VORTEX

Virginia's Oyster Reef Teaching EXperience

An Educational Program for Virginia Science Educators

What is VORTEX?

Virginia's Oyster Reef Teaching EXperience (VORTEX) is a multi-component program focusing on the importance of oyster reef communities in the Chesapeake Bay ecosystem. VORTEX is designed specifically for science educators by the Virginia Insitute of Marine Science. The program includes a series of workshops and multimedia materials including a CD ROM and Internet web sites. All program components are designed to provide a basic biological and ecological background to enable participants to integrate program materials into hands-on science lessons.

Program partners and co-sponsors include:
- Virginia Institute of Marine Science
- Virginia Sea Grant Marine Advisory Program
- Virginia Environmental Endowment
- Chesapeake Bay Restoration Fund Advisory Committee

For more information, visit the VORTEX web site at: www.vims.edu/fish/oyreef/vortex.html or contact Juliana Harding (jharding@vims.edu), Vicki Clark (vclark@vims.edu), or Roger Mann (rmann@vims.edu).

Overview

Practical demonstration of interdisciplinary environmental issues is one of the major challenges currently facing science educators. Before students can successfully apply critical thinking, problem-solving, or decision-making skills to an issue, they must have a basic understanding of both the scientific concepts and the regional context in which the issue is relevant. Because of their diversity and historical prominence, oyster reef communities provide an ideal model for integrating basic biological and ecological concepts with chemistry (water quality), physics (currents), economics, and local history in the Chesapeake Bay region. Many Virginia residents are familiar with the Chesapeake Bay and the regional industries that depend on seafood resources. However, connections between oyster reefs and the fauna that they support (e.g., blue crabs, striped bass, Atlantic croaker, osprey) are largely unrecognized.

The strategy of the VORTEX program is simple: Establish a basic biological foundation using commonly recognized Bay fauna. Expand from the basics to an interdisciplinary perspective using several complimentary formats: field and laboratory experience supported by a multimedia CD-ROM, printed materials, and dedicated Internet web sites. The project goal is to enable educators (and through them, their students) to understand the environmental issues of oyster reef restoration thoroughly enough to apply problem-solving and critical-thinking skills in classroom settings and, more importantly, civic and policy settings.

Harding, J.M., Mann, R., and V.P. Clark. 1999. Oyster Reef Communities in the Chesapeake Bay: A Brief Primer. Virginia Institute of Marine Science, Gloucester Point, VA. VSG-99-05, VIMS-ES-44 4/99.

A publication of the Virginia Sea Grant Marine Advisory Program

Virginia Institute of Marine Science
Gloucester Point, VA 23062

Oyster Reefs in the Chesapeake Bay: A Brief Primer

Oyster reefs developed over the past 8 to 10 thousand years as the Chesapeake Bay was slowly inundated by rising sea level. An oyster reef is a three-dimensional matrix of oyster shells and living oysters that supports a diverse ecological community. Oyster reefs have topography much like tropical coral reefs and are ecologically important for many of the same reasons. Reefs, both oyster and coral, are made by living organisms. Both oysters and corals are benthic filter feeders that secrete a hard outer covering as they grow. The reef structure grows over time vertically and horizontally as younger animals settle onto the clean, fresh substrate created by older oysters or corals. As reefs accumulate, their structural complexity increases. With more nooks and crannies comes more surface area where other plants and animals may attach and grow. Flora and fauna attached to the reef attract grazers. Grazers attract upper level predators and perpetuate the food chain. Ecologically diverse reef communities are possible because of the structural complexity inherent in the reef.

Biology of Oysters

There are approximately 100,000 species of molluscs, a group of invertebrates that includes oysters as well as other familiar animals such as snails, clams, squid, and octopi. About 8% of all molluscs are bivalves, a group characterized by paired hinged shells or valves.

Oysters, including the native Chesapeake Bay oyster *Crassostrea virginica*, are unusual because of their gregarious lifestyle and, consequently, their reef building capabilities. Oysters are either males or females, releasing sperm or eggs into the water during spawning. Fertilization occurs in the water column, resulting in a microscopic member of the plankton: the oyster larva. These tiny larvae drift and swim for 2 to 3 weeks, feeding on phytoplankton. When the oyster larvae reach about 0.25 mm in size (approximately the diameter of a human hair), they undergo a dramatic metamorphosis, changing from a freely swimming organism to a permanently attached form in 24 to 36 hours. In order to successfully settle and grow, the tiny oyster larvae must find a firm surface. The settlement surface of choice is another oyster's

Oyster facts at a glance

- Oysters grow approximately 30 mm per year.
- Oysters longer than 3 inches are considered harvestable or "market" sized.
- A market oyster is at least 3 to 5 years old.
- The left shell valve of an oyster is cupped while the right valve is flat.
- Adult oysters can typically filter 5 liters of water per hour per gram of tissue weight at 25° C (Newell, 1988).
- Oysters are usually sexually mature by the time they are 1 year old.
- A single female oyster produces 10 to 100 million eggs annually. A single male oyster produces about a billion sperm annually.
- Recently settled oysters or "spat" are eaten by blue crabs, mud crabs, and large hermit crabs.
- Adult oysters can be eaten by snails such as oyster drills that can bore through the oyster's hard shell.
- Oyster catchers are large shore birds that have specially designed bills to efficiently crack, open, and extract oysters.

A close-up of an adult Eastern oyster (J. Harding).

shell. It is this preference to settle on members of their own species that results in small clumps of oysters that over time grow bigger and bigger. Eventually as older oysters at the bottom die, the clump grows up and out and a reef is formed. This is how extensive reef systems in the Chesapeake Bay formed over the past eight to ten thousand years.

Why Are Oyster Reefs No Longer Prominent in the Chesapeake Bay?

When Captain John Smith sailed up the James River in the early 1600s there were so many large oyster reefs that he was forced to sail AROUND and BETWEEN them. These reefs were both channel markers and navigation hazards. The filtering capacity of this huge oyster population was so great that the Bay's entire water column was filtered in THREE TO SIX DAYS (Newell, 1988).

Native Americans harvesting intertidal oysters in colonial days.

It did not take the colonists long to learn that oysters were good to eat and easy to harvest. Even though native Americans were here long before the colonists, their numbers were so small that their harvesting activities had minimal impact on oyster populations. When the colonists arrived, harvest pressure increased. The impact of this can be traced over time.

How the Oyster Reefs Disappeared: Harvesting the Bountiful Resource

PHASE 1: From the 1600s to 1834

The presence of very old large oyster shell piles or "middens" indicate that oysters were extensively harvested by native Americans and early settlers in the Chesapeake Bay. Because oysters were abundant in the intertidal zone during this period, they were easy to harvest by hand picking or with hand tongs, similar to those still in use today.

PHASE 2: 1834 to 1890

This phase begins with the opening of the first oyster packing house in Baltimore in 1834, the opening of the transcontinental railroad, and the expansion of transatlantic shipping. By this time, Chesapeake Bay oysters were regularly shipped as far afield as California and England. In 1865, 6.95 million bushels of oysters were harvested annually in the Chesapeake Bay. By 1875 annual production had nearly tripled to approximately 17 million bushels.

Watermen tonging for oysters in the James River, VA.

This was truly the heyday of oyster exploitation, and the effects of continued overfishing were about to be seen. William Brooks published his famous book on oysters (*The Oyster: A Popular Summary of a Scientific Study*) in 1891 and commented on the overfishing and the need to conserve. Over 100 years later, this advice is still appropriate.

The public oyster grounds of Virginia were surveyed by Lt. J. Baylor (U.S.N.) in the late 1800s. This survey, published in 1894, defined the area that was to be left in public trust and managed by the Commonwealth. These "Baylor Grounds" cover about 243,000 acres, including everything from the remaining oyster reefs to mud, and are still in place today.

Leasing of sub-optimal Baylor (public) oyster grounds to private growers began soon after the Baylor survey and continues today. About 110,000 acres of sub-optimal ground were leased. Because these areas were often in deposition zones where mud accumulated over time, they often required continued applications of oyster shell to maintain a firm substrate and prevent the oysters from becoming buried.

The Virginia portion of the Chesapeake Bay with the Baylor or public oyster grounds shown in black.

Oyster leases allowed private growers to buy oyster "seed" oysters (small, recently settled oysters harvested from Baylor grounds), plant the seed on leased or private grounds for grow-out, and eventually harvest and sell the mature oysters. Leased grounds had to be replenished with seed oysters obtained from other parts of the Bay. Seed oysters created an important connection between the public oyster fishery on Baylor grounds and the private fishery on leased grounds. Seed oysters were obtained from a limited number of locations, notably the James River, and to a lesser extent the Piankatank River, the Great Wicomoco River, and Mobjack Bay. The James River prevailed as the major source of seed, and seed was shipped throughout the Chesapeake Bay and into New England.

The combination of private leasing and the use of power dredging put Virginia ahead of Maryland in production by the turn of the centery, a position it retained until about 1960. Oyster shells were not usually returned to the Bay; they were sold for use in roads, concrete, and other construction materials.

PHASE 3: 1890 to 1912

By this time overfishing had taken its toll. Virginia oyster production decreased to between four and seven million bushels per year, less than half of the production seen just 25 years earlier.

PHASE 4: 1912 to 1940

Production of oysters in Virginia fell from six million bushels in 1912 to 2.4 million bushels in 1931- 32. Over-exploitation combined with sluggish national and international economics began to negatively affect production. The small European market for Chesapeake Bay oysters disappeared during World War I and The Great Depression effectively eliminated much of the national market. However, the small regional market stablized and oysters (and oyster shells) continued to be removed from the Bay. Oysters were still relatively abundant and could be gathered free for local consumption. Because they provided a free source of food for many economically distressed families, oysters took on the stigma of being "poor people's food." Children who took oysters to school for lunch often did not eat them in public to avoid teasing from their classmates.

PHASE 5: 1945 to 1960

During this period, oyster production from private (leased) grounds continually exceeded public production. Annual oyster production was still well below turn of the century production. Both market oystering and seed oystering continued to be productive activities. "Buy boats" took seed from the James River and sold it to private lease holders in other Chesapeake Bay tributaries.

During this period, a significant infrastructure for oyster shucking and shipping was developed and is still in place today. Ironically, Virginia remains a major national oyster processing center despite low local production.

An oyster buy boat on the James River loading seed oysters in the 1950s.

PHASE 6: 1960 to the present
The past four decades have been marked by the appearance and persistence of two oyster diseases: *Haplosporidium nelsoni* or MSX and *Perkinsus marinus* known as "Dermo." These diseases infect and eventually kill oysters in the higher salinity regions of the Bay. The cumulative effect of the diseases and many decades of overfishing and environmental decay is a sadly depleted Chesapeake Bay oyster resource.

Oyster Reefs in the Bay: Why Are They Important?

Oysters are filter feeders, straining microscopic single celled plants (phytoplankton) from the water column. Because of their dominant position in the food chain as primary consumers, oysters are often termed the "keystone species" of the Chesapeake Bay. They also make phytoplankton useful to species further up the food chain by eating it. Not all animals can eat a food particle that is only a few microns in diameter (there are 1,000 microns in a millimeter, so a micron is very small). The oysters can and do filter these tiny plants from the water. Many other species, such as blue mussels, hard clams, and Atlantic menhaden can also feed on phytoplankton, but oysters historically occurred in such large numbers that they were by far the dominant filter feeder in the Bay. Oysters feed on phytoplankton, and in turn, the oysters can become food for other species. Oyster larvae are eaten by small animals such as fish larvae. Bigger oysters are eaten by blue crabs, snails, and some birds. And so a food chain begins.

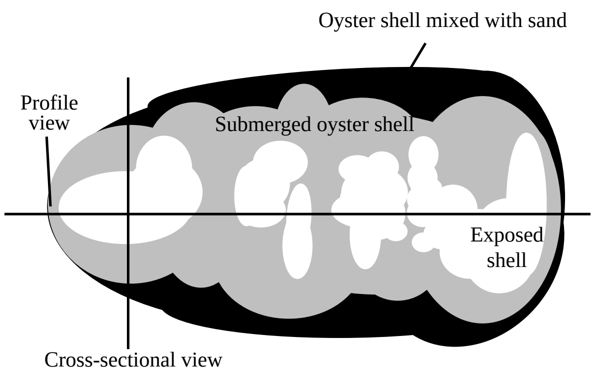
The oyster's ability to filter phytoplankton from the water column is also important to Chesapeake Bay water quality. As nutrients such as nitrate and phosphate compounds arrive in the Bay with runoff from the watershed, they fertilize the growth of the single-celled phytoplankton. If phytoplankton is not consumed, it eventually dies and decomposes. This decomposition process uses up a great deal of oxygen. If there are huge amounts of decaying phytoplankton, the end product is oxygen depletion, or eutrophication, which is not good! Thus, oysters are important in stopping oxygen depletion before it starts by reducing the amount of phytoplankton in the water.

A close look at the surface of an oyster reef. The spaces between the shells provide favorable habitat for many small animals (J. Harding).

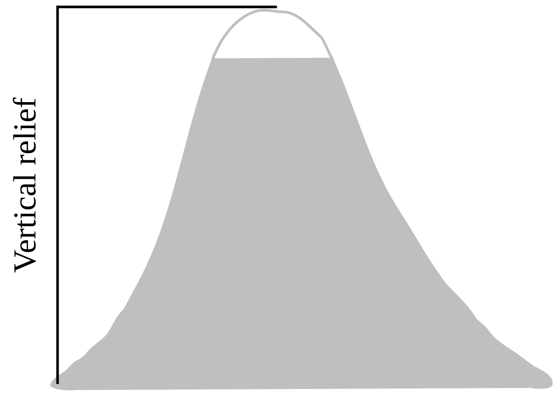
How much water can oysters filter? Before 1877, the Chesapeake Bay oyster population could filter the entire volume of the Bay in three days. Now there are so few oysters that it would take them about one year to filter the Bay.

that are exposed at low tide are usually just a very small portion of the actual reef. The diagram below shows what the actual reef structure would look like from an airplane without the water. The white areas are exposed at low tide. The grey areas show oyster shell that is not exposed at low tide. The black areas indicate the portion of the reef closest to the sand bottom where the oyster shell is partially mixed with sand.

An aerial view of oyster reefs near Fisherman's Island, VA (J. Wesson).

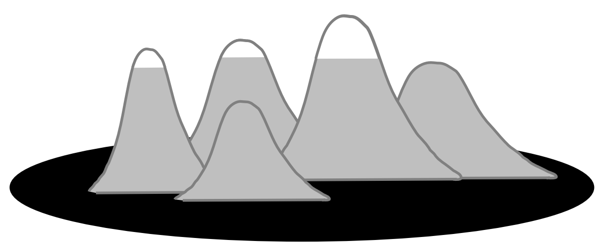


A cross-sectional slice of the reef taken at the vertical black line in the aerial schematic shown above at high tide (when the reef is completely covered with water) would look a lot like the small hill shown at the top of the next column. Note the height of this mound off the bottom; this is what the term "vertical relief" describes.



A cross-sectional view of an oyster reef.

A profile or landscape slice of the reef taken at the horizontal black line shown in the aerial diagram would look similar to a small mountain range. Not only are there many individual mounds, the overall effect of all of the mounds is a large increase in the amount of shell surface area on the reef in contrast to the surface area of the flat bottom. Note the many "canyons" or channels created between mounds: these are excellent places for hungry fish to cruise through and look for food!



A profile or landscape view of an oyster reef.

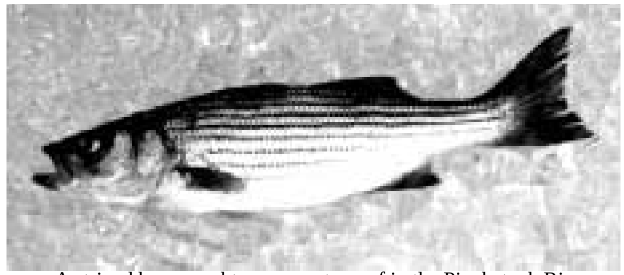
Oyster reef restoration efforts in Virginia

The term "oyster reef restoration" describes a variety of activities that are linked by a common goal: an increase in oyster abundance on oyster reefs in the Virginia portion of the Chesapeake Bay. The primary method for oyster reef restoration is to build oyster shell mounds from clean shells in areas where there are oyster spat that can settle on the shell. To date, the Commonwealth of Virginia, through the Virginia Marine Resources Shellfish

A living oyster reef is a complex structure in which many species can both live and feed. It is this complexity that makes the reef both unique and important. An oyster reef is not just a pile of dead shells but a veritable condominium for many other species. All the nooks and crannies within the reef are occupied by species that specialize in occupying these very special nooks and crannies. The spaces between the shells come in all sorts of shapes. Flat spaces are occupied by flat species such as skilletfish. Tall thin spaces are occupied by thin profile fish such as blennies. More regular-shaped spaces are occupied by gobies, whose bodies are about equal in height and width. All of these species of fish may eat similar things, but they coexist in the greater reef structure because they occupy different spaces at a small scale. Thus each species has its own unique microhabitat requirements within the reef. Successful species are able to make the most of available space and resources.

A feather blenny (25 mm long) peers out from between oyster shells (J. Harding).

These small fish species not only live and feed in the reef, they breed there also. Their larval forms eat oyster larvae, so the interdependence of the reef residents is strengthened. These fishes are called intermediate reef fishes because they are resident on the reefs and intermediate in the reef food chain. These small fishes are eaten by other resident species like mud crabs, and by transient but larger species, ranging from blue crabs to large predatory fishes. These large predators, such as striped bass, bluefish, and others seasonally move into the rivers and feed on intermediate reef fishes. The food chain becomes a food web, growing in complexity.



A striped bass caught on an oyster reef in the Piankatank River (J. Harding).

Oyster reefs are important because:

1. Reefs naturally aggregate oysters. Aggregation increases fertilization and settlement success for oysters.

2. The three dimensional relief inherent in the reef structure lifts the oysters off the bottom and helps protect them from sedimentation.

3. The reef matrix includes many nooks and crannies that are home to small fishes and invertebrates. These small animals are prey for larger species.

4. Nooks and crannies in the reef matrix also provide protected places for oyster larvae to settle and avoid predation by crabs.

5. The food is better near the top: the vertical relief gives oysters near the top of the reef an optimal place to graze on healthy phytoplankton. Oysters near the top of the reef will grow faster, reproduce more, and increase reef shell area because the food is better.

6. Oyster grazing reduces phytoplankton biomass and helps prevent seasonal eutrophication and hypoxia.

A Closer Look at Oyster Reef Habitat

An oyster reef is essentially a large mound or series of mounds made of oyster shells. If we looked down on an oyster reef from an airplane, we would be able to see the tops of the mounds at or near the water's surface. The tops of the oyster reef mounds

Replenishment Program, has restoration projects in progress at 14 different sites in the Bay including the Piankatank and Great Wicomico Rivers as well as near Fisherman's Island on the Eastern Shore. Virginia Institute of Marine Science (VIMS) fishery scientists are working with the Virginia Marine Resources Commission Shellfish Replenishment Program to monitor the development of reef communities as well as the general status of the oyster resource.

Some basic oyster reef restoration rules of thumb include:

1. Pick a site with hard sand bottom and little deposition preferably on the footprint of a historic or former oyster reef.
2. Locate the reef where tidal currents will enhance oyster settlement and recruitment on the reef not export larvae to less favorable habitat.
3. Choose a tributary that not only satisfies rules 1 and 2 above but is also small enough so that oyster settlement in the tributary can be easily monitored after reef construction.
4. Choose a site that balances the benefits of a shallow intertidal location (reduced vulnerability to seasonal hypoxia) with the risks inherent in shallow waters (increased vulnerability to ice scour and freezing in cold winters).
5. Be prepared to do follow-up monitoring both on the reef and within the tributary. Monitoring data is necessary to evaluate the success or failure of the restoration effort.

Simple criteria for evaluating restoration success

1. Oyster abundances at the restoration sites are similar to abundances at local natural sites within 3 to 5 years of the restoration initiation.
2. Representatives of upper oyster reef community trophic levels including blue crabs, striped bass, great blue herons, and others are observed using and living in the reef and adjacent habitat within 3 to 5 years of the restoration.

Patience is a requirement when monitoring restored reefs or evaluating their success. The oyster resource did not disappear overnight and the restoration effort requires time for sucess.

Almost every oyster reef trophic level is shown in this picture.
(Original by K. Forrest, modified with permssion by J. Harding).

Oyster connections to water quality

As mentioned earlier, the removal of phytoplankton from the water column by oysters can prevent or reduce eutrophication and seasonal low oxygen dissolved levels in the Bay. Environmental factors including water temperature, salinity, and dissolved oxygen levels can affect oyster filtration efficiencies and rates and, subsequently, Bay water quality.

Water temperature

The Chesapeake Bay is a temperate estuary. Temperate describes a habitat where the annual seasonal temperature range includes extended periods of cold and warm temperatures. In the winter the water in the Bay is uniformly cool from surface to bottom (also known as "isothermal"). During warmer periods like summer, the surface water is warmer than the deeper water. This stratification or layering of the water column produces a thermocline or zone of abrupt temperature change. Because most Chesapeake Bay oyster reefs and bars (two dimensional aggregations of oysters) are found in shallow waters, thermoclines of less than 5° C are most common in oyster habitat, if thermoclines are present at all.

Oysters can survive at water temperatures as low as -2° C and as high as 49° C; survival at either temperature extreme increases when the oysters are covered with water. The optimal temperature range for oyster growth and reproduction is approximately 12 to 26° C.

Because oyster metabolism is directly correlated with water temperatures, temperatures affect every aspect of oyster biology including reproduction, larval success, settlement, feeding, and growth. At very low and very high temperatures, oyster metabolic rates decrease to maintenance levels. At intermediate or "normal" temperatures, oyster metabolic rates increase seasonally enabling growth and reproduction. The graph below shows the annual average temperature cycle from 1990 to 1998 for an intertidal area of the York River near Gloucester Point. This temperature cycle is representative of the conditions that most Virginia oysters are exposed to during the course of a year.

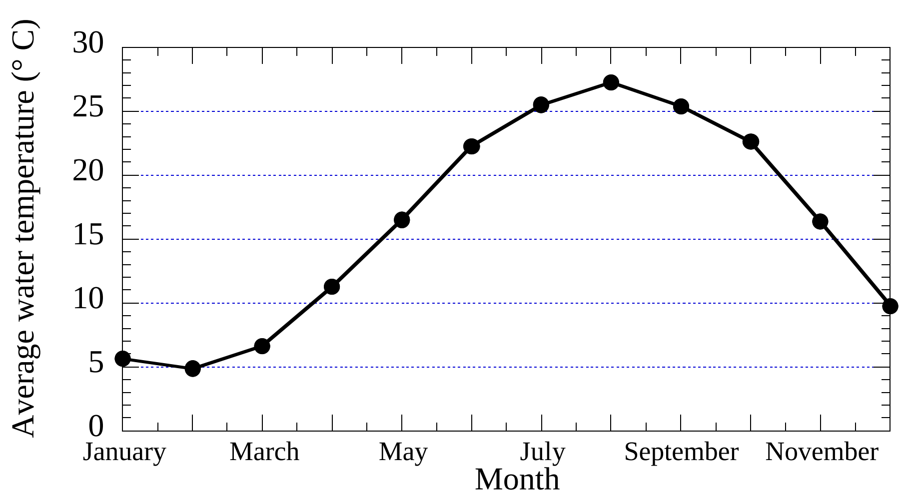
Salinity

Salinity refers to the total amount of salt dissolved in water and is measured in parts per thousand (ppt). Oceanic salinities are approximately 35 ppt. "Fresh" water has salinities of 1 to 2 ppt. The term "estuary" describes an area where a river meets the sea, mixing fresh river water with more saline sea water. The salinity of the water at a particular point in an estuary varies depending on the distance from the sea, the amount of freshwater discharge from the river, and the strength of local tidal currents.

While oysters function normally at salinities as low as 7 ppt, the optimal salinity range for oysters is 14 to 28 ppt. Oysters can survive for very short periods of time at salinities as low as 2 ppt.

Dissolved oxygen

Oxygen is a necessity for most estuarine organisms. Oxygen dissolves in water and is used by organisms for the metabolic reactions that are required to sustain life. In shallow unstratified waters, the two main sources of oxygen are photosynthetic activity by phytoplankton and other plants and atmospheric oxygen transported from the surface to the bottom by wind, waves, and tidal currents. Oxygen is most commonly measured in units of milligrams of oxygen per liter of water (mg/L).



Seasonal water temperature cycle from the York River, VA (Data courtesy of VIMS Data archive).

"Normal" healthy oxygen levels in summer estuarine waters are between 8 and 10 mg/L.

In deeper waters, where the water column is stratified into a definite top layer and a definite bottom layer, sometimes the bottom layer has very low oxygen levels (2 to 4 mg/L) and is said to be "hypoxic" or oxygen limited. Organisms that find themselves in hypoxic conditions must either move to oxygen rich waters or be able to survive the period of low oxygen availability. Oysters and other bivalves can shut their shells and wait for oxygen levels to increase; however, if oxygen levels do not increase after a day or two, the oysters will die since they are attached to the bottom and cannot leave the hypoxic area.

How Can Citizens Help the Restoration Process?

The Chesapeake Bay oyster resource cannot be successfully restored unless citizens understand the necessity for healthy oysters in the Bay. For those that understand the central ecological role that oysters and reef communities play in the Chesapeake Bay, reef restoration is a necessary and sensible process. Interested citizens can participate in a range of educational workshops, mini-courses, and volunteer experiences throughout the Tidewater region.

Current information on oyster-related educational programs and curriculum materials is available from the following VIMS Internet web sites:

- www.vims.edu/fish/oyreef/vortex.html
- www.vims.edu/marine/adv
- www.vims.edu

Information may also be obtained by writing or calling the VIMS Marine Advisory Program Office at:

Virginia Sea Grant Marine Advisory Program
Virginia Institute of Marine Science
P.O. Box 1346
Gloucester Point, VA 23062
(804) 684 - 7000

References

Newell, R. 1988. Ecological changes in the Chesapeake Bay: Are they the result of overharvesting the American oyster, *Crassostrea virginica*? In: Understanding the estuary: Advances in Chesapeake Bay Research. Proceedings of a Conference held March 29-31, 1988, Baltimore, MD. Chesapeake Research Consortium Publication 129. CBP/TRS 24/88.

Virginia teachers explore a restored oyster reef in the Piankatank River, VA under the guidance of VIMS marine scientists and educators during a VORTEX Program workshop in July, 1998 (R. Kelly).

WILLIAM & MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE

VIRGINIA
Chesapeake Bay Restoration
Fund Advisory Committee
FRIEND OF THE CHESAPEAKE

Sea Grant
Virginia

Virginia's Oyster Reef Teaching EXperience
VIMS

Virginia Environmental Endowment

VORTEX