In order to describe the ecosystem benefits provided by restored oyster reefs, the NOAA Chesapeake Bay Office (NCBO) initiated the Oyster Reef Ecosystem Services (ORES) project in 2013. ORES consists of three primary efforts intended to quantify the ecosystem benefits provided by restored oyster reefs:

- An NCBO-implemented field study of fish utilization of a variety of sites in the Choptank River area;
- NCBO-funded projects being carried out by research institutions on fish, crab, and other species’ use of reef areas and denitrification (nitrogen removal) carried out by reefs and their associated organisms in both the Choptank area and other Chesapeake tributaries; and
- Computer modeling to explore ecosystem and economic benefits of restored reefs.

Large-scale oyster restoration projects in the Chesapeake Bay, under way to meet the Chesapeake Bay Watershed Agreement’s goal to restore oysters in 10 tributaries by 2025, provide unprecedented opportunities to conduct this type of research. The restored reefs are essentially underwater laboratories where many key characteristics of the reefs are being measured and tracked through time. Many of the restored reefs where research is under way are young, providing researchers insight into how reefs develop and mature, and how their benefits to the ecosystem evolve over the years; they focus on tangible examples. Modeling efforts that are part of ORES are able to project the effects of restored reefs, system wide, many years into the future.

While data analysis continues, scientists note some preliminary results at and near restored reefs:

- Enhanced nitrogen removal
- Increased oyster biomass
- Increased density and biomass of macrofauna (used as food by fish and crabs)
- Evidence of fish successfully foraging on reefs
- New seagrass colonization
- Measurable positive effects on water column health

A variety of stakeholders are interested in information on the benefits restored oyster reefs bring to the ecosystem, including resource managers and public policy decision makers. Of note, the Choptank River watershed was designated a NOAA Habitat Focus Area in 2014. Information gathered from the ORES project is of great interest to partners in the Choptank Habitat Focus Area effort, including community organizations, interested citizens, and educators and students, as it may support increased job opportunities, improved water quality, and enhanced recreational opportunities.
NOAA Chesapeake Bay Office Fish Utilization Field Study

To identify the fish and other species that use oyster reefs as habitat in the Choptank River area, the NCBO ecosystem science team has conducted field work in Choptank tributaries since 2013. (Primary Investigator David Bruce, NOAA Chesapeake Bay Office)

The NCBO field study uses a before-after, control-impact (BACI) study design, which allows comparison of fish abundance before and after restoration in addition to comparisons between restored and unrestored, or control, sites. Sampling work from 2013 through 2017 took place on reefs in different stages of restoration. These sites are not considered fully functioning oyster reef ecosystems; researchers expect that it would take at least several years post restoration to become a fully functioning reef ecosystem.

In 2017, working from on board NCBO’s research vessel Bay Commitment, NCBO scientists deployed and then retrieved—after allowing them to “fish” for 24 hours—numerous lines of fish traps. Each line included traps of different sizes, each designed to catch different types of fish (black sea bass, spot, eel, pinfish, and minnow pots; using bait consisting of ground menhaden and razor clams). While retrieving traps, NCBO staff recorded the species, numbers, and size of each animal before returning them to the water.

Fish traps were set on eight sites in both the Tred Avon and Little Choptank rivers (minimum two lines at each site, each line consisting of five different trap types), using ground menhaden and razor clams as bait. The sites were a combination of restored and unrestored/reference sites; restoration sites included reefs that had been constructed using hard substrate (shell or stone) and then seeded with spat-on-shell oysters, or simply seeded with spat-on-shell.

In total, including field seasons through 2017, 1,075 fish and crabs were collected in the Little Choptank River and 793 in the Tred Avon River. Fish catch in these tributaries was dominated by American eel, oyster toadfish, white perch, and blue crab. Additional species were collected on study sites using trawls and gillnets that were not observed in traps: bay anchovy, bluefish, menhaden, spotted seatrout, weakfish, and gizzard shad. In all, eight finfish species, three crustacean species, and one turtle species were collected in fish trap samples from oyster restoration sites.

NCBO scientists are beginning analysis of the full multyear data set, including relating fish utilization to restoration treatment (substrate and seed; seed only). Based on initial analyses of fish trap catch rates, American eels generally preferred constructed rock reefs to unrestored reference sites. In the Little Choptank River, fewer blue crabs were caught on constructed oyster reefs than on unconstructed reference sites—perhaps because more crab prey were available in the softer bottom habitat of the reference sites, while prey were able to find refuge from crabs in the crevices of the constructed reefs. And contrary to expectations, white perch and oyster toadfish did not seem to prefer restoration sites over unrestored reference sites.

No NCBO field work on this project is scheduled for 2018; NCBO will explore additional sampling in the future to see how fish use more mature restored reefs.

These graphs show distribution of species caught in traps by the NCBO ORES field team during the NCBO fish utilization portion of ORES.
NCBO-Funded Research by Academic Partners

To increase the reach of the ORES project, NCBO funds research that is conducted by academic research institutions that complement NCBO field work. These projects cover different geographic areas and different types of ecological and economic benefits of oyster reef habitats. NCBO and researchers from these academic institutions collaborate throughout their research to share information, discuss implications of their findings, and develop a holistic picture of the ecosystem services provided by Chesapeake Bay oysters. Projects also enable high school, undergraduate, and graduate students to gain experience in this type of research.

Research and analysis under each of these projects continues; most projects will have completed the bulk of their field work in 2018 and are focusing on analysis and conclusions. More detailed information may be obtained from individual research teams. Many have noted the challenges involved in accurately documenting fish utilization of oyster reefs. The following projects are working to quantify various aspects of oyster reef ecosystem services.

“Integrated Assessment of Oyster Reef Ecosystem Services” is a set of three projects that are a collaboration among the Virginia Institute of Marine Science, University of Maryland Center for Environmental Science, and University of Maryland. The principal investigators (PIs) on these three projects plan and implement research together, to get maximum benefit and cost efficiency out of samples collected. Their research also focuses geographically on Maryland’s mid-Eastern Shore, enabling efficiency of effort and knowledge sharing. The collaboration increases the amounts and types of data available to each project. These integrated projects focus on fish utilization, secondary production, trophic linkages, macrofaunal utilization, nutrient assimilation, and quantifying denitrification rates and nutrient fluxes.

“Integrated Assessment of Oyster Reef Ecosystem Services” Project 1: Virginia Institute of Marine Science (VIMS), “Fish and Crustacean Utilization, Secondary Production, and Trophic Linkages” (PI Lisa Kellogg). The goal of this research is to understand finfish use of oyster reefs as a food resource. In 2015 and early 2016, gillnets were used to sample fish from five restored and three nonrestored sites in April, June, August, October, and January/February. Based on catch per unit effort, the experimental design was altered in 2016 and 2017 to focus on sampling at dusk in warmer months (monthly sampling May through October) and on sampling smaller fish (largest mesh replaced with 1.9-cm mesh). Sample collection is complete, and analysis so far indicates that some species shift their diets to focus on prey that are readily available on restored oyster reefs. White perch caught on reefs in Harris Creek tend to have a greater
proportion of the sea squirt *Molgula manhattensis* in their stomachs than white perch sampled as part of ChesMMAP, a long-term finfish diet-monitoring program in the Chesapeake Bay. Striped bass caught in Harris Creek tend to have a greater proportion of benthic invertebrates, including polychaete worms and mollusks, than striped bass caught as part of the ChesMMAP monitoring program. These findings suggest that, when oyster reefs are present, these species shift their diets to use the abundant prey found in these habitats.

**“Integrated Assessment of Oyster Reef Ecosystem Services” Project 2: University of Maryland, “Macrofaunal Utilization, Secondary Production, and Nutrient Sequestration,” (PI Ken Paynter).** This project seeks to quantify the relationships between macrofaunal abundance/biomass and oyster biomass density on restored reefs, at small (0.1 square meter), intermediate (1 square meter) and reef scales, while also assessing seasonal and annual patterns in abundance, diversity, and biomass at restored reef sites, nonrestored former reef sites, and soft-sediment sites. Data analyzed thus far suggest that oyster biomass density at small scales (0.1 m²) can be a good predictor of the biomass of associated macrofauna in some seasons. However, these patterns are sometimes complicated by species-specific responses to other factors driving the biomass of seasonally abundant species (e.g. *Molgula manhattensis*).

In 2016, researchers developed a suction sampling technique that enables them to collect macrofauna samples from all subtidal habitat in Harris Creek, allowing for direct comparisons of macrofaunal communities across habitats. In 2017, suction samples were collected in April, June, August, and October from restored reefs, seagrass beds, and a range of soft-sediment habitats. All field sampling for this project has been completed; data processing and analysis are ongoing.

**“Integrated Assessment of Oyster Reef Ecosystem Services” Project 3: University of Maryland Center for Environmental Science (UMCES), “Integrated Assessment of Oyster Reef Ecosystem Services: Quantifying Denitrification Rates and Nutrient Fluxes,” (PI Jeff Cornwell).** This project seeks to quantify denitrification rates in relation to reef age, assess seasonal patterns in denitrification and nutrient fluxes, and estimate annual rates of denitrification. Denitrification is the process that transforms biologically available nitrogen, such as nitrate (NO₃), into relatively inert nitrogen gas (N₂).

Researchers completed field work in early June and late August 2017; they have completed the field work aspects of the project and are analyzing all of the data, including relating the biogeochemical flux parameters to the biotic composition of the restored reefs. Initial results indicate reefs process a considerable amount of nitrogen in the form of biodeposits, resulting in increased microbial removal of nitrogen relative to surrounding sediments. Researchers also explored how much oysters, rather than sediment, contribute to total oyster reef denitrification. By looking at clumps of oysters plus sediment vs. just clumps of oysters, they found that oysters without sediment have high rates of denitrification and nutrient fluxes on restored oyster reefs. This suggests that studies of sediment alone are insufficient to characterize these ecosystems.
“Natural Engineers in Ecosystem Restoration: Modeling Oyster Reef Impacts on Particle Removal and Nutrient Cycling.” UMCES (PI Lora Harris). Researchers on this project are developing an enhanced computer model to describe how oyster reefs benefit the ecosystem, incorporating processes related to nutrient cycling and oyster bioenergetics. The model simulates the movement of particles in the water column to track algae through filtering oysters and into sediments where the particles are either recycled as nutrients back to the water column, or removed as nitrogen gas. By focusing on oyster biology, hydrodynamics, and biogeochemistry, the model helps to increase understanding and prediction of nitrogen removal as a consequence of oyster reef restoration. In 2017, researchers used a filtration model to look at daily cycles in phytoplankton and chlorophyll abundance, and found the different reefs have different chlorophyll removal efficiencies, which depend on reef size, density of oysters, and site hydrodynamics. Looking forward, researchers want to add in sediment flux on the oyster shells, and to validate their improved model by using actual data from Harris Creek reefs.

“Application of Dual-frequency Imaging Sonar to the Study of Oyster Reef Ecosystem Services.” Smithsonian Environmental Research Center (SERC) (PIs Matthew B. Ogburn, Anson H. Hines). This project is helping to assess fish and crab utilization of restored oyster reefs by conducting a multiyear survey of fish and crab abundance in restored reefs and control sites using DIDSON (dual-frequency identification sonar) acoustic camera. In 2017, researchers continued with 10-minute recordings at each site monthly from June through October.

Researchers are investigating whether the abundance of fish or crabs differs by habitat type (rock and oyster seed; mixed shell and oyster seed) in the Tred Avon River oyster restoration project area. On both types of restored reef, they found seasonal variation in fish abundance from June to October, but little pattern for crabs. Initial results showed an increase in abundance of fish greater than 150mm during the summer on rock and seed reefs.

This project is also exploring whether the abundance of fish or crabs differs between on- and off-reef sites in Harris Creek. While overall abundance was less in 2017 than it was in 2016, in general, fish greater than 150mm were more abundant on the reef sites in both 2016 and 2017; researchers did not discern any consistent patterns for small schooling fish or crabs.
Researchers continued their work to describe reef habitat quality in tributaries of the Choptank River by analyzing hard substrate coverage (whether it be biogenic or anthropogenic) and the quality of that coverage (using a scale from 1 to 4 of reef quality). Harris Creek had the highest percentage of high scores; other tributaries rated were the Little Choptank and Tred Avon rivers and Broad Creek.

“Ecosystem Services of Restored Oyster Reefs in the Lower Chesapeake Bay.” Virginia Institute of Marine Science (VIMS) (PIs Rom Lipcius and Rochelle Seitz). This project uses fish traps, underwater video, and gill nets in the Great Wicomico, Lafayette, Piankatank, and Lynnhaven Rivers, Virginia, to quantify fish and crab use of different kinds of reefs. Researchers are examining lower Bay tributary oyster populations using a patent tong survey. They found that sanctuary reefs in the Great Wicomico River are doing well except when they exist on mud bottom or where poaching has occurred, and a small area in the Lynnhaven River where a storm washed away a constructed reef.

Researchers are also looking at the benthos by examining benthic community structure on restored reefs using trays. Results so far indicate that restored oyster reefs support diverse and productive macrofaunal communities; the community composition differs depending on the river, and salinity appears to be a driving factor of diversity. Total live oyster volume was a positive and significant predictor of mean macrofaunal density and biomass.

The project is also determining finfish and blue crab utilization of oyster reefs in relation to reef and environmental conditions using gill nets, and investigating prey availability by doing gut content analysis. One notable finding is that silver perch consumption rate and caloric intake were greater on the reef than on a reference site.

Using underwater cameras, researchers are examining the roles of crabs on an experimental natural reef as both predator and prey. Juvenile crab survival was higher on the oyster reef than on bare sand.

“Pathways to Production: An Assessment of Fishery Responses to Oyster Reef Restoration and the Trophic Pathways that Link the Resource to the Reef.” Virginia Commonwealth University (VCU) (PI Steve McIninch). This project focuses on quantifying fish utilization of reefs and other areas in the Piankatank River. During sampling, researchers found little variation in diversity or density of pelagic fishes among habitat types. They did note significant variation at different times of the year and day vs. night, but the differences were similar among reef and off-reef habitats. In 2017, researchers added 137 randomly selected sites to investigate whether distance from reef may be related to movement and density of pelagic fishes. Initial analysis indicates that pelagic fishes of commercial catch size were more frequently found around reefs (but not all reefs) at night. Researchers continued gut analysis; they investigated 547 stomachs, mostly from three highly mobile fish predators (striped bass, bluefish, cobia) and three bottom foragers (Atlantic croaker, spot, southern kingfish). Those predators were found to consume mostly fishes and mudcrabs; the bottom forager’ diets were more varied but were dominated by crustaceans, polychaetes, and detritus.
NCBO and Partner Ecosystem and Economic Modeling

NOAA staff members are collaborating with researchers at Morgan State University to estimate ecosystem services—including fisheries production and nitrogen removal—before and after large-scale oyster reef restoration in selected Bay tributaries. The goal is to examine how these ecosystem services generate regional economic effects including dockside revenues, income, and jobs.

These researchers developed five realistic oyster reef management scenarios using previously collected data on biomass and density estimates for key living resources associated with the Choptank River complex. Each management scenario produced an estimate of finfish and shellfish harvest for key species. These estimates were then used in conjunction with dockside sales prices and regional economic impact modeling software to estimate the regional economic effects. Model projections for the full Choptank complex suggest:

- Newly restored reefs allow for a 50% increase in blue crabs available, relative to prerestoration conditions.
- When new oyster reefs are allowed to mature in a sanctuary, the model predicts a more than doubling of the amount of blue crabs available, compared to the same prerestoration conditions. Corresponding increases in the harvest of blue crab and other species could yield total economic impacts of approximately $20 million annually to Dorchester and Talbot counties.

Their final report is expected in November 2018.

Next Steps

Work in all three aspects—NCBO field study (data analysis), NCBO-funded research at partner institutions, and ecosystem and economic modeling—of ORES continues in 2018. ORES project partners plan to meet, as they have for the past several years, in early 2019 to share ideas and information. One topic they plan to explore is collaborating on a special journal edition to share all their results and discussion as a final synthesis project.

ORES PIs discuss data and collaborate on future plans at their annual meeting held in early 2018.