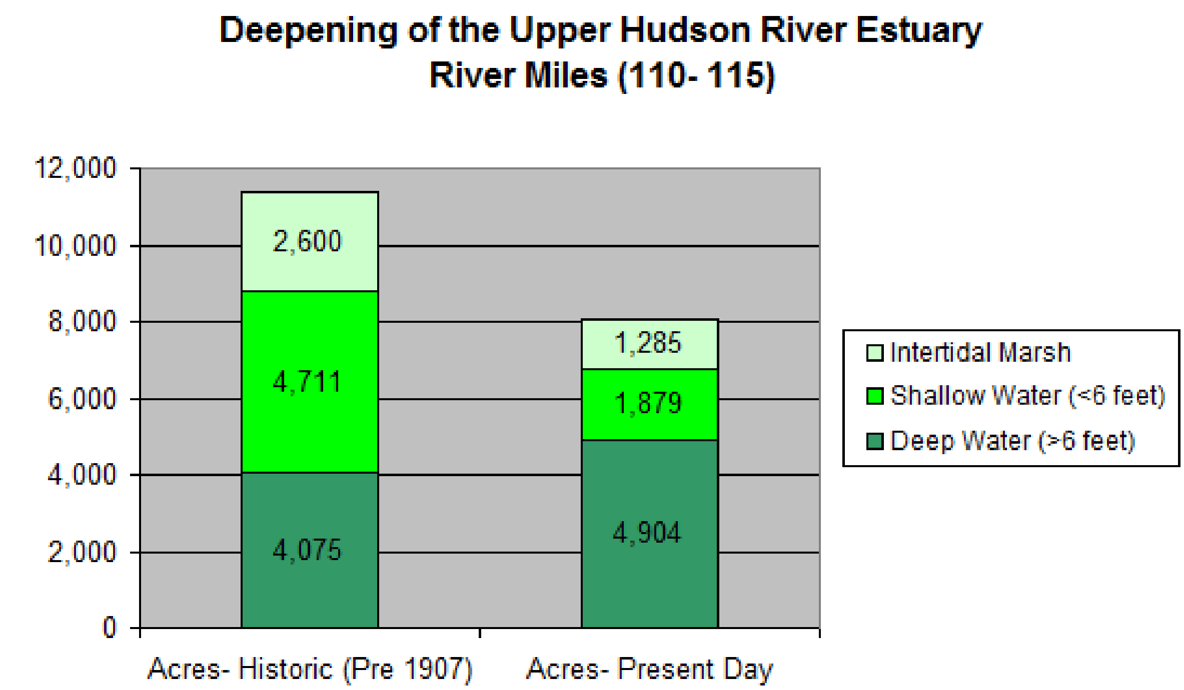


Figure 3: The chart above shows the historic and current amounts of intertidal, shallow and deep-water habitats in the upper Hudson River estuary (river miles 110 to 152). This portion of the river, which is important spawning and refuge habitat for fish and forage habitat for other species, was converted from a river dominated by shallow and intertidal areas to one that is dominated by deep water.

In the 1940s, the Hudson River was invaded by water chestnut (*Trapa natans*), a prolific non-native plant species that quickly overtook shallows in protected or semi-protected areas. Water chestnut is a rooted annual with long stems to support rosettes of leaves and flowers that float on the water surface and shade plants below. Water chestnut replaced native plants such as water celery in protected shallows and today occupies almost 2,000 acres of Hudson River shallows, from Hastings to Troy (river miles 33 to 152).[25] Unlike native vegetation, it reduces oxygen in the surrounding area and provides far less benefit to the food web.

Current and future stresses on shallow habitats include climate change and accelerated sea-level rise. Rising sea level will likely cause shallow-water areas to deepen, and reduce the amount of light that reaches submerged plant communities, in time causing the plants to die off. Projected increases in the severity of storms and flooding will also mobilize sediments, reducing the amount of light penetration to the beds, physically damaging or uprooting plants and burying some beds with sediment. Protection of intertidal areas that will become shallow-water habitat as sea level rises will help allow submerged aquatic vegetation to persist into the future.

[25] Cornell IRIS, 2011.

Shorelines

Shorelines along the Hudson River estuary are diverse. About half of the shorelines from Troy to the Tappan Zee Bridge are "natural," ranging from steep rock to shallow slopes. Some are unvegetated, while others support a mix of woody or grassy communities on mud, sand, cobbles or bedrock. The other half of the shoreline has been engineered with a variety of structures designed to protect property or support transportation, recreation or industrial activities. Common engineered shorelines include revetment, bulkhead, cribbing and riprap.

Developed shorelines, like this one near Troy, NY, provide access to large boats and can protect property and important infrastructure, but they are often poor habitat for fish and wildlife. (Photo: Carl Alderson, NOAA)

Many natural shorelines are vegetated with native or non-native plant species. Vegetation stabilizes shoreline, reduces wave energy and provides habitat for fish, invertebrates, birds, reptiles, mammals and amphibians. Natural shorelines with a gradual slope also enable a variety of animals to migrate between the riparian zone (banks and shores) and the estuary. Studies have found that natural sandy vegetated shorelines in the Hudson support high abundance of small fish species, while rocky shores support a high diversity of larger but fewer fish. The accumulation of wrack (natural debris) on shorelines with gradual slopes provides structure for a variety of organisms, including shelter for small animals and perching sites for birds. Vertical shores, particularly seawalls and bulkheads, support fewer plants and animals.[26]

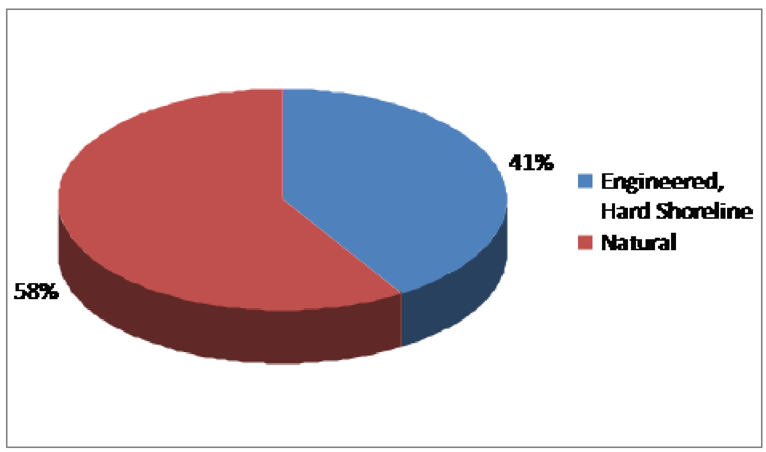


Figure 4: The image above shows the relative proportion of natural and engineered shoreline on the Hudson River between the Tappan Zee Bridge and Troy, NY. Nearly half of the shoreline is engineered, most of which is associated with railroad lines. (Source: NYSDEC)

Stresses on Shoreline Habitats

A significant amount of natural shoreline has been eliminated or altered over the past 200 years. Comparisons of modern and historic maps have estimated that 71 miles of shoreline

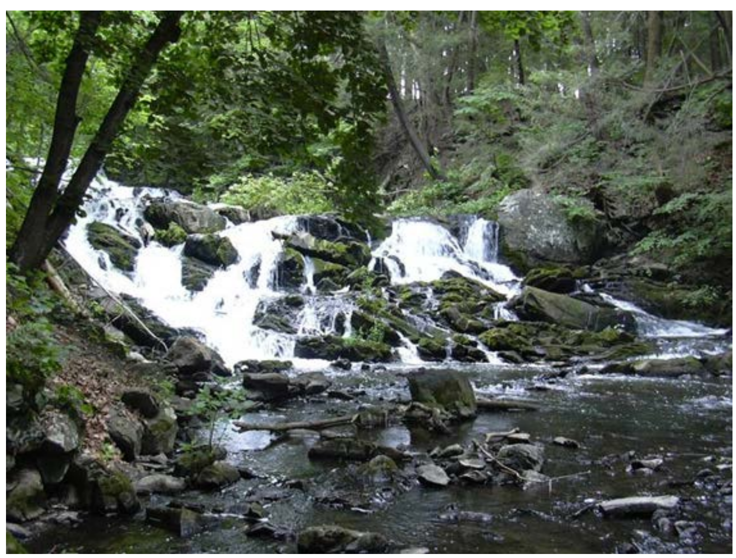
[26] Strayer and Findlay 2010; Strayer, et al., 2012.

in the upper estuary were eliminated when shallows and backwaters were filled during construction of the federal navigation channel.[27] In addition, many shorelines in the Hudson have been straightened and hardened to protect property from erosion or to create platforms for industry, transportation or cultural uses. An inventory of shoreline types by NYSDEC found that nearly half of the shoreline from the Tappan Zee Bridge to the Troy dam is engineered shore, meaning it has been altered by bulkheads, riprap, dikes, or other structures. Most of the engineered shore is associated with: railroad lines; dikes built in the upper estuary during the late 19th and early 20th century; and development of docks or shoreline erosion controls for riverfront communities and properties.

Current and future stresses on shoreline habitats include continued development pressures, direct impacts of climate change and sea-level rise and human response to climate change. Rising sea level and high-water events associated with severe storms threaten to alter or submerge existing shoreline habitats. They also threaten communities and infrastructure near or adjacent to the river. Communities may respond to the risks posed by sea-level rise and severe weather by constructing additional heavily engineered shoreline structures designed to stabilize the shore or to protect adjacent communities and infrastructure from flooding. Although they provide protection for property, some engineered solutions may severely degrade habitat. Land owners, regulators and policy-makers should consider using a combination of shoreline stabilization techniques, including "ecologically enhanced shoreline treatments" and strategies designed to minimize flooding and erosion risks while protecting or enhancing habitat.

Tributary Stream Habitats

Tributaries are important habitats for a diverse community of fish and wildlife throughout the Hudson River estuary watershed. They deliver water and transport nutrients and sediment from the surrounding landscape to the estuary while providing habitats for resident and migratory fish, including alewives *(Alosa pseudoharengus)* and occasionally blueback herring *(Alosa aestivalis)* and American shad.



These falls are near the mouth of the Saw Kill, a tributary to the Hudson River in northwest Dutchess County.

American shad and blueback herring typically migrate to and spawn in the main channels of the Hudson and Mohawk rivers.

[27] Miller, et al. 2006A, Collins and Miller. 2011.

However, most alewives migrate upstream and spawn in the Hudson's tributary streams.[28]
All three species have historically supported important commercial fisheries in the Hudson, although recent declines due to a number of factors, including habitat loss, ecosystem
change and overfishing, have resulted in fishery restrictions or closure. Herring and shad also historically supported robust cod fisheries on the Atlantic coast, because cod feed on them.

Dams create barriers to fish migration, including river herring and American eel. They also fragment habitats for resident species, degrade water quality and interrupt downstream sediment transport.

As a result of the Hudson River Valley's steep topography, the historic range of migratory river herring (alewives and blueback herring) in tributaries to the Hudson is limited, as are the dams that block river herring passage. However, American eel (*Anguilla rostrata*) have a greater range upstream in tributaries due to their remarkable ability to climb steep gradient streams. After hatching in the central Atlantic Ocean near Bermuda, young eels migrate to coastal estuaries, including the Hudson River.[29] Eels continue their migration up the Hudson's tributaries, where they find fertile and productive habitats throughout the estuary watershed and mature for up to 20 years before returning to the mid-Atlantic Ocean to spawn.

Culverts are used to pass streams and tributaries under roads or other developed properties. If not properly designed and installed, they can disrupt fish and wildlife movement and wash out during floods. (Photo: Carl Alderson, NOAA)

Stresses on Tributary Habitats

Many habitats historically used by herring and eels are no longer accessible due to construction of hundreds of dams originally designed for many purposes, including hydropower for mills and industry, irrigation and recreation. Access to habitat for American eels

[28] Werner, 1986.
[29] Smith, 1985.

has been greatly reduced by the construction of dams in New York State, possibly contributing to recent declines in eel populations.[30]

Dams also disrupt the natural flow of water, sediment and nutrients downstream. As a result, water temperature increases and available oxygen decreases, impacting the fish and invertebrate communities that live in a stream. Impoundments created by dams trap sediment, disrupting the supply to shallow areas and wetlands downstream.[31] To restore fish passage, removal of dams wherever possible is preferred over installing fish ladders because of the additional benefits of restoring in-stream habitats, sediment and nutrient transport processes and water quality. In addition to dams, hundreds of culverts have been installed where streams and waterways cross under roads or other infrastructure. Culverts improperly sized or "perched" above the natural streambed can be impassable to migratory and resident species, fragment stream communities and disrupt stream processes. Replacing them with properly sized and positioned culverts and bridges is important.

Impacts of Exotic and Invasive Species

In addition to the physical alterations and destruction described above, nearly all habitats in the Hudson River estuary ecosystem have been affected by the introduction of exotic and invasive plant and animal species. These species have significantly impacted the function of the estuary and the native species that inhabit it in a variety of ways. In marshes, the invasive common reed *(Phragmites australis)* is capable of displacing native vegetation communities with dense single-species stands, altering nutrient cycles and habitats for marsh animals. Water chestnut covers large areas of shallows in the freshwater Hudson with thick dense mats that can reduce oxygen and light levels in the water and degrade habitats.[32] One of the most dramatic invasions has been the zebra mussel *(Dreissena polymorpha)*, starting in the early 1990s. After introduction, the small mollusks quickly spread throughout the freshwater portion of the estuary, attaching to hard surfaces such as rocks, pilings, boat hulls and water intakes. Zebra mussels feed on microscopic plants and animals (plankton) and other small particles by filtering a tremendous amount of river water. At the height of their population, zebra mussels reduced the amount of phytoplankton in the river by 80 percent and the amount of food available to fish by 50 percent.[33] This caused shifts in fish communities and likely contributed to the decline of some species. Loss of phytoplankton as a source of food energy for the ecosystem has made other sources of energy more important. The SAV in shallow areas of the upper Hudson estuary played an increasingly important role for fish that live in shallows following zebra mussel invasion. Open water young-of-the-year fish moved downstream where zebra mussels were less abundant.[34]

[30] Busch, et al., 1998; Machut, et al., 2007.
[31] Ligon, et al., 1995.
[32] Caraco and Cole, 2002; Hummel and Findlay, 2006.
[33] Strayer, D. L., 2009.
[34] Strayer, et al., 2004.

The Hudson River was the site of the earliest recorded introduction of common carp (*Cyprinus carpio*) to North America. In 1831, several carp were swept into the Hudson from ponds between Newburgh and New Windsor when dams and floodgates failed during a heavy freshet (rains and snow melt).[35] The fish established a breeding population and are now found throughout the freshwater portion of the river, where they uproot submerged aquatic vegetation and decrease water clarity as they root through sediments in search of food.

Once introduced and established, exotic and invasive species can be extremely difficult to control or eradicate. Therefore, early detection of newly introduced species before they become established and concerted efforts to prevent new introductions are essential. Where feasible and ecologically justified, efforts to control species already introduced to the ecosystem can be an important part of habitat restoration.

REGIONAL RESTORATION PRIORITIES

Regional differences in the natural landscape and history of human development are found along the length of the estuary shoreline. These factors result in different restoration opportunities within different regions of the Hudson. Restoration actions described later in this plan may not apply equally to all regions of the estuary. For example, freshwater tidal and shallow habitat restoration will be a priority in the upper regions of the estuary, where these habitats historically occurred in large proportion to deep water and were lost when the navigation channel was constructed. Figure 5 shows typical restoration opportunities by region within the estuary.

[35] Lever, 1996.

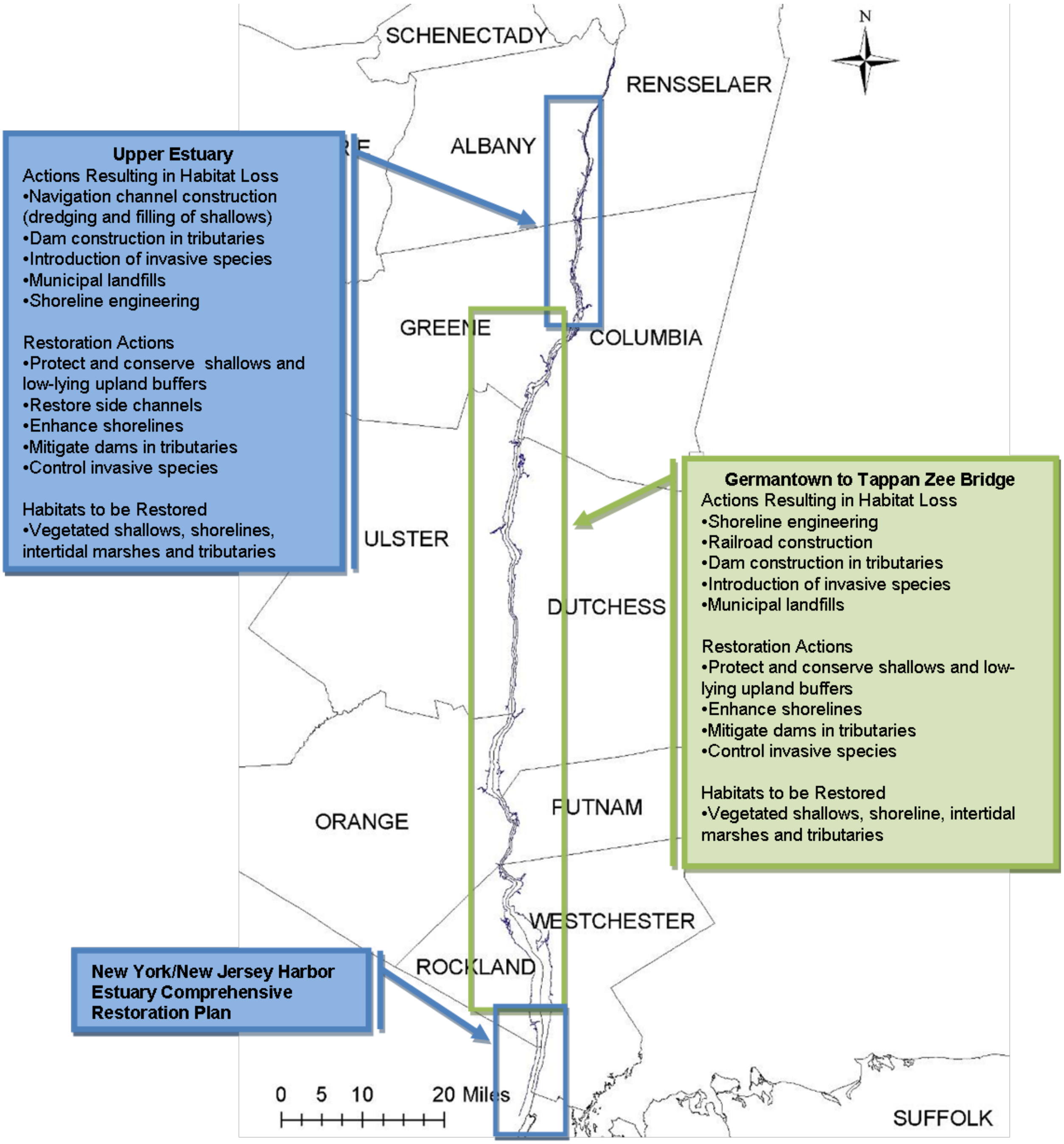


Figure 5. Regional Human Influences on Hudson River Habitats and Proposed Restoration Actions

IV. RESTORATION VISION AND ACTIONS

ENVISIONING A MORE RESILIENT AND HEALTHY HUDSON RIVER ESTUARY

This restoration plan envisions the future of the Hudson River estuary as a resilient ecosystem that provides a wide range of benefits to the fish, wildlife and residents of the region through increases in the amount and value of intertidal, shallow and shoreline habitats, improved accessibility to tributary stream habitats for migratory fish and ecological enhancements to the Hudson's engineered shorelines.

DEFINITION OF RESTORATION

The Society for Ecological Restoration (SER) is a non-profit membership organization dedicated to promoting ecological restoration to sustain the diversity of life on Earth and re-establish an ecologically healthy relationship between nature and culture. SER serves the growing field of restoration by promoting and supporting the work of researchers and practitioners; disseminating guidance and best practices; increasing awareness of, and public support for, restoration; and contributing to policy discussions at the national and international level. SER defines restoration in the following way:

"Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed."[36]

Habitats and ecosystems are constantly evolving and changing over time. The goal of restoration is not to re-create a single unchanging set of desirable conditions for a habitat. Rather, the goal of restoration is to remove the stresses that inhibit a habitat from functioning and evolving on a natural path or trajectory. This can include a wide range of activities, from preserving existing habitats to fostering natural recovery or actively removing or mitigating a stressor that is preventing an ecosystem or habitat from reaching its full health and potential. The restoration actions listed in the next section will promote the recovery of priority habitats by eliminating or mitigating stresses that have been placed on the ecosystem over the past 200 years. This plan also recognizes many opportunities for taking actions to reduce the impact of or help offset future stresses on the estuary. Central among these is the protection of in-river habitats and the shoreline and estuary floodplain, all vital to maintaining and restoring the Hudson River estuary's resiliency as climate changes and we experience more storms, higher temperatures and accelerated sea-level rise. On a more regional scale, conservation of natural resources in the watershed is also important.

RESTORATION ACTIONS

Despite the pervasive impact of human activities throughout the Hudson River estuary, many opportunities for restoration remain. Estuaries and freshwater systems by nature are dynamic. Plants and animals in these systems have adapted to live in an environment with natural variation in water quality, temperature and other environmental conditions. Because of this resilience, estuarine and freshwater systems are predisposed to restoration

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[36] Society for Ecological Restoration, 2004.

and enhancement of degraded habitats. In many cases, restoration requires removal of the mechanism(s) or stresses degrading or destroying a habitat. Restoration may include reestablishing natural water flows by removing a dam or fill, altering nutrient inputs or restoring wetland elevations.

Several factors determine readiness to implement restoration actions and restore habitats described in this document, including availability of restoration sites, technical feasibility, current state of knowledge, cost, regulatory issues and public support. In some cases, restoration opportunities will restore several habitat types with a single action. For example, restoring side channels to the upper estuary will result in restoration of natural shoreline, intertidal marsh and vegetated shallows. These types of projects should be seen as high value because of the multiple benefits that could result from a single action. Table 1 shows proposed restoration actions and their potential benefits to habitat.

Table 1: Hudson River Estuary Restoration Actions and Benefits to Priority Habitats

Restoration Actions	Priority Habitats for Restoration			
	Intertidal Habitats	Shallow Habitats	Shorelines	Tributary Habitats
Protect and conserve existing estuary habitats	X	X	X	X
Restore side channels	X	X	X	
Promote and implement construction of fish passage (FP) structures, dam removal (DR) and culvert right-sizing & placement(CRS)	DR, CRS	DR		DR, FP, CRS
Promote and implement use of ecologically enhanced shoreline treatments	X	X	X	
Implement programs to control invasive plant species	X	X	X	

Climate Change Considerations

To restore and sustain the Hudson's estuarine habitats, it is essential that restoration planners and practitioners plan for changing sea-level conditions. Both short-term restoration methods and long-range conservation strategies must adaptively factor these trends into restoration, conservation and preservation planning and implementation. Ultimately, action to reduce carbon in the atmosphere will slow the rate of sea-level rise and must be a companion strategy.

Protect and Conserve Existing Estuary Habitats

Conservation of existing habitats and their environmental function is essential to the success of this restoration plan. Ecosystems that have evolved over long periods are complex and only partially understood by natural resource managers. It is reasonable to presume that restoration of a habitat, no matter how successful, will not achieve the level of ecosystem health and function present in similar, naturally occurring protected habitats. In addition, the cost of restoring a degraded habitat can greatly exceed the cost of protecting a similar habitat currently in good condition.

There are many ways to protect and conserve existing habitats. Federal, state and local laws and regulations are important tools used by regulatory agencies to conserve and protect habitats. Environmental Conservation Law NY ECL Part 608, "Use and Protection of Waters" regulates activities that alter or disturb streams and navigable waters within the state. Articles 24 and 25 establish permit programs intended to regulate and protect freshwater and tidal wetlands, including those in the Hudson River estuary. Several recent mapping efforts have identified the current extent of these habitats in the estuary. Enforcement of existing laws designed to protect theses habitats is essential to restoration efforts and, therefore, the success of this plan.

Protection of existing habitats can also be achieved through purchase of development rights, conservation easements and adoption of local land use laws that identify and conserve important and sensitive environmental areas.

Protection and conservation of existing habitats such as Hallenbeck Creek in Columbia County is the least expensive, most reliable form of restoration

Near-shore aquatic areas and uplands adjacent to shorelines are key to healthy riverine and estuarine systems. Many nutrient-cycling and chemical processes that maintain water quality and habitat value in the river occur at these locations as well as in the larger watershed. Shorelines of the Hudson and its tributaries are also where development pressure can be intense. Access to the river has been an important part of the economic development of many municipalities and is also an important recreational and scenic resource. The economic and social needs of shoreline communities must be balanced with the important environmental functions these areas provide. Additionally, rising sea levels associated with climate change will cause low-lying areas adjacent to the estuary to become vulnerable to inundation. Protecting low-lying uplands and encouraging development at higher elevations will reduce the possibility of future economic loss because of damage to infrastructure and property due to sea-level rise or intense storms, such as Irene and Lee in 2011 and Sandy in 2012. Protection of natural shorelines and low-lying areas adjacent to the river will also keep lands available where wetlands can migrate, allowing these natural communities to persist into the future.

Conserving natural areas surrounding tributaries and restoration of riparian buffers in the watershed are important to maintaining water quality, managing sediment transport to the estuary and minimizing risk to human communities during intense storms or spring snow melt. Because of the links between healthy flood plains and riparian buffers to healthy Hudson River ecosystems, this plan supports flood plain protection and riparian habitat restoration efforts such as the Hudson River Estuary Program's Trees for Tribs program.

Restore Side Channels

Restoration of side channels in the upper Hudson River estuary will be a challenging task, requiring removal of dredge material, establishment of native vegetation and creation of conditions that support high biodiversity and productivity of native plants and animals. Side channel restoration will return uplands created by dredge material deposits back to aquatic habits and contiguous backwater habitats into side channels. Side channel restoration will increase the amount of forage, refuge and reproductive habitats for resident and migratory fish, birds, invertebrates and other estuarine life. Those evaluating opportunities to do so must consider existing infrastructure, access, sediment disposal and effects on current species usage, including protected plant and animal species, upland habitats, property ownership, river-wide sediment budgets, probability of success and cost.

The construction of side channels to restore priority habitats identified in this plan has unique advantages that increase the potential benefit and likelihood of project success. The advantages include:

- *Multiple Habitat Benefits* - Side channel restoration will incorporate restoration of at least three of the priority habitats identified in this plan that have been lost on a significant scale due to construction of the federal navigation channel: shallows, intertidal marsh and shorelines. These habitats are known to be highly productive spawning, nursery and feeding habitats for resident and migratory species such as American shad and striped bass, as well as many birds, mammals and reptiles.

Hallenbeck Creek (on right) in Columbia County, NY is one of the last remaining side channels in the upper Hudson River estuary. It will serve as a reference site for restoration of these important fish and wildlife nursery and refuge areas. (Photo: NYSDEC)

- *Important Forage and Refuge Habitat Restored* - Side channels have been virtually eliminated from the upper estuary in an effort to constrict water flow to the main channel. These backwater areas are less exposed to high-energy regimes of the main navigation channel and will act as moderate velocity, high-biodiversity refuges for a variety of aquatic plant and animal species, especially during high-flow periods associated with extreme rainfall.[37]
- *High Degree of Design Control* - Channel width, capacity, location and morphology can all be designed to create optimal conditions for native plant and animal communities to thrive in the restoration site.
- *Restoration Site Protection* - Side channels will be protected from extreme energy regimes in the main channel, including: high water velocity, ice scour, large wind-driven waves and wakes caused by commercial and private boat traffic. Floating booms installed at both ends of the channel will keep motorized boats out during construction and recovery.
- *Undeveloped Sites Available* - Restoration sites could include locations where historic side channels have been filled, or channels could be constructed in wide areas of fill adjacent to the main channel. These sites may not represent a historic condition, but they would restore a historic structural element of the ecosystem that has been lost. Many of these locations remain undeveloped and are owned by state agencies.

Climate Change Considerations

Restored side channels will primarily consist of shallow and intertidal habitats. These habitats will be particularly vulnerable to sea-level rise. With sufficient space available, restoration sites could be designed to include low-elevation areas surrounding the sites to allow shallow and intertidal habitats to migrate as sea level rises.

Tivoli North Bay, Dutchess County - Backwaters and side channels are refuge areas for fish and wildlife and provide recreational opportunities for canoeists and kayakers seeking refuge from strong currents, wind and traffic that can occur in the main channel. (Photo: NYSDEC)

Expected Benefits

Side channels are typically less deep and have lower water velocities than the main channel and can be important refuge areas for juvenile fish.[38] Larval and juvenile American shad may select eddies and backwater areas where water flow is reduced.[39] In addition to serving

[37] McMahon and Hartman, 1989; Bowen, et al., 2003.
[38] McMahon and Hartman, 1989; Bowen, et al., 2003.
[39] Crecco and Savoy, 1987.

as refuge for juvenile fish, side channels can also serve as overwintering habitat and/or provide a refuge from major flood events for a variety of aquatic species.[40]

Side channel restoration and the resulting restoration of shoreline, intertidal and shallow habitats would restore the historic functional contributions these habitats provided to the ecosystem. By restoring lost intertidal habitat and its associated biota and functions such as primary production, nutrient and contaminant uptake, bird habitat, and forage fish refuge, sediment stabilization and trophic web dynamics will be restored. Intertidal wetland restoration has the potential to increase habitats for rare or endangered plant species that are restricted to the types of tidal habitats found in the Hudson. If restored on a large enough scale, these functions would have positive, meaningful effects on water quality, fish stocks and bird and amphibian populations.

In addition to their primary functions, including providing refuge from high-energy environments for fish and wildlife, side channels and backwaters could provide similar refuge for people enjoying the river experience. If side channels are restored in the Hudson River, regulatory agencies should consider maintaining them as no-motor zone, important environmental areas. Kayakers and canoeists could use these areas as refuge from the natural winds and currents of the main channel. Restored side channels would also provide a safe and enhanced natural experience, away from commercial shipping and recreational powerboat traffic, for angling, birding, nature study and other passive recreational activities. Restored side channels of the upper Hudson River estuary could become an eco-tourism destination that highlights the State of New York's commitment to environmental stewardship while supporting the region's tourism industry.

Promote and Implement Construction of Fish Passage Structures, Dam Removal and Culvert Right-Sizing and Placement

Restoration of tributary habitats will focus on human-made barriers that block migratory fish from reaching historically accessible habitat, disrupt natural stream processes and degrade water quality. The environmental impact of dams and culverts varies greatly, depending on size, design and location. Each restoration action, including removing dams, installing fish passage structures and culvert right-sizing and placement, has a unique set of environmental benefits and limitations. Descriptions of each action and its potential benefits are below.

Removing Dams

Dam removal provides more comprehensive restoration benefits than installing a fish ladder. Removing dams in tributaries to the Hudson would improve water quality, defragment habitat, allow for resident and migratory fish movement,[41] and restore sediment transport regimes that support tidal wetland creation and accretion in the estuary.

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[40] Saldi-Caromile, et al., 2004.
[41] Ligon, et al., 1995; Stanley and Doyle, 2003.

Intertidal marshes and shallows are often found at the mouths of tributaries where they meet the Hudson. It is likely that some of the sediment for these shallows is supplied by the tributary entering the Hudson, much like a river creates a delta where it reaches a bay. Removal of dams and restoring downstream sediment transport regimes could restore sediment supply for building and maintaining shallow habitats where tributaries meet the river. However, in some cases, sediments that have accumulated behind dams could contain contaminants. Identification and management of contaminated sediments must be considered on a site-by-site basis. Additional research is needed to determine the role of dams in sediment transport in tributaries to the Hudson.

Installing Fish Passage Structures

At locations where dams are barriers to migratory fish (river herring or eels) and dam removal is not a viable option, fish passage structures such as fish ladders, rock ramps, or fish weirs can be used to restore fish migration to historically accessible habitats. Dams actively managed for water supply, power generation or flood control, or that have historic significance may be candidates for installation of fish ladders.

Volunteers remove eels from an eel ladder at the base of a dam on Crum Elbow Creek in Hyde Park, NY. (Photo: NYSDEC)

Experimental eel ladders have been successfully installed in the Saw Kill and Crum Elbow Creek in Dutchess County and in Furnace Brook in Putnam County. These low-cost, low-maintenance eel passage devices are effective in capturing small eels at the base of dams, where they can be passed to upstream waters by local project partners, including community and school groups or local activists. Because of the biology of American eels, providing passage would not restore spawning habitat. Instead, it restores access to habitats used while the eels grow and mature. Restoring access to these habitats will help increase the production of mature individuals leaving the Hudson as they migrate to the Atlantic Ocean to spawn, supporting the future of the stock.

Culvert Right-Sizing and Placement

Opportunities to restore habitat connectivity and access for migratory fish are not limited to dams. Many streams contain numerous culverts, where they intersect with built infrastructure such as roads, bridges and causeways. "Perched" culverts discharge water above the natural streambed, creating a small drop or step that can be impassable to migratory and resident species. In addition to the risk of failure and being displaced during high-flow events, undersized culverts can create velocity barriers to fish passage (water flows that are too fast and without rest areas for fish to swim upstream). Culverts should be evaluated for corrective actions, including increased size, repositioning and bridge replacement that address potential problems such as restricted flow, incorrect slope, inadequate light, and unsuitable bottom substrate. New York State provides guidelines, and standards are available and should be reviewed when planning a project to redesign and construct stream crossings.[42]

Culvert right-sizing and placement and removal of other human-made flow restrictions can also be used to increase tidal flushing in impounded tidal freshwater wetlands, resulting in improved water quality, control of invasive species and increased interaction with the main river channel.

Climate Change Considerations

Rising sea level associated with climate change will require shallow and intertidal habitats to build up with additional sediments to maintain their position in the water column and to insure their continued existence. Removal of dams and restoring downstream sediment transport regimes could supply a portion of the additional sediments needed to enable some of these important habitats to persist during accelerated sea-level rise. In addition to the restoration benefits, removal of derelict dams will have a positive effect by eliminating existing environmental hazards. Continued aging and degrading of dams in the watershed, coupled with the likelihood of increased and more intense precipitation associated with climate change, suggest that the rate of dam failures will increase in the future. Already, three candidate dam removal sites (Claverack Creek, Moodna Creek, and Quassiack Creek) have breached during recent storms. Controlled removal of dams is more desirable than uncontrolled breaching. Safety concerns, including downstream flooding and sudden uncontrolled release of sediments (possibly contaminated), can be addressed during controlled removal projects.

Expected Benefits

The benefits of dam removal, culvert right-sizing, and fish passage include restored access to migratory fish spawning habitats, such as for river herring, and restored access to habitat for American eels. These actions as well as others to conserve tributaries, such as flood plain protection, creation of stream buffers and commitment to streamside plantings, will result in improved water quality, restored stream communities, restored sediment transport regimes and elimination of property and natural resource hazards.

[42] http://www.dec.ny.gov/permits/49066.html

Promote and Implement Use of Ecologically Enhanced Shoreline Treatments

The Hudson River estuary presents some unique challenges to soft shoreline engineering. Shoreline along the upper portion of the estuary is subject to intense scouring produced by fast currents during storms, large ice floes driven in two directions by incoming and outgoing tides and wakes from recreational boats and ocean-going ships. Creating shoreline that is resistant to erosion and is habitat friendly may be difficult in some areas. In areas where the hard shoreline no longer serves an economic purpose, restoration of a naturally dynamic shoreline may be an option. In areas where shoreline stabilization is necessary to protect waterfronts or retain dredge material, shoreline enhancement through developing "ecologically enhanced, engineered shoreline" structures should be explored.

An "ecologically enhanced, engineered shoreline" was built in Coxsackie, NY. The shore included a series of terraces made of stone and plantings. The shoreline was designed to protect a public parking lot while enhancing shoreline and river habitats.

Ecologically enhanced, engineered shorelines are designed to protect property but also have design components that provide habitat and ecosystem functions similar to natural shorelines. They are often called "living shorelines" because many incorporate vegetation that provides structural stability and habitat value to the engineered structure.[43] Several methods have been used in a variety of coastal and stream systems. NYSDEC's Hudson River National Estuarine Research Reserve has been leading the Hudson River Sustainable Shorelines Project—a collaborative, science-based effort to identify shoreline treatments that protect property while providing habitat for fish, birds and invertebrates that live in natural shoreline habitats. The effort accounts for short- and long-term costs, human needs, habitat value and structural stability during current conditions and predicted conditions associated with climate change and sea-level rise.

Several alternatives for soft shoreline practices that may be applicable to Hudson River estuary shorelines have been identified.[44] Site-by-site evaluation is needed to determine which alternative is appropriate for an individual site. Evaluation should include structural needs to protect property, opportunities to enhance and protect habitat, community needs, and the effects of sea-level rise on the shoreline and near shore areas. For more information see:

http://www.hrnerr.org/hudson-river-sustainable-shorelines/

[43] NOAA, 2013
[44] Rella, A. and J. Miller. 2012a and Rella, A. and J. Miller, 2012b

Expected Benefits

Shorelines are important to the health of the estuary and the people of the Hudson River Valley. Protection of existing property and infrastructure and redevelopment of historic industrial shorelines create opportunities to enhance human use of the river and to protect and restore habitat. Using "ecologically enhanced, engineered shoreline" practices can result in municipal shorelines that incorporate design features that serve multiple community needs (e.g., river access, protection of property) while protecting or enhancing habitat.

Alternative shoreline treatments that stabilize shoreline but retain or enhance habitat quality for fish, invertebrates and aquatic plants will minimize the impacts of development and necessary shoreline protection projects. A natural, soft shoreline with a low sloping incline, vegetated with native upland and intertidal plants, will reduce wave energy and provide stable habitat for fish, invertebrates, birds and amphibians. A natural shoreline also facilitates interaction between upland habitats and the estuary, allowing land animals to interact with the estuary. Additionally, soft or living shorelines also are self-maintaining, often costing less to maintain in the long term than hard shorelines.[45]

Implement Programs to Control Invasive Plant Species

Invasive species can be harmful to native plant and animal communities. When introduced, they often displace native species, alter habitat and disrupt natural ecological processes. Invasive plant and animal species are found throughout the Hudson River estuary watershed. While they can be found in relatively pristine areas, habitats that have been altered or disturbed in some way are particularly vulnerable. Therefore, restoration of conditions that support native species over invasive species should be considered where appropriate as another method of invasive species management. Where restoration of historic conditions is not practical, control and management methods, including mechanical removal, bio-control and application of herbicides, are considered. Determining the best strategy or combination of strategies to manage invasive species should be evaluated on a case-by-case basis.

Strategies used to manage invasive species include:

- Prevention of new introductions
- Early detection and control, before invasive species become established and widespread
- Long-term containment, control and eradication of established invasive species
- Manipulation (restoration) of environmental conditions favoring native over invasive species

[45] Caulk, et al., 2000.

Prevention and Early Detection of Invasive Species

Many exotic and invasive species have been introduced and have become a permanent part of the Hudson River estuary ecosystem, often to the demise of native species.[46] Control or eradication of alien or invasive species can be difficult, costly and unreliable.[47] Therefore, preventing the introduction of an exotic and known invasive species is often the best and only way to protect an ecosystem from potential undesirable effects.

Creating a healthy and resilient future for the Hudson River estuary depends on successful implementation of the actions in this plan. However, additional efforts outside the scope of this plan, including identifying and preventing introductions of new invasive and exotic species, are equally important to achieving that goal. Regulatory agencies and all Hudson River estuary stakeholders should partner to take actions to prevent known invasive threats from becoming established in the Hudson River. These include mitten crab, snakehead (fish) and emerald ash borer. Future concerns include Asian carp, hydrilla, and other invasives.

An area in Tivoli North Bay, Dutchess County was previously dominated by invasive *Phragmites*. In 2006, this area was treated with herbicides. Three years later, cattails and other native marsh plant communities have recovered.

Control of Invasive Strains of Common Reed (Phragmites australis)

Using herbicides to control *Phragmites* in tidal marshes has been underway at the Tivoli Bays Wildlife Management Area in Dutchess County, Stockport Creek Wildlife Management Area in Columbia County, Ramshorn Marsh in Green County and at the Iona Island in Rockland County, NY. Herbicides containing glyphosate have been used at each site to kill *Phragmites* and allow native vegetation to recover. Recovery of native vegetation is being monitored at all sites. Early results from these control experiments have demonstrated that although complete eradication of *Phragmites* has been difficult to achieve, native plant communities have recovered vigorously within the treatment areas. Continued maintenance of the sites requires far less effort than needed at the beginning of the projects, and the prospect of complete eradication remains a possibility.

Although some success controlling *Phragmites* has been achieved in isolated Hudson River marshes, there needs to be continued evaluation of the use of herbicide as a control method as well as the role of *Phragmites* as a marsh plant community in an ever-changing climate and ecosystem. An abundance of caution must be exercised in decisions to use an

[46] Strayer, et al., 2005.
[47] Strayer, et al., 2005.

application of herbicide to protect non-target species and surrounding communities. Continued evaluation of long-term effects of specific herbicides on the environment is recommended to inform future decision-making and refine the methods of using herbicides to improve project outcomes and minimize risks.

Alternatives to herbicides for controlling *Phragmites* should also be explored. Experimental control of *Phragmites* has been implemented by managers of Constitution Marsh near Cold Spring, NY. Small *Phragmites* stands were cut down, and black plastic was used to cover the area in an attempt to kill any remaining living plant material. As with all invasive control methods, including application of herbicides, annual monitoring and maintenance is required for several years before project success can be determined.

Control of Water Chestnut (Trapa natans)

Control of water chestnut will be a component of some side-channel restoration projects. Low-energy contiguous backwaters have been identified as candidate side-channel restoration sites. In their existing condition, these sites are dominated by water chestnut during the summer growing season. Restoration/creation of side-channel conditions at these sites will need to alter flow regimes to encourage the reduction of water chestnut and the return of native submerged aquatic vegetation.

Water chestnut (*Trapa natans*) covers shallow, low-flow areas of the Hudson River. The water's surface in Tivoli South Bay is not visible through the invasive plant in late summer.

Climate Change Considerations

Climate change and anticipated sea-level rise will alter the roles of many plant species in the Hudson River estuary ecosystem. The role of plant communities, including invasive species, in building up marshes as sea level rises may affect invasive species management goals. For example, *Phragmites* is known to build up marshes more quickly than native vegetation. Therefore, the existence of *Phragmites* may contribute to conservation of Hudson River tidal marshes, requiring the need to re-evaluate *Phragmites* management goals. At the same time, this must be balanced with the goal of maintaining native biodiversity, which may be lost as a result of *Phragmites* invasion.

Expected Benefits

Benefits from invasive species control include maintained or increased biodiversity, increased productivity and restoration of native communities. In the case of eliminating water chestnut in side-channel sites, water quality improvements will improve fish habitat, provide forage opportunities for predatory fish and birds and provide open water refuge for waterfowl.

RESTORATION GOALS (Target Ecosystem Characteristics)

This habitat restoration plan identifies priority habitat types for restoration based on a number of factors, including their important role in maintaining ecosystem health, a history of loss or degradation, and the availability of feasible opportunities to restore. Following the publication of this plan, NYSDEC and its Estuary Program partners will begin to develop more specific, quantified objectives for restoring each habitat type and milestones for doing so (how much by when?). Identifying these goals will require assessment of technical feasibility, availability of potential restoration sites, and the latest understanding of the ecology of the Hudson River to determine how much restored habitat is needed to improve the health and productivity of the river.

The process we will use is similar to the one developed for the *Hudson-Raritan Estuary Comprehensive Restoration Plan* (HRE/CRP), organized by the Hudson River Foundation as part of a collaborative effort for the United States Army Corps of Engineers (USACOE) and several other federal, state, and local government and non-governmental partners. The effort resulted in the document, *Target Ecosystem Characteristics for the Hudson Raritan Estuary: Technical Guidance for Developing a Comprehensive Ecosystem Restoration Plan*, containing 11 specific, measurable Target Ecosystem Characteristics (TECs) that serve to guide the *Hudson-Raritan Comprehensive Restoration Plan* for areas south of the Tappan Zee Bridge.[48] A similar process can be used for the area north of the Tappan Zee Bridge, addressing the unique conditions and opportunities of the more freshwater reaches of the estuary, and result in opportunities for implementation of restoration projects throughout the entire estuary by state, federal, local and non-governmental partners.

TECs will address a broad set of issues from ecosystem functions to human use and access. They will be developed using a collaborative, science-based process similar to the efforts in the *Hudson-Raritan Plan*. For more information on TECs and their development, please see:

http://www.harborestuary.org/reports/TECReport07.pdf

V. IMPLEMENTING RESTORATION PROJECTS

RESTORATION PRINCIPLES

Restoration projects can be complex and challenging. Restore America's Estuaries (RAE), a non-governmental organization that supports estuarine restoration efforts throughout the coastal United States, has published *Principles of Estuarine Habitat Restoration*, containing 14 principles intended as a guide for all types of restoration activities, including large-scale and community-based restoration projects. The principles focus on science-based decision-making, public involvement, project goal setting and success evaluation. The principles can be found in Appendix B and are available online at:

[48] Bain, et al. 2007.

http://www.estuaries.org/principles-of-estuarine-habitat-restoration.html

This *Hudson River Estuary Habitat Restoration Plan* also adopts by reference the more detailed guidance on the restoration process developed by the Society for Ecological Restoration (SER), found in the following two publications:

- *The SER Primer on Ecological Restoration* (2004)
- *Guidelines for Developing and Managing Ecological Restoration Projects* (2005)

The SER Primer on Ecological Restoration defines restoration, the role of restoration in natural resource management and the many terms associated with the restoration process. The *Guidelines* publication provides a practical 51-step process intended to guide restoration practitioners and managers through individual restoration projects, consistent with *The SER Primer*.

Both publications and other resources for implementing ecological restoration can be found at: http://ser.org/resources

THE RESTORATION PROCESS AND ADAPTIVE MANAGEMENT

The goal of restoration is to improve the ecological conditions of a restoration site or ecosystem. This plan proposes to do that by focusing on removing or mitigating stresses placed on priority habitats in the Hudson River estuary ecosystem. To understand the relationships between restoration designs and results and to determine whether a restoration is successful, project managers must have an in-depth understanding of the habitats before, during and after restoration. In addition to evaluating project success, an equally important goal of the restoration process is to learn as much as possible from each project and then apply those lessons to improve future restoration attempts. The process of continuously refining management techniques based on lessons learned from previous and ongoing actions is known as "adaptive management." The United States Geologic Survey identifies adaptive management as:

"…a systematic approach for improving natural resource management, with an emphasis on learning about management outcomes and incorporating what is learned into ongoing management."[49]

The restoration process includes several steps that identify baseline conditions, develop and implement management actions, then evaluate success and apply lessons learned to modify existing or future restoration actions. Therefore, the restoration process outlined below is a framework for incorporating adaptive management into restoration projects.

The diagram below shows five general steps in the restoration process:

[49] http://www.usgs.gov/sdc/adaptive_mgmt.html

1. Feasibility Study and Baseline Data Collection - Project managers collect environmental data from the restoration site and a reference site (if available) to identify project goals, design appropriate and feasible alternative actions for meeting goals and develop a monitoring system for measuring success. Collection of baseline data is essential to the process of understanding the results of restoration actions and improving the reliability of future efforts.
2. Project Design and Permitting - Preferred design alternatives are selected and developed. Necessary permits are identified and obtained.
3. Construction - Project managers implement project designs.
4. Project Monitoring - Physical, chemical and biological response to restoration actions are monitored and compared with reference and baseline conditions, as applicable, to determine project success.
5. Lessons Learned and Adaptive Management - Information and experience gained are used to revise and improve current projects and publish results to improve the quality and reliability of other ongoing and future restoration projects.

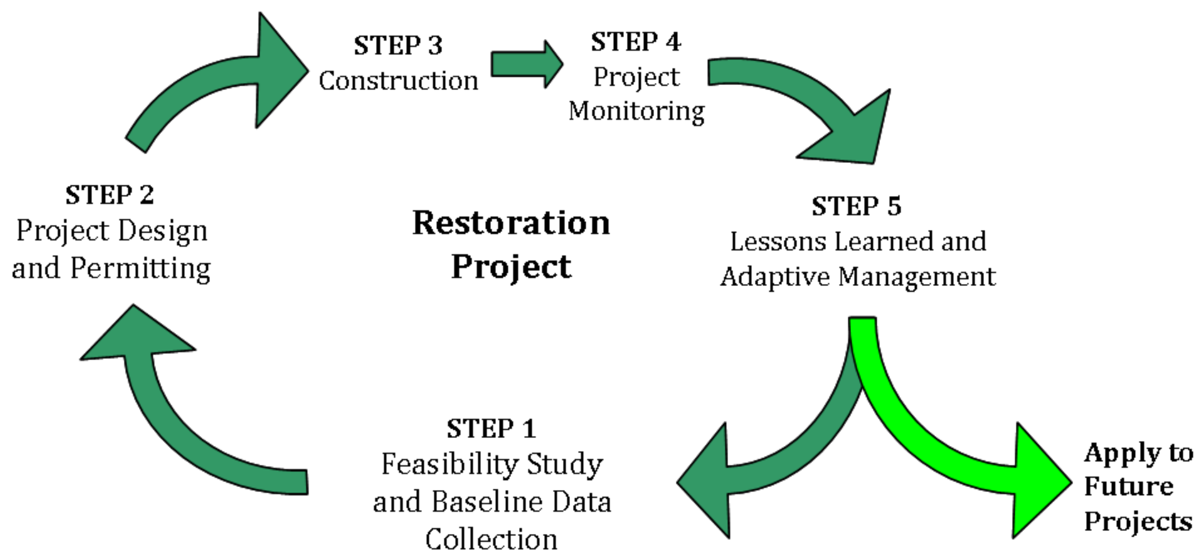

Figure 6: The Restoration Process

Project Monitoring

Each restoration project should define a series of appropriate and measurable goals that will be used to determine success. Monitoring of physical, chemical and biological characteristics of a site that are linked to project goals is essential to understand the long-term success of individual restoration projects and to inform potential adaptive management actions that could be taken to improve project performance. In addition, long-term monitoring of restoration projects contributes to the understanding of how best to restore and manage habitats, thereby increasing the success and reliability of future restoration efforts. Specific project monitoring plans should be considered an indispensible part of any restoration effort and should be included in all restoration project proposals.

VI. COORDINATING RESTORATION PARTNERSHIPS, FUNDING AND DECISION-MAKING

The many resources necessary to fully implement this plan cannot be provided by a single agency, municipality or non-governmental organization. Smaller, individual projects, such as installing an eel ladder, are relatively inexpensive and easy to implement by a single group. However, other larger scale projects such as side-channel restoration or major dam removals are likely to require greater financial resources and involve several regulatory agencies. Implementing these large-scale and complex restoration projects will require partnerships between state and federal agencies, along with local and regional municipalities and non-governmental organizations.

Furthermore, to understand and achieve regional and ecosystem-scale goals, large and small individual projects should be coordinated into a single, effective and efficient restoration effort. Coordination of the many stakeholders, resources and activities involved in restoring the Hudson into a single ecosystem-scale effort could be one of the greatest challenges to implementing this plan. The Hudson River Estuary Program is well positioned to facilitate such partnerships on a regional scale.

In addition, the *Hudson-Raritan Estuary Comprehensive Restoration Plan* (HRE-CRP) has successfully identified restoration priorities for the lower Hudson River south of the Tappan Zee Bridge and for the New York-New Jersey harbor area and has facilitated restoration projects on a large scale.[50] Discussions are currently underway with the Department of Environmental Conservation (NYSDEC), the New York State Department of State (NYSDOS), and the United States Army Corps of Engineers (USACOE) and several non-governmental organizations to develop a similar "Comprehensive Restoration Plan" (CRP) for the Hudson River estuary north of the Tappan Zee Bridge. The plan could address a broad set of issues, from ecosystem functions to human use and access.

The Hudson River National Estuarine Research Reserve, affiliated with both NYSDEC and the U.S. Department of Commerce, NOAA, is also positioned to support a comprehensive restoration effort through coordinated planning efforts currently underway.

SOURCES OF RESTORATION FUNDING

There are many potential sources of funding to support restoration, including Natural Resource Damage Claims (NRD), mitigation funding, federal (National Oceanic and Atmospheric Administration and the United States Fish and Wildlife Service) and state coastal habitat restoration programs, coastal resiliency programs and NGO grant programs. All have the potential to contribute significant funding to implement this plan. Ideally, all funding sources supporting restoration efforts on the Hudson should be coordinated with the goal of ensuring that restoration efforts are complementary to each other and consistent with the plan and overall restoration goals.

[50] http://www.nan.usace.army.mil/harbor/index.php?crp

Funding for larger partnership projects, particularly side-channel restoration in the upper river, may be available through the United State Army Corps of Engineers' Section 206 Aquatic Ecosystem Restoration and Section 1135 Environmental Improvement programs. These federal programs provide significant funding, with a 35 percent non-federal match to restore or improve aquatic resources (206) or to modify existing corps projects to restore aquatic resources (1135).

Federal funding is also available for acquisition of buffer lands adjacent to the Hudson. NOAA's Coastal and Estuarine Land Conservation Program (CELCP - pronounced "kelp") supports state and local governments' ability to acquire coastal and estuarine lands that have ecological conservation, recreation, historical or aesthetic values under threat. CELCP provides matching funds to purchase property or conservation easements on land from willing sellers. For more information on CELCP, see:

http://coastalmanagement.noaa.gov/land/

INFORMATION AND PROJECT COORDINATION

Every restoration project offers an opportunity to further understand and refine restoration techniques for ongoing and future projects. It is imperative that information collected during the restoration process be consolidated and disseminated to allow individual projects to contribute to the body of knowledge of restoration science in the Hudson River estuary. A well-administered regional restoration program will continually integrate experience at individual sites to produce more reliable and predictable projects.[51] This can be enhanced by creation of a database of restoration activities within the Hudson River estuary. This database would include all relevant project information, including delineations of site boundaries and all ecological and biological data collected on site and at reference sites during the restoration process. Information from multiple sites will then be available for program managers to assess restoration on a system-wide scale and for managers and designers of future projects.

[51] Hackney, 2000.

VII. RESTORATION SCIENCE NEEDS IN THE HUDSON RIVER ESTUARY

CURRENT STATE OF KNOWLEDGE

Understanding of the Hudson River estuary has advanced substantially in the last 20 years, especially knowledge of habitat locations, functions and patterns of change. NYSDEC's Hudson River Estuary Program (Estuary Program) has supported high-resolution mapping of the bottom of the Hudson to better understand the shape and composition of these habitats.[52] The Estuary Program, in partnership with other state, federal and non-governmental organizations, has also supported mapping and monitoring of vegetation communities to track their distribution over time. These partners have also studied some of the many chemical and biological processes in a wide range of important habitats, from deep muddy channels to wrack-covered shorelines. Research on fish movement in the estuary and of fish communities in specific habitats has helped identify spawning and feeding areas, and long-term monitoring of water chemistry has increased understanding of changing environmental conditions over long periods, as well as during extreme weather events such as drought or heavy rainfall. Monitoring and tracking studies of fish, including Atlantic and shortnose sturgeon (federally endangered), American shad, river herring and striped bass, have led to regulatory protections and, in some cases, recovery of migratory fish populations.

Much of the past and present research exists in the form of published literature, maps, geographic databases and data sets. While not comprehensive, Appendix A provides a list of essential information particularly relevant to understanding Hudson River habitats and their context in the estuary, and to planning and evaluating habitat restoration projects.

RESTORATION SCIENCE NEEDS

Habitat restoration is a complex undertaking that involves manipulating environmental conditions with the intent of improving habitat and ecosystem health. Restoring the habitats identified in this plan will rely heavily on past and current research efforts. It will also require additional research to provide vital understanding for designing and implementing individual projects, as well as improving our understanding of ecosystem health and restoration priorities as the plan is implemented and conditions change. It is important to maintain support for restoration research throughout implementation of this plan. Increasing our understanding of how the Hudson's habitats work and the results of our actions (restoration efforts) will increase the likelihood of restoration success.

Research efforts on the Hudson River estuary over the past several decades have been implemented by many organizations, including state and federal agencies, colleges and universities, not-for-profit research institutes and conservation organizations. Continued collaboration and coordination among these organizations will help to satisfy the ongoing research needs associated with implementation of this plan. Below are current priorities

[52] Bell, et al., 2006; Strayer, et al., 2006; Nitsche, et al., 2010.

for advancing restoration science on the Hudson. No doubt other needs will emerge in the future as the science and understanding of the Hudson River evolves.

Research Needs Related to Restoration Actions Proposed in this Plan

An in-depth understanding of the river's habitats and the methods used to restore them is essential to the restoration process (Figure 6). Monitoring of reference sites—existing examples (if available) of habitats that represent the intended outcome of restoration actions—is needed to set appropriate and technically feasible project goals, inform project design and determine success. For each restoration project, baseline and post-construction monitoring of the restoration site is also needed to evaluate project success.

In addition to project-specific and reference-site monitoring, research is needed to increase understanding of the relationships between restoration efforts and ecosystem health. How much restoration is required to improve ecosystem health needs to be determined as part of the process of identifying appropriate restoration goals (see page 36, "Restoration Goals"). Doing so will require assessment of technical feasibility of restoration actions, quantifying availability of restoration sites, and continuously improving our understanding of the ecology of the Hudson River.

Current research needs for each priority habitat are described below:

Research Needs for Intertidal and Shallow Habitat Restoration

As identified above and in Appendix A, several research efforts have already contributed to understanding the physical, chemical and biological characteristics of tidal-wetland and shallow-water communities in the Hudson, including identifying and assessing reference wetlands using a modified hydrogeomorphic method.[53] Preliminary research needs have been identified for discrete habitat types, which will improve our success in designing effective restoration. With time, this list of research needs will be refined.

Research on side-channel restoration is needed to better understand the biological communities as well as the physical characteristics of these habitats. This work will increase the likelihood of success and enable project managers to establish appropriate and technically feasible project goals. Additional side-channel research efforts include:

- Study of sediment transport in the upper and lower Hudson River estuary and in tributaries to the Hudson:
    - How will sediment transport regimes in the estuary and in tributaries to the Hudson affect the design of restored side channels?
    - How will side-channel restoration affect maintenance of the federal navigation channel?

[53] Findlay, et al., 2002; Mihocko, et al., 2003

- Study of the habitat requirements of fish and wildlife that will use restored habitats:
  - What are the optimal habitat conditions for fish, birds and invertebrates that will use side channels for reproduction, refuge and forage during multiple life stages, seasons and extreme weather events (high discharge)?
- Study and identification of physical conditions in side channels required for restoration of priority habitats:
  - What physical conditions in side channels are needed to support persistent, high-functioning freshwater tidal wetlands, tidal marsh, shorelines and vegetated shallow habitats?
- Study of effects of climate change and sea-level rise on project designs, longevity and benefits:
  - How will sea-level rise affect restored habitats?
  - What are the design options for maintaining restored habitats during sea-level rise?

Research Needs for Tidal Wetland Restoration

Opportunities to restore tidal wetlands other than side channels are found throughout the estuary. Invasive plant control is identified as a restoration action for these habitats in this plan, although we need to develop our understanding of the advantages and disadvantages of different approaches for controlling invasive plants, as well as how restoration decisions affect the resiliency of nearby communities to wind-driven waves and storm surges. Fill removal and restoration of hydrologic connections between the river and isolated wetlands are also potential restoration actions that can be implemented under this plan. Several current research projects identified in Appendix A are relevant to design, implementation and evaluation of these types of restoration projects. Additional research needs include:

- Study of sediment accretion patterns in tidal marshes:
  - How rapidly does sediment accumulate in Hudson River tidal marshes, and how does it vary with plant communities?
  - How will changing climate conditions affect sediment accumulation and marsh elevation relative to sea level in Hudson River tidal marshes? (Research addressing this question is currently underway at the Hudson River National Estuarine Research Reserve and Cary Institute for Ecosystem Studies.)
- Study of the feasibility of increasing hydrologic connections between the main stem of the Hudson River and marshes impounded by construction of railroad lines:
  - What is the engineering feasibility and cost of increasing the tidal exchange between impounded marshes and the Hudson River?
  - What are the ecological benefits of such an action?
  - How would the decision to implement such a project be affected by sea-level rise?

Research Needs for Submerged Aquatic Vegetation Restoration

Submerged aquatic vegetation (SAV) on the Hudson has been studied for decades. Its important role in production of food, maintaining water quality and providing habitat has been well documented.[54] Inventories of all SAV in the estuary have shown that some SAV beds will expand and contract from year to year.[55] During the summer of 2012, almost no SAV was found in the river. It is possible that the loss of SAV was caused by in-river conditions resulting from tropical storms Irene and Lee in fall 2011.

Restoration of SAV is an important component of the success of the shallow water restoration proposed in this plan. Design of shallow-water habitats associated with side channels or other locations should include conditions that support SAV growth. However, successful restoration of SAV has proven difficult in locations where it has been attempted. It is also important that attempts to restore SAV do not lead to increases in the invasive water chestnut. Additional research needs for SAV restoration include:

- Study of the environmental conditions that support SAV growth in the Hudson River:
    - What hydrologic conditions are most supportive of SAV growth?
    - How do those conditions relate to conditions preferred by water chestnut?
    - Are there hydrologic conditions that will support SAV growth while resisting water chestnut invasion?
- Experimental studies to develop and refine methods for establishing native aquatic plant communities:
    - What are the best methods, timing and conditions for maximizing transplanted SAV in a restored shallow-water habitat?
    - Will SAV colonize restored shallow-water habitats without additional planting?

Research Needs for Shoreline Restoration

NYSDEC's Hudson River Sustainable Shorelines Project is supporting several studies to determine shoreline management options appropriate for when shoreline protection from erosion and prolonged flooding is necessary. The suite of research includes climate change and sea-level rise modeling, engineering analysis of alternative shoreline treatments, modeling and analysis of shoreline energy regimes in the estuary, inventories of engineered and natural shorelines, high-resolution mapping of uplands adjacent to the shore, habitat value of natural and engineered shorelines and economic and social analyses. A list of the many informational products and publications resulting from the ongoing project are listed in Appendix A.

In addition to protection of shoreline from erosion or inundation, protection and conservation of adjacent low-lying lands is proposed to allow intertidal and shallow-water habitats to migrate inland as sea level rises. Research quantifying the amount of upland available for this process is currently underway. However, continued research on how

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[54] Korschgen and Green, 1998; Wigand, et al., 2001; Strayer, et al., 2003; Findlay, et al., 2006; Strayer and Malcolm, 2007.
[55] Nieder, et al., 2009.

upland habitats will transition to intertidal habitats and how that process can be enhanced is needed.

Opportunities to remove engineered shorelines, thereby removing barriers to wetland migration, may also exist at locations where engineered shoreline is not providing a human benefit, such as enhanced access to the river or protection of property or infrastructure. The engineering feasibility, ecological benefits and implications for federal navigation channel maintenance must be studied.

Research Needs for Tributary Restoration (fish passage structures and dam removal)

This plan identifies removal of derelict dams as a way to restore habitat for migratory and resident fish species and restore sediment transport processes. Several efforts have been made by researchers and natural resource agencies to inventory dams in the Hudson River estuary watershed and to prioritize them for removal or installation of fish passage structures.[56] One known benefit of dam removal is the restoration of sediment transport downstream. However, the relative role of downstream sediment transport in building shallows and tidal wetlands at the mouths of tributaries compared to sediment supplied by the Hudson River is unknown and likely varies between sites. While the benefits of dam removal on in-stream habitats is well established,[57] research on the potential benefits of restored sediment transport in tributaries on shallow water and intertidal habitats of the Hudson is needed.

Additional Research Needs

The research needs for restoration identified in this plan are intended to inform restoration design to increase the success and reliability of habitat restoration projects in the Hudson. These needs focus on understanding the physical, chemical and ecological process and characteristics of specific habitat types. However, additional research is needed to increase understanding of how habitats are used by specific species of fish and wildlife. Several studies supported by NYSDEC have been completed or are currently underway to map habitats (SAV, tidal wetlands and benthic mapping). NYSDEC is also supporting studies of fish and wildlife use of mapped habitats, including tagging and tracking studies of Atlantic sturgeon, shortnose sturgeon, American shad and river herring (alewives and blueback herring). Information from tracking studies is being used to identify habitat preferences for these adult fish for feeding and spawning activities. However, it is likely that larval and juvenile life stages of these and other fish have different habitat needs, which could also vary as river conditions change. Study of how larval American shad use backwater and shallow habitats has begun. Additional studies that characterize how, where and when fish species use different habitats is needed. A research agenda containing several proposed studies supporting American shad recovery can be found in the document, *2010 Hudson River American Shad: An Ecosystem-Based Plan for Recovery*.[58]

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[56] Schmidt and Cooper, 1996; Alderson and Rossman, 2013; Alderson and Rosman in prep
[57] Ligon, et al., 1995; Stanley and Doyle, 2003.
[58] Hattala, 2010

VIII. CONCLUSION

For centuries, the Hudson River estuary has been a centerpiece of the cultural and economic development of New York and the nation. The river was critical to the economy and culture of Native Americans before the Colonial era. After European arrival, the Hudson supported many trades and industries, from the fur trade of the 1600s to industrial production, commercial fishing, tourism and recreation. Towns and cities with transportation connections along the banks of the river flourished. The bounty of its waters continues to support robust economic and recreational opportunities. The scenic beauty of the Hudson has inspired generations of artists and continues today to attract and inspire its citizens, new residents and tourists from around the world.

However, many years of development and neglect led to a slow but significant decline in environmental quality in the river. Development of river fronts, building of wharves, improvement of the navigation channel and construction of railroads destroyed or eliminated important habitats that supported the river's plants, fish and wildlife. The river was used to dispose of industrial wastes, invasive species were introduced, and fishery resources were over-harvested in coastal waters. Recognizing the health of the Hudson River is vital to the region and its people, local citizens along with state and federal agencies began work to reverse the trend and improve the Hudson's health. Today, the river's recovery is reflected in improved water quality and reduced pollution. However, many challenges remain. Fish populations dependent on the Hudson are at all-time lows. Some plant species have declined to just a handful of individuals, while others are now lost to the Hudson River. Important habitats that sustain productivity and biodiversity remain lost or degraded, and an ever-expanding human population, along with climate change and sea-level rise, are creating new stresses today and will into the future.

This habitat restoration plan identifies opportunities to continue recovery of the health of the Hudson River estuary, while planning for and adapting to anticipated climate change and sea-level rise. Restoration of habitats through actions in this plan will conserve and restore habitats important to the recovery of plant, fish and wildlife populations and to the many human benefits nature provides. These same actions are also practical strategies for protecting shoreline communities from losses due to sea-level rise and intense storm events and can help guide local waterfront revitalization efforts. Actions described in this plan will restore natural systems that will improve the productivity and biodiversity of the Hudson River estuary while strengthening the ecological and economic resiliency of the river, its communities and New York State.

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APPENDIX A

SELECTED RESOURCES FOR PLANNING AND EVALUATING RESTORATION PROJECTS IN THE HUDSON RIVER ESTUARY

Information gathered to date:

TIDAL WETLANDS

Projects, Inventories and Databases:

- Hudson River NERR tidal wetland vegetation inventories (NYSDEC, Hudson River Research National Estuarine Reserve).
- Phragmites control projects monitoring reports (NYSDEC, Hudson River Research Reserve)
- Sentinel site for climate change monitoring: long-term biological (marsh vegetation), surface elevation and tide gauge monitoring in Tivoli Bays Wildlife Management Area/Hudson River NERR. (NYSDEC, Hudson River Research Reserve)
- Schodack Island State Park wetland mitigation (New York State Office of Parks Recreation and Historic Preservation)
- Ramshorn Marsh Phragmites Control Project (The Nature Conservancy)

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SUBMERGED AQUATIC VEGETATION (SAV)

Projects, Inventories and Databases:

- Estuary-wide inventories and change analyses (1995/97, 2002, 2007), (NYSDEC, Hudson River Research Reserve).
  http://gis.ny.gov/gisdata/inventories/member.cfm?organizationID=529

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SIDE CHANNELS AND HUDSON RIVER CHANNEL MORPHOLOGY

Publications:

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SHORELINES

Projects, Inventories and Databases:

- Map of the Hudson River between Troy and Hudson City, New York. 1890. United States Army Corps of Engineers. Scale 1/20,000
- Hudson River Improvement Charts. 1907 United States Army Corps of Engineers. Scale 1/5000

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- LiDAR- Topographic Elevation Point Data for areas of coastal New York including Long Island, eastern Westchester, and the tidal extents of the Hudson River. Project developed by the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center in partnership with the New York State Department of Environmental Conservation (NYS DEC). Meta can be found at: http://gis.ny.gov/elevation/metadata.htm
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TRIBUTARY STREAMS AND BARRIER MITIGATION

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- Inventory of biologically important stream barriers in the Hudson River estuary watershed. Report to the NYSDEC, Hudson River Estuary Program (The Nature Conservancy, in development)
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SEA-LEVEL RISE AND ECOSYSTEM RESILIENCY

High Resolution Topographic Maps

- Hudson River LiDAR Data. http://www.orthos.dhses.ny.gov/

Flood Zones

- Federal Emergency Management Agency (FEMA) flood maps http://www.fema.gov/national-flood-insurance-program/map-service-center

WATER QUALITY AND ENVIRONMENTAL DATA

- Hudson River Environmental Conditions Observing System (HRECOS): long-term, estuary -wide, water quality monitoring partnership. http://www.hrecos.org
- System-Wide Monitoring Program (SWMP): long-term weather and water quality monitoring at HRNERR component sites. NYSDEC, Hudson River National Estuarine Research Reserve. http://cdmo.baruch.sc.edu/
- Hudson River Salt Front Data. United States Geological Survey. http://ny.water.usgs.gov/projects/dialer_plots/saltfront.html

FISHERIES AND FISH HABITAT

Projects, Inventories and Databases:

- Young-of-year (YOY) herring monitoring data (NYSDEC Hudson River Fisheries Unit)
- Striped bass monitoring (NYSDEC Hudson River Fisheries Unit)
- Atlantic and shortnose sturgeon tracking (NYSDEC Hudson River Fisheries Unit)
- American shad tracking (NYSDEC Hudson River Fisheries Unit)

- Long-river surveys (Hudson River Utilities)
- Larval American shad habitat use and condition study (SUNY ESF)
- Eel Monitoring Program (NYSDEC, Hudson River Estuary Program and HRNERR)
- Black bass and walleye tracking (NYSDEC Fisheries Units Regions 3 and 4)

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APPENDIX B

Principles of Estuarine Habitat Restoration

Habitat restoration is, by its very nature, a joint venture between scientists and practitioners. In keeping with this theme, Restore America's Estuaries and the Estuarine Research Federation developed this set of principles to guide restoration activities in our coastal estuaries. A concentrated, year-long process involving scientists and restoration professionals across the nation produced this agreement—a gold standard for estuarine habitat restoration.

These principles are intended as a guide for all types of restoration activities—large-scale and community-based restoration projects. Acknowledgements and case studies illustrating these principles can be found on www.estuaries.org.

The complete document, Principles of Estuarine Habitat Restoration, can be found at http://www.estuaries.org/principles-of-estuarine-habitat-restoration.html.

PRINCIPLE 1: Preservation of existing habitat is critical to the success of estuarine restoration.

PRINCIPLE 2: Estuaries can be restored only by using a long-term stewardship approach and developing the constituencies, policies and funding needed to support this.

PRINCIPLE 3: The size, scale and amount of restoration activity must increase substantially to have a significant effect on overall estuarine functioning and health.

PRINCIPLE 4: Greater public awareness, understanding and involvement in estuarine habitat restoration are necessary to the success of individual projects and to achieve national restoration goals.

PRINCIPLE 5: Restoration plans should be developed at the estuary and watershed levels to set a broad vision, articulate clear goals and integrate an ecosystem perspective.

PRINCIPLE 6: Estuarine restoration plans should be developed through open regional processes that incorporate all key stakeholders and the best scientific thinking available.

PRINCIPLE 7: Project goals should be clearly stated, site specific, measurable and long-term—in many cases greater than 20 years.

PRINCIPLE 8: Success criteria for projects need to include both functional and structural elements and be linked to suitable, local reference habitats.

PRINCIPLE 9: Site plans need to address off-site considerations, such as potential flooding and salt water intrusion into wells, to be sure projects do not have negative impacts on nearby people and property.

PRINCIPLE 10: Scientifically-based monitoring is essential to the improvement of restoration techniques and over-all estuarine restoration.

PRINCIPLE 11: Ecological engineering practices should be applied in implementing restoration projects, using all available ecological knowledge and maximizing the use of natural processes to achieve goals.

PRINCIPLE 12: Adaptive management should be employed at as many restored sites as possible, so they continue to move toward desired endpoints and self-sustainability.

PRINCIPLE 13: Long-term site protection is essential to effective estuarine habitat restoration.

PRINCIPLE 14: Public access to restoration sites should be encouraged wherever appropriate, but designed to minimize impacts on the ecological functioning of the site.