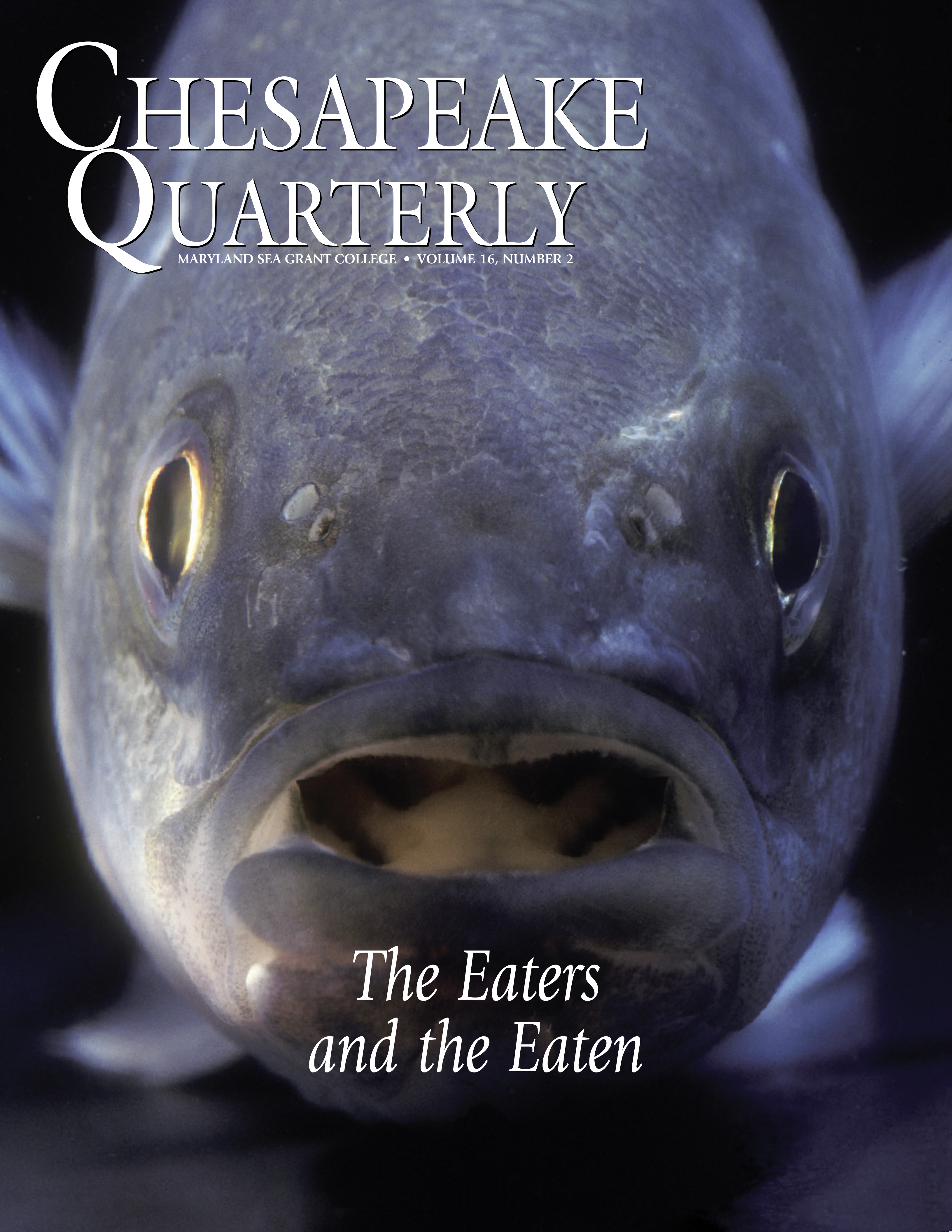

Chesapeake Quarterly

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The Eaters and the Eaten

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Cover photo: *Striped bass like this one can grow to 60 pounds or more, making them among the top predators in the Chesapeake Bay and one of its most iconic fisheries. New scientific research has examined what stripers and other predators eat and how much — knowledge that may assist fisheries managers to ensure that harvests remain sustainable.* PHOTOGRAPH, DAVID HARP

Small Fry, Big Deal for Fisheries

Stories by Jeffrey Brainard

The anglers were out at their favorite spots on the Chesapeake Bay this summer, as usual, dropping lines in the water. Near Sandy Point State Park on the western shore, some kayaked out to catch black drum under the Bay Bridge. On the opposite side of the estuary, off the Bill Burton Fishing Pier on the Choptank River, others cast for white perch and sea trout. And out on the estuary's mainstem, fishers participated in the world's largest striped bass tournament, the annual Championship on the Chesapeake.

For those of us who like to catch fish for our dinner plates, or to sell, or just for fun to release, keeping Bay fish stocks healthy and sustainable is a vital concern. Many people involved in fisheries management agree that a critical ingredient to ensure that the estuary's fisheries are sustainable is a better scientific understanding of the connections between these popular fish species and the ecosystem where they live. One of these important connections is the abundance of small fish, worms, shrimp, and other creatures that provide food for the larger fish species that we like to catch.

In recent years, those interactions between predators and prey have been the subject of new scientific studies and tools. This issue of *Chesapeake Quarterly* examines information and approaches that resulted from this research and how they are helping increase the knowledge base needed for effective fisheries management.

The first article ("Who's Eating Whom in the Chesapeake Bay," opposite page) takes readers aboard a research cruise that's part of a long-running project called ChesMMAP to collect important data about Bay predators and what they eat. Two other articles describe separate efforts: "Counting the Fish in the Sea" (page 11) examines fresh research findings about the population dynamics of menhaden, a small fish important both for commercial harvest and as a prey species. "Guess Who Came for Dinner?" (page 14) describes how scientists are developing techniques of DNA sequencing to identify precisely the stomach contents of the estuary's predator fish.

It's good timing for these efforts. In 2014, officials revised the Chesapeake Bay Watershed Agreement, a document that guides regional efforts to improve water quality, and the new version calls for a strategy to assess stocks of the Bay's prey species. In addition, the Atlantic States Marine Fisheries Commission, a regulatory body, is considering a new approach for setting commercial harvest limits for menhaden; it would be designed to leave enough menhaden in the water to sustain populations of predator fish, such as striped bass.

These developments reflect a growing interest among natural resource managers in the Mid-Atlantic region to learn more about the many prey species that the prized, larger predator fish depend on for food — and to apply this knowledge to the ongoing work of managing fish stocks in the Chesapeake Bay and along the East Coast so that they remain sustainable, not overfished, and part of a healthy, balanced ecosystem for years to come.

— *brainard@mdsg.umd.edu*

WHO'S EATING WHOM IN THE CHESAPEAKE

Fish stomachs yield clues useful for managing the estuary's fisheries

***Striped bass** are known to eat juvenile blue crab, another iconic Chesapeake species, shown here in a grass flat in the Bay's Tangier Sound. Researchers say more data are needed to know exactly how much.* PHOTOGRAPH, JAY FLEMING

The boat is bobbing up and down on a late spring day on the Chesapeake Bay. The previous day was rainy, and tomorrow will be, too. But this crew is on a mission, and they work through bad weather.

They're aboard the R/V *Bay Eagle,* the 65-foot-long, main research vessel of the Virginia Institute of Marine Science (VIMS). About four miles east of Chesapeake Beach, they've arrived at the first stop of the day on a planned route in the estuary's Maryland portion.

Captain John Olney Jr. sounds a horn, the signal for VIMS marine scientist Gregg Mears to begin deploying a trawl net wrapped on a big spool mounted above the stern. Commercial trawling isn't allowed in the Chesapeake, which makes this operation an unusual sight. But trawling can be useful to study the estuary's fish populations, which is what this crew is doing today.

The ship motors at a constant three knots for exactly 20 minutes. The scientists winch up the net and steer it onto the deck. A mass of marine life squirms at the bottom of the net. By trawling the same way each time across many locations in the Bay, scientists can turn the wet piles they collect into reliable data about fish populations in the Chesapeake Bay, America's largest estuary.

The net is unloaded and disgorges 13 striped bass, which are among the estuary's top predator fish and are prized by both commercial and recreational fishers. The scientists sort and measure them. They will also examine the fish to find out what's inside their stomachs — what kinds of little fish and other small creatures are they eating? The scientists on this ship are fish detectives, and they're gathering clues.

The clues are helping them and other researchers solve mysteries about the Bay's larger fish and the smaller fish they eat. Knowing more about how they interact could help fisheries managers better manage stripers and other big fish. Among the mysteries still to be solved: why have populations of some important larger species, like Atlantic croaker and summer flounder, declined?

An Ecosystem-Based Approach

In 2001 two VIMS fisheries scientists, Rob Latour and Chris Bonzek, attended a meeting at the Chesapeake Biological Laboratory (CBL) in Solomons, Maryland, a part of the University of Maryland Center for Environmental Science. The topic was how to apply a new approach in fisheries management, called ecosystem-based fisheries management, in the Chesapeake Bay. The idea behind this approach is that to set sustainable harvest levels for larger predator fish species, you have to take a broad view. You have to study and consider the many influences within the ecosystem where the fish live that influence their survival. For one, you have to pay attention to what the predator fish eat.

Bonzek had recently attended a meeting in Canada about studying fisheries and ecosystems. An important point, Bonzek recalls from that discussion, was that "if you are going to go down this path towards multispecies or ecosystem-based management, the main thing you need on top of your routine monitoring is the diet data — who is eating who, and how much." Latour adds, "I realized we didn't have a lot of data on this, even though the Chesapeake Bay is a data-rich area."

Bonzek and Latour knew that finding out more about fish diets would require collecting a lot of data in a more comprehensive way than ever before.

An early study in the estuary showed how it might be done here. In the early 1990s, Kyle Hartman was a Ph.D. student at CBL. Working with his adviser, Stephen Brandt, Hartman caught some of the Bay's top predator fish — bluefish, weakfish, and striped bass — off the lab's dock in Solomons. He cut them open and identified their stomach contents. Hartman published some of the first scholarly studies about what these species were eating. But the work had its limitations. It was focused at just one location in the Chesapeake, whose length stretches 200 miles from its mouth at Virginia Beach to its top at Havre de Grace, Maryland.

After Bonzek and Latour's meeting at CBL, as they made the long drive back to VIMS, they tossed around an idea. Could they team up on a survey that would collect these kinds of detailed data about what the big predator fish species were eating over the entire expanse of the Bay?

Latour was a freshly minted Ph.D. looking for a substantial research project. He and Bonzek had lined up some funding that would allow VIMS to piggy-back additional data collection work onto some existing research cruises that Bonzek was overseeing to monitor striped bass and other economically important predator fish in Virginia waters.

In 2002 the new project was born, christened the Chesapeake Bay Multispecies Monitoring and Assessment Program or ChesMMAP. Bonzek and Latour originally figured they could run the project for at least a year and then judge whether to go on. In the end they garnered funding and support to keep it going to this day. Scientists go out on the *Bay Eagle* and collect samples of predator fish five times a year along nearly the entire length of the Maryland and Virginia portions of the Bay. The project has created one of the largest databases

The **Predators** and the **Prey**

To find out who is eating whom in Chesapeake Bay, scientists looked inside the stomachs of predator fish. There they discovered that these five important predators did much of their dining on these 10 species of prey. Surprisingly, a large part of their diet was small invertebrates, animals like mysids and worms that have no backbones. And these five predators also feed on the young of other fish, especially on small spot, croaker, and weakfish.

This chart maps out the major food sources for these predator fish, based on data collected from 2002 to 2012. A fat line linking predator and prey means more of that prey showed up in that predator's diet. A thinner line means less.

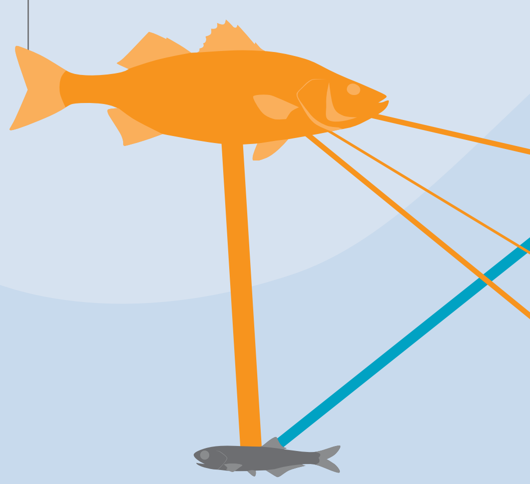
Striped bass
Morone saxatilis

Size: Up to 36 inches

Life span: Up to 30 years

Key facts: Up to 90 percent of the Atlantic striped bass population spawn in the Chesapeake Bay's fresh water. As adults, some stripers migrate into the Atlantic Ocean.

Favorite prey: Bay anchovies



Bay anchovy
Anchoa mitchilli

GRAPHIC: NICOLE LEHMING; SOURCE: SCIENTIFIC AND TECHNICAL ADVISORY COMMITTEE, CHESAPEAKE BAY PROGRAM

Atlantic croaker
Micropogonias undulates

Size: Up to 24 inches

Life span: Up to 8 years

Key facts: Born on the continental shelf in the Atlantic Ocean, these fish enter the Bay to grow larger, eventually migrating back to the ocean to spawn.

Favorite prey: Worms

White perch
Morone americana

Size: Up to 10 inches

Life span: Up to 17 years

Key facts: Though a relative of the striped bass, this fish spends its entire life in the Chesapeake Bay.

Favorite prey: Worms

Summer flounder
Paralichthys dentatus

Size: Up to 22 inches

Life span: Up to 20 years

Key facts: Born in the Atlantic Ocean along the continental shelf, larvae drift into the Bay in fall and winter. Once adults, flounder migrate back to the ocean.

Favorite prey: Mysids

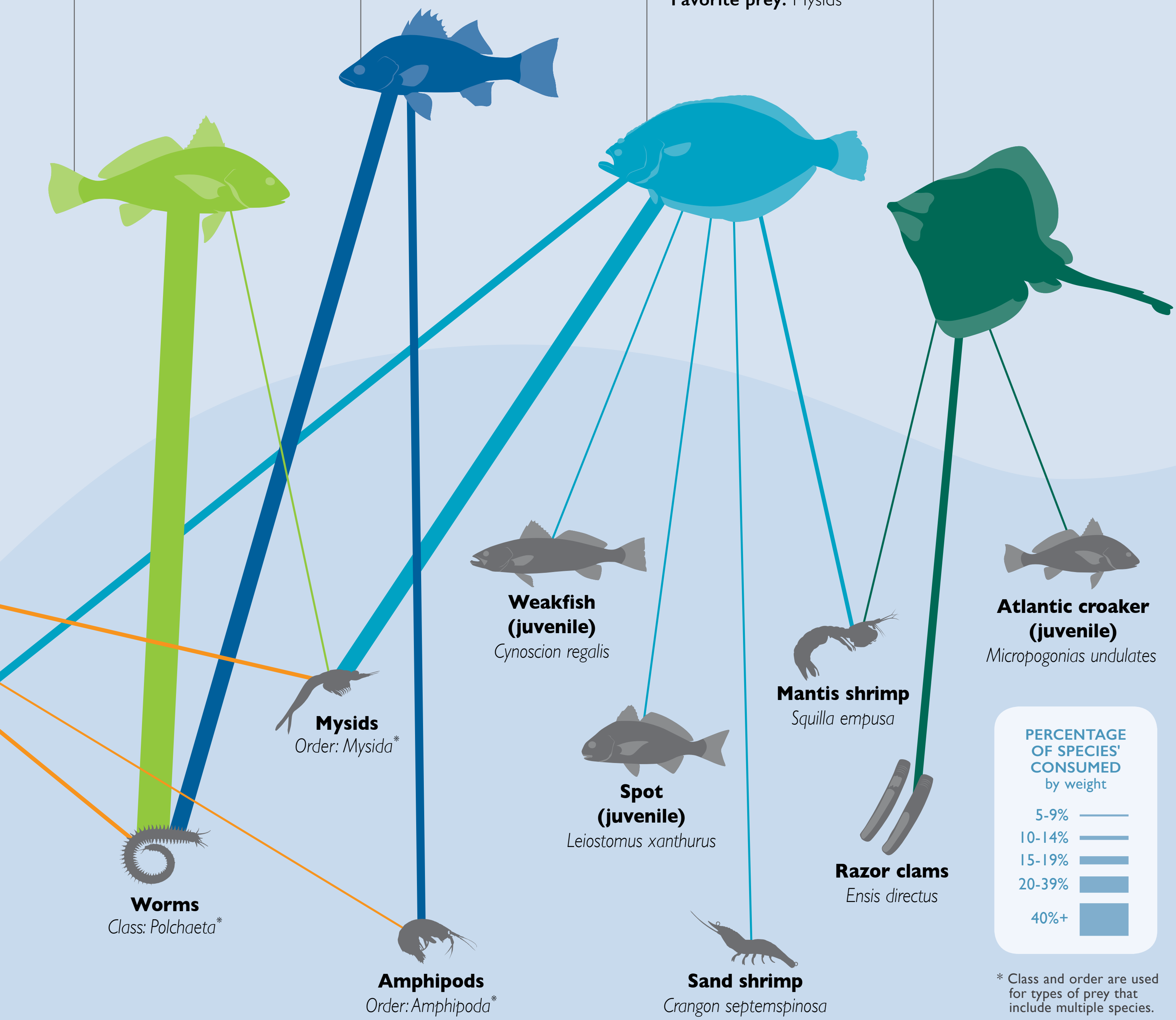
Clearnose skate
Raja eglanteria

Size: Up to 30 inches

Life span: 5 years or more

Key facts: They live primarily in salty water near the Bay's mouth in Virginia.

Favorite prey: Razor clams



about fish diets in any estuary in the world. And that database has emerged as an important tool for scientists in Maryland and Virginia who are working together to understand more about fish food in the Chesapeake.

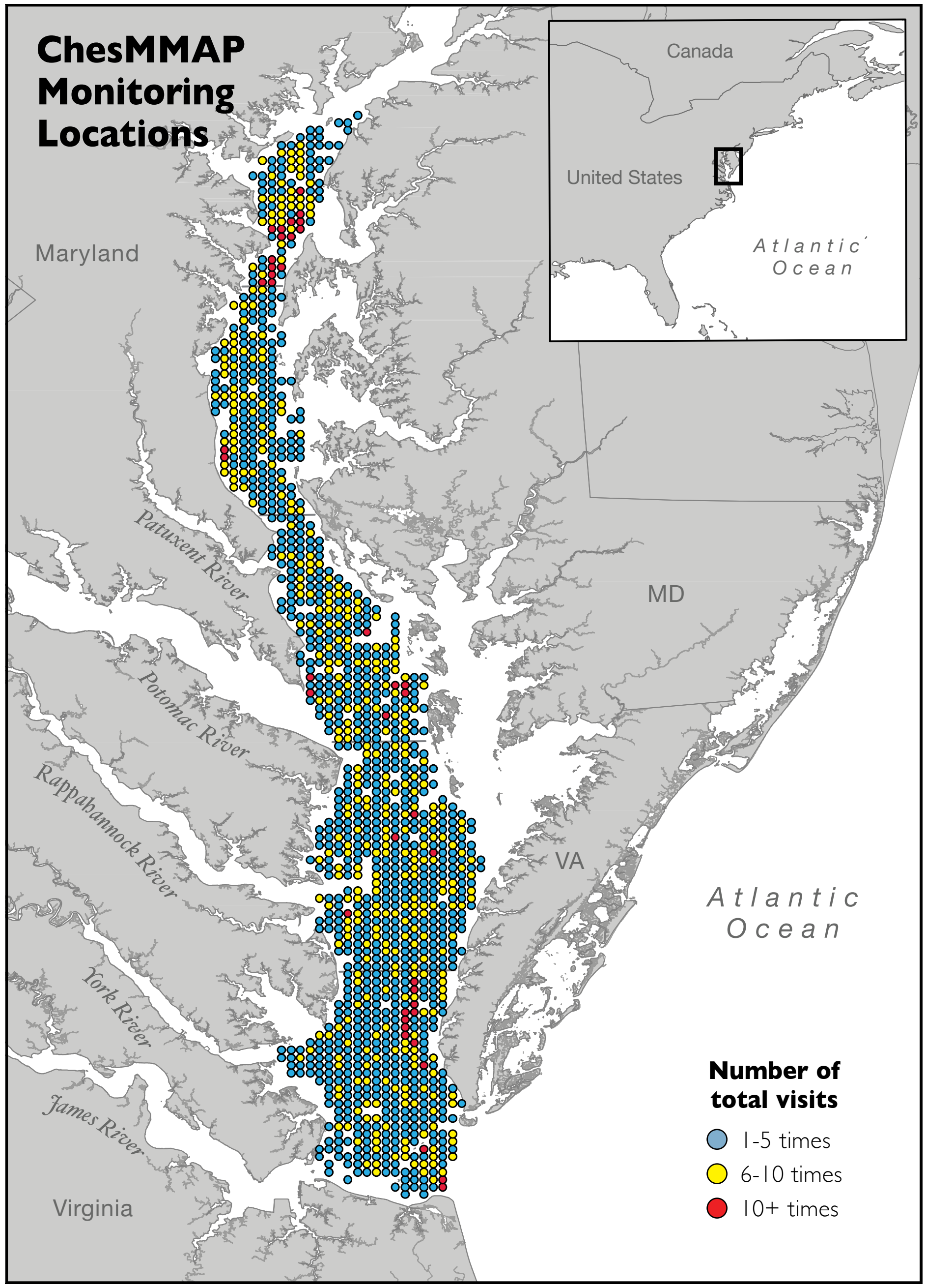
Trawling for Data

Aboard the *Bay Eagle,* VIMS marine scientist Gregg Mears drops the trawl net again. The *Bay Eagle* is just off Kenwood Beach on the Bay's western shore, its net skimming the bottom 27 feet below.

Mears and the other crew members have the procedures of trawling down well — they traveled to a university in Newfoundland, Canada, to go through a special training program there. During each cruise, the ChesMMAP crew will raise and lower their trawl net many times, collecting samples at approximately 80 locations across the Maryland and Virginia portions. Avoiding underwater obstacles in a shallow waterbody like the Chesapeake Bay is a constant challenge. The network of ChesMMAP monitoring stations omits the estuary's upper section, north of Pooles Island, because it contains so many submerged trees that the researchers call it Sherwood Forest. Lower in the Bay, Captain Olney occasionally has to back up the *Bay Eagle* to free the net when it snags on something. The crew continually maps these obstacles on GPS so the ship can avoid them on future cruises.

Each cruise takes about eight days to complete. The crew bunks onboard in sleeping bags. That can mean a lot of days away from family. Mears keeps a close eye on whether the cruise dates conflict with his daughter's twice-a-year dance recitals.

Still, he says, "It's the best job I've ever had." The work can contribute to managing Chesapeake Bay fish populations, he notes, both as a food resource and as part of a healthy, balanced ecosystem. "Humans have a tendency to not be good stewards of the environment and to push things out of whack. I'd like to think some of what we do helps to bring things back in balance."



***Since 2002, the ChesMMAP research project** has run five annual cruises, each of which collects fish at 80 randomly selected stations spread around the Bay. That adds up to more than 5,800 stations sampled and a massive trove of data on fish diets. This map shows the locations and frequency of past visits. Each circle represents a square mile; some circles contain more than one monitoring station.* MAP, VIRGINIA INSTITUTE OF MARINE SCIENCE

What the scientists catch in the trawl net varies with the season. In the spring, striped bass are plentiful as they migrate from the Atlantic Ocean up the estuary to spawn. In late fall, the stripers migrate back out to the ocean. Atlantic croaker (also called hardheads) turn up in greater numbers in summer months, migrating back to the ocean by around September.

As the *Bay Eagle*'s trawling run off Kenwood Beach ends, the crew members spring into a flurry of coordinated action. They haul up the trawl net, which is again squirming. This time it contains five stripers, two white perch, and one menhaden. For each species caught, the scientists sort each individual by size. Bigger, older fish tend to eat different kinds

***A long-running project** by the Virginia Institute of Marine Science (VIMS) has provided insights into the feeding habits of populations of predator fish in the Chesapeake Bay. The VIMS crew hauls in a sample using a bottom trawl net (above left). On the* Bay Eagle*'s shipboard lab (above right), Alex Johnson and Rebecca Hailey weigh and process fish for further analysis. Back at VIMS, Gregg Mears (bottom) examines and weighs the contents of predators' stomachs.* PHOTOGRAPH, VIMS (TOP LEFT); JEFFREY BRAINARD (TOP RIGHT AND BOTTOM)

of prey than smaller, younger ones do, and the scientists want to track those differences to build a detailed picture of consumption patterns.

Mears measures the length of each fish. No need to use a tape measure. He simply places each one on a FishMeter, a sensing device that looks like a large ruler. He touches an electronic sensor at the fish's tail, and its length is automatically recorded on a shipboard computer. Then on to the next fish, and the next.

To find out what the fish are eating, the scientists pick out up to five individual fish from each size group within each species. Why only five? Other fisheries research has shown that this sample size is highly representative of the rest of the fish from that species caught in the net as well as others left swimming in the estuary. That's because fish of similar ages tend to gather in the same school and feed together.

The representatives are brought below deck to a shipboard lab. In these cramped quarters, trawling chief Dustin Gregg and research specialists Alex Johnson and Rebecca Hailey have set up a kind of assembly line. They collect additional data about each fish, including its precise age, which they determine by removing its otoliths — bone-like mineral deposits in its head bearing rings that record age, like tree rings do. The scientists remove each fish's stomach and store it in preservative for later analysis. It's one more set of clues relevant to knowing who is eating whom in the Chesapeake.

Clues Inside the Fish

Once a ChesMMAP cruise ends, Mears returns to a bigger lab at VIMS, in Gloucester Point, Virginia. This is where he will analyze the stomach contents.

Mears sits at a lab table in this white room and carefully unties a cheesecloth bag that contains a fish stomach. Some people call him and his colleagues the "fish medical examiners" because of what they do next. He cuts open a stomach from a striped bass. Inside Mears finds two menhaden, a favorite prey of stripers. He measures them and records the details in a computer database.

On to the next fish stomach. These contents are harder to identify. There's a soft pulp; before the fish was caught, it had partially digested whatever living thing this was. Mears marks down the material as "unidentified." For some species, that mystery category describes a significant portion of the total stomach contents by weight — 15 percent for Atlantic croaker, for example. The ChesMMAP data can only reveal so much about fish diets. "We do the best we can with what's in front of us," Mears says.

The stomachs yield more than fish flesh. Mears displays a tray of objects that he and his colleagues have pulled from fish stomachs over the years. There's a rock the size of your palm. There are also shell pieces from blue crabs and vertebrae from skates.

In a single day, Mears can process as many as 80 fish stomachs from ChesMMAP. During the past 15 years, more than 47,000 ChesMMAP stomachs have passed through this room. That's a lot of fish guts — and data.

The ChesMMAP survey *began in 2002 when scientists Rob Latour (top, left) and Chris Bonzek (top, right) of the Virginia Institute of Marine Science secured funding to launch the project. They have worked with scientists Ed Houde (bottom, left) and Ryan Woodland (bottom, right) of the Chesapeake Biological Laboratory in Maryland to analyze the data collected. Houde and Woodland have examined how environmental factors like springtime temperatures can affect the abundance of prey species eaten by larger predators.* PHOTOGRAPHS, JEFFREY BRAINARD (TOP), NICOLE LEHMING (BOTTOM)

The ChesMMAP project had collected more than a decade's worth of data when in 2014 a new effort was launched to sift through and interpret the clues that the fish detectives had so carefully and steadily collected. The Chesapeake Bay Watershed Agreement, a document that guides planning efforts among the federal and state partners working to improve the estuary's water quality, was revised that year. The updated agreement called for evaluating the Chesapeake's "forage fish base," a term scientists use to describe prey eaten by larger predatory fish species.

The Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) took up the call. The committee held a workshop of scientists, who pored over the ChesMMAP data and generated a report that offered surprising new insights about which forage species were most important in the diets of the predators.

The workshop report focused on the feeding patterns of five predators deemed representative of all Bay predators because of their variation in body type and behavior: Atlantic croaker, clearnose skate, striped bass, summer flounder, and white perch. The report's authors, among them Chris Bonzek and Tom Ihde, identified which forage species showed up in the stomach contents of each of these five. Forage species were deemed "important" food sources if they represented at least five percent by weight in the stomach contents of at least one predator collected during a single ChesMMAP survey trip. "Key" forage species were those that showed up in more than one predator's stomach.

Overall, the predators had an extensive dining menu, but only ten Bay species were "key." The leading one was a small but mighty fish, the bay anchovy. This species measures only about four inches long but is the most abundant fish in the Chesapeake.

Another prey fish, Atlantic menhaden, widely known to be a staple of the striped bass diet, didn't make the select list of "key" forage species — the other predators didn't favor it as much — but did make the list of "important" species, of which there were also ten.

Although bigger fish were eating smaller fish, a striking finding was that bigger fish were also eating plenty of invertebrates. These small creatures lacking backbones were six of the ten key prey species, the analysis found — animals such as mysids (shrimp-like crustaceans), marine bristle worms (a class called Polychaetes), and mantis shrimp. That abundance was notable because predators more quickly and completely digest soft-bodied invertebrates like worms than they do bony fish, leaving fewer clues in their stomachs. The soft invertebrates may be even more abundant in fish diets than the analysis suggested.

Unexpectedly the ten key forage species also included juvenile fish from three species of Bay predators: Atlantic croaker, spot, and weakfish. These young fish were small enough that they offered easy pickings for bigger, older predators. Juvenile fish abound in the Chesapeake Bay because it is the most important nursery area on the East Coast for these and other Atlantic Ocean species. But this nursery is also a dining hall.

Is There Enough Food?

The STAC workshop raised additional questions beyond what predators were eating. How much fish food does the Bay contain overall? Is it enough for the larger predator species? How does the abundance of food change over time?

Some fresh insights came in a 2016 report by fisheries scientists Andre Buchheister and Ed Houde of the Chesapeake Biological Laboratory. Buchheister, a postdoctoral researcher, expanded on studies of fish diets that he had begun at VIMS as a graduate student of Rob Latour's. Buchheister and Houde merged data from ChesMMAP and other sources to create a set of indices estimating abundances over time for different kinds of forage species and predator fish.

What they found was striking. The populations of many types of forage fish and invertebrates had remained largely stable since ChesMMAP began collecting data about the bigger fish in 2002. But the top predators themselves were eating less of this food during this period. That was because, other than striped bass, most of the other top predators studied had declined in abundance. There were fewer Atlantic croaker, spot, summer flounder, and weakfish in the estuary.

"We're hearing anecdotal observations of anglers around here saying, 'I can't catch any flounder any more. Where are all the flounder?'" Latour says. "That is a scary sort of prospect." Like striped bass, these species are popular among recreational fishers and important players sitting at the apex of the Bay's food web. "When some species start to decline," he says, "it does have cascading effects, albeit it can be difficult for us to measure sometimes. If it goes too far in one direction, you get things out of sync."

Where have the predators gone? The stability of the forage indices may rule out one possible cause — that there is not enough food in the estuary for the bigger fish to eat, Latour says. Other causes might be at work. Latour says one might be climate change. As waters in the Chesapeake Bay and coastal Atlantic Ocean warm, the ranges of these species may be shifting northward as the fish seek cooler waters.

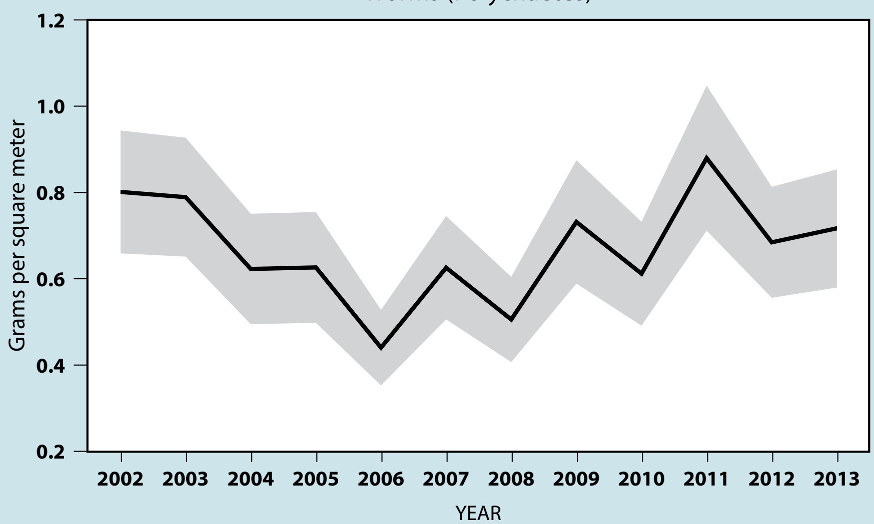
Fisheries scientists may need to consider other effects of a changing climate on the forage species in the Bay and the predators that eat them. Ryan Woodland, also of the Chesapeake Biological Laboratory, has worked with Buchheister, Houde, and Latour to study how populations of forage species vary under a variety of environmental conditions. One finding is that in years when springtime came early to the Chesapeake — when the estuary warmed up relatively early in

Stable Prey, Declining Predators

Scientists have measured the abundance of prey species and the predator fishes that eat them in the Chesapeake Bay. For many of the most-consumed types of prey, abundance has been stable since 2002. But for several species of predator fishes, the number has declined. Fisheries scientists continue to explore why the number of predator fishes fell while the amount of food available for them to eat did not.

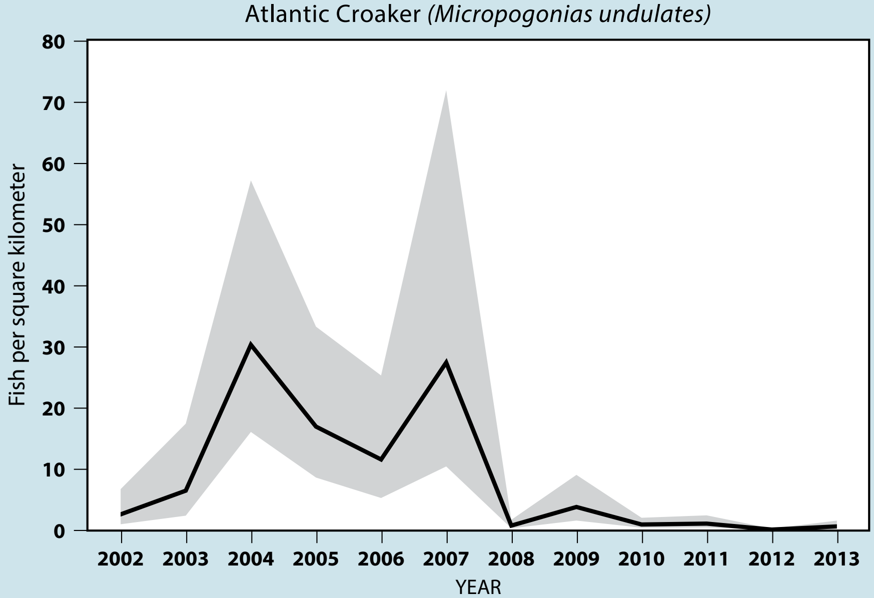
The prey (worms) and predator (Atlantic croaker) shown here represent these trends. Abundance is shown using different, but comparable, calculated measures: total weight for worms and number of fish for croaker.

PREY ABUNDANCE
Worms (Polychaetes)



Note: Gray areas represent margins of error.

PREDATOR ABUNDANCE
Atlantic Croaker *(Micropogonias undulates)*



Note: Gray areas represent margins of error.

SOURCES: ANALYSES OF CHESMMAP AND OTHER SURVEY DATA BY ANDRE BUCHHEISTER, ED HOUDE, AND CARLOS LOZANO FOR THE CHESAPEAKE BAY PROGRAM'S SUSTAINABLE FISHERIES GOAL IMPLEMENTATION TEAM AND THE CHESAPEAKE BAY TRUST the year — forage species were affected in different ways. For invertebrates, like worms, an early spring was associated with higher abundances in Bay tributaries. But for forage fish, like Atlantic silverside, the effect was lower abundances in the Bay's mainstem.

Informing Management

Scientists hope that by identifying and exploring interactions among predators, their prey, and environmental conditions, they can provide natural resource managers with useful new tools for managing both predators and prey at sustainable levels.

"If we can pinpoint conditions that are particularly good or particularly bad for forage, then we can also have an idea of when there is going to be a lot of food available for these predators that we love to catch and eat," Woodland says. "The dream is to have this sort of information available to fisheries managers so when they are making the decisions about harvest limits or size limits, they have the information to say, there's going to be a lot of food available for striped bass this summer, so we don't have to worry about it being a poor year for stripers based on food alone."

But if evidence indicates the populations of forage species have declined that year, fisheries managers might decide to compensate by lowering the allowable harvest of a predator like striped bass. That could avoid what might otherwise be a decline in the striper population that might persist into future years. The fisheries managers could add data about forage availability to the other data they now consider — such as how many young stripers hatched recently — to generate more accurate answers to the key question: how many stripers can be safely and sustainably harvested over time without overfishing the population?

Managers have a limited set of other tools to reverse any decrease in the abundance of forage species that might occur in the future. With little exception, most types of the key prey species are not directly regulated. One management option is to increase the acreage of healthy nursery grounds for forage fish, such as underwater grass beds in tidal marshes and creeks; increasing these is also a leading goal of the Chesapeake Bay Watershed Agreement. Information about where prey species are abundant could help managers target the restoration efforts to protect and increase that abundance. This information might also influence decisions about shoreline development. Studies by the Smithsonian Environmental Research Center found that after property owners installed bulkheads to control shoreline erosion, forage abundance in adjacent Bay waters declined.

The recent research findings about predators and forage are helping to support the development of ecosystem-based fisheries management in the estuary, says Bruce Vogt, a scientist with the National Oceanic and Atmospheric Administration who coordinates a Chesapeake Bay Program committee on sustainable fisheries. "I think we've made significant progress in a short period of time," he says. But more work remains. "Our next step is to figure out how to best serve those findings up to managers in a way that they can utilize them."

Finding ways to manage prey species may require more research to puzzle out some remaining mysteries about them.

An important one is to plug gaps in information about the abundance of forage fish. The ChesMMAP trawl net is designed primarily to catch the larger predator fish; smaller prey fish can slip through. Other monitoring programs run by VIMS and the Maryland Department of Natural Resources use different nets designed to capture smaller, forage fish, but collectively these programs do not cover as wide an expanse of the Bay as ChesMMAP does. VIMS expects to collect more extensive data about forage fish starting in 2018 when it launches a new research vessel to replace the *Bay Eagle*. Unlike its predecessor, this 93-foot vessel will be large enough to deploy two different kinds of trawl nets at a single location, one designed to catch bigger predator fish and another to snare small prey fish.

Another mystery to be solved is how well the forage species themselves are fed. The 2014 STAC report called for a Bay-wide survey to count zooplankton, the tiny crustaceans and other creatures floating in the estuary. These form the foundation of the Bay's food web and provide food that the forage species eat. Such data have not been collected in the Chesapeake Bay since 2002, when funding for a survey that collected zooplankton ended.

Yet another need, cited in the STAC report, is for better sampling of forage species in the Chesapeake's shallow, near-shore waters, which support the underwater grass beds where many forage species live. Neither the *Bay Eagle* nor its successor can collect fish in depths shallower than about 12 feet. One consequence is that blue crabs, which make up the Bay's largest commercial fishery by value and which frequent the shallows, may be undercounted as a significant source of prey for predator fish.

Unraveling these mysteries requires scientists and resource managers to take the kind of broad view of the Chesapeake Bay espoused under an ecosystem-based fisheries management approach.

"There has been a lot of work on individual components of the forage" in the Chesapeake, says Woodland. His colleague Ed Houde spent years doing seminal studies of the population dynamics of the bay anchovy and Atlantic menhaden, for example. "What no one has really done," Woodland says, "is to take the whole forage base and look at how predators are consuming that. Putting it all together into a coherent idea of what's going on at the level of the ecosystem is relatively new. I think it's really exciting."

— Jeffrey Brainard

Counting the Fish in the Sea

New evidence about menhaden could inform new approaches to managing them

Oily and bony, they measure only about a foot long as adults. But Atlantic menhaden have been called the most important fish in the sea, with good reason.

They are among the favorite dinner choices of striped bass, the finfish species highly valued by commercial and recreational anglers in the Chesapeake Bay. Menhaden *(Brevoortia tyrannus)* are fished in their own right and processed into fish oil, fertilizer, and animal feed, among other products. This commercial fishery is the largest by quantity on the East Coast.

For a fish as important as menhaden, scientists and fishery managers want to know as precisely as possible how many live in the Chesapeake and the coastal Atlantic Ocean and where they are. The regulators are responsible for regularly conducting stock assessments of the menhaden population and determining how many fish can be harvested without reducing their numbers below sustainable levels.

To estimate the menhaden population, it helps to know not only how many are born but also how many die annually, not just from fishing but also from being eaten by larger fish. Maryland Sea Grant recently funded research projects that examined in new ways the menhaden death rate and other questions, yielding some unexpected results.

The timing for an expanded understanding of menhaden is good: regulators are considering whether to use new methods to adjust their existing approach to managing the species. Researchers hope to help answer a long-standing question: do existing harvest levels leave enough menhaden in the Chesapeake Bay and Atlantic Ocean as food for predator fish, such as striped bass, that we humans in turn like to eat?

Measuring Mortality

No one can count every fish in the sea, so fisheries scientists have long relied on mathematical models to estimate numbers of menhaden and other species.

Those models are based on lots of data and assumptions about the many factors that collectively determine population size. One factor is fishing. Today, the East Coast's commercial menhaden industry is dominated by a single company, Omega Protein, which operates a fishing fleet and processing plant based in Reedville, Virginia. Other fishers catch menhaden for bait.

Another important influence on the population is natural mortality. How many menhaden die each year from natural causes, such as disease? How many are eaten by bigger fish like striped bass or by raptors like ospreys? It's notoriously difficult to quantify precisely the natural mortality of fish in the wild, but better estimates can give fisheries managers more accurate estimates of menhaden survival. If the remaining fish outnumber those lost to natural causes and fishing, the population should tend to be sustainable over time.

About five years ago, Mike Wilberg, a fisheries scientist at the Chesapeake Biological Laboratory (CBL), began thinking that the existing official estimate of menhaden's rate of natural mortality was due for an update. That meant taking a fresh look at a large set of data about menhaden collected 50 years ago.

The Atlantic States Marine Fisheries Commission, which regulates menhaden and other commercial species along the U.S. East Coast, uses a model

Atlantic menhaden *form large schools in the Atlantic Ocean and Chesapeake Bay that are sought after by fishers and predators.*
PHOTOGRAPH, NOAA FISHERIES/JERRY PREZIOSO

A commercial "reduction" fishing industry *nets menhaden to be processed as nutritional supplements and animal feed.*
PHOTOGRAPH, GORDON CAMPBELL / AT ALTITUDE GALLERY

of the menhaden population to set harvest limits, and its model includes an estimate that 42 percent of adult menhaden die each year. The estimate was developed based on studies of menhaden's biology and life cycle and also on findings from a research project on menhaden movement and mortality conducted from 1966 to 1969 by the National Oceanic and Atmospheric Administration's Beaufort Laboratory in North Carolina. During those years, researchers caught approximately one million adult menhaden, injected them with metal tags, and released them into the ocean along the East Coast. It was a massive undertaking to tag so many individual fish by hand. "I can't imagine anyone suggesting doing that study today and not getting laughed at," Wilberg says.

Some of those tagged fish were recovered when commercial fishermen brought their menhaden catches to processing plants. The companies participated in this "mark-recapture" study by installing magnets above the conveyer belts that moved large masses of menhaden through the plants; the magnets scooped up the metal tags to be collected for analysis. In all, more than 100,000 tags were recovered. By knowing how many tagged fish were released and later recovered, researchers were able to estimate how many died.

Wilberg and his colleagues wondered if they could obtain a better estimate of the natural mortality rate if they analyzed this historic data using contemporary statistical methods. They also hoped to learn new details about the migration patterns of menhaden, another important consideration in managing the species.

First the team needed the numbers in a form they could analyze. An electronic copy of the data set was lost during the 1990s, but the information had lived on, recorded on voluminous paper print-outs stored in binders stacked six feet high. Help came from the Atlantic States Marine Fisheries Commission and Maryland Sea Grant. The commission paid to digitize the data, and starting in 2014, Sea Grant funded a graduate fellow, Emily Liljestrand, who took a lead role in analyzing it.

What the scientists found was striking and challenged some long-standing conclusions about menhaden. Based on earlier studies, fisheries scientists had believed that much of the Atlantic menhaden population migrated south for the winter to warmer waters off the Carolinas.

But the new analysis by Wilberg's team indicated that about 50 percent of the menhaden in the northern part of its range — from Cape Hatteras, North Carolina, past the Chesapeake Bay to New England — remained there over the winter. That behavior may persist today. A more recent study by a master's student working with Wilberg found large amounts of menhaden larvae in the northern area, from Virginia to Rhode Island, during wintertime.

Also striking was the team's new estimate of the natural mortality rate of adult menhaden — that 69 percent of adult menhaden die each year, or more than two out of three. That was significantly higher than the estimate of 42 percent in use by the Atlantic States Marine Fisheries Commission.

Both findings could influence the future monitoring and management of menhaden. For now, the commission said in August of this year, harvest levels continue to be sustainable and the menhaden population is not overfished. But the commission has also called for considering in its next stock assessment, scheduled for 2019, whether using a better estimate of menhaden's natural mortality could improve the model.

Wilberg and other scientists say an alternative method, one that would reflect what actually happens in the ocean, would use a new approach to estimating the rate of natural mortality: it would assume the rate varies over time. The commission's existing model for menhaden stock assessments assumes that this rate doesn't change.

"For a fish like menhaden, we expect the natural mortality to be driven a lot by predation," Wilberg says. "And we know that some of their predators, like striped bass, have had major changes in abundance [up and down] over the past 50 years." As a result, Wilberg says, the annual mortality rate of menhaden probably has risen and fallen, too. The Atlantic Ocean and Chesapeake Bay are ever-changing ecosystems, so assuming that the rate of natural mortality for menhaden has remained unchanged may yield an incorrect estimate of the size of the menhaden population today.

Considering the Ecosystem

The fisheries commission has for years expressed similar concerns and is examining new approaches for estimating the menhaden population size to address this shortcoming, approaches that could showcase a new style of fisheries management.

Genevieve Nesslage, also a fisheries biologist at the Chesapeake Biological Laboratory, is supporting this effort in a separate, innovative project funded by Maryland Sea Grant.

She is developing a new mathematical model for menhaden, a hallmark of which is that it assumes the rate of natural mortality, including predation, varies over time. The model estimates future changes in the population's total biomass or fish flesh — the grand total you'd get if you counted up all the individuals in the population and weighed them one by one. Biomass can provide a more complete picture of a population than abundance alone because older fish tend to be bigger and bulkier than younger ones of the same species.

The fisheries commission spent several years working to include a variable rate of natural mortality in its mathematical model of the menhaden population. In the end, however, the agency decided not to do so because scientific reviewers weren't convinced that the approach produced reliable-enough results that improved the existing model. Nesslage has designed her model to avoid some of the technical difficulties the commission encountered. So far, she says, her model has shown promising results in tests of its ability to provide reliable estimates of menhaden biomass.

The Atlantic States Marine Fisheries Commission is considering a plan to complete by 2019 a scientific review of Nesslage's model and other approaches that use different methods to estimate the natural mortality of the menhaden population and how many can be sustainably fished. The commission would then decide whether to use any of the new approaches to help it set menhaden harvest limits.

The commission says a better model of the menhaden population should not only account for the effects of predation. It would also make useful predictions about how changes in the menhaden population conversely affect the predators that depend on them for food. Besides commercial fish like striped bass and bluefish, these predators include seabirds, such as ospreys, and marine mammals, such as humpback whales.

Managing the menhaden population with those concerns in mind reflects a new style of fisheries regulation called multispecies or ecosystem-based fisheries management. It represents a departure

Scientists Genevieve Nesslage and Mike Wilberg *(above) have been studying new ways to estimate the menhaden population.*
PHOTOGRAPH, NICOLE LEHMING

from the existing approach, called single-species management, which largely focuses on how to maximize the fishing harvest of a single species without reducing its population to unsustainable levels. The ecosystem approach presents technical challenges and requires deep understanding of many moving parts in the natural world, and so this method has yet to be implemented fully in the Chesapeake Bay region or for that matter anywhere in the United States. But Atlantic menhaden could be the first case.

Nesslage says she expects her work will shed light on the commission's first question, how do predators affect the menhaden population? But not on the second, how many menhaden should be left in the water to feed the predators?

Answering the second question, Nesslage says, "requires a ton of data, and it's still very cutting edge to even attempt to do it." But her model is a step in that direction. "We need to start incrementally moving, even if it's just small baby steps, towards a more ecosystem-based approach for managing these forage fish," she says. "Even if our approach is very menhaden-centric, it's a complement to the current model from an ecosystem point of view because it's saying that things aren't static in the environment, things are changing and affecting menhaden dynamics. So you want to try to manage them sustainably despite that fact."

— Jeffrey Brainard

Guess Who Came for Dinner?

Researchers use DNA clues to study the diets of Chesapeake Bay fish

The blue catfish has a huge appetite, and it is not a picky eater. Its dinner menu includes plants, insects, crustaceans, worms, and other fish, like menhaden, shad, and river herring.

Recreational fishers have a big appetite of their own for hooking blue catfish as trophies because of their size. The largest landed in Maryland waters, caught in 2012 in the Potomac River, weighed 84 pounds. Blue catfish *(Ictalurus furcatus)* are among the Chesapeake Bay's largest predators, and a supersize fish needs a lot to eat.

To resource managers, the blue catfish has fast become a big nuisance. The species is not native to the Bay; introduced to Virginia rivers in the 1970s as a game fish, blue catfish rapidly spread to all of the Chesapeake's major tributaries. Like a boorish dinner guest who won't leave, these fish have proceeded to chow down on a variety of native species like menhaden and blue crab that are important to maintaining the estuary's ecosystem and fishing industries.

To curb these effects, federal and state managers drew up plans in 2014 for reducing the abundance and range of this invasive species in the Chesapeake. The plans call in part for finding out more about exactly what blue catfish are eating in the estuary and where. But getting those answers is not easy. Fisheries scientists can remove and examine the stomach contents of a blue catfish. But if it ate its last meal more than 12 hours or so before it was caught, the contents may be partially digested goop, difficult to identify.

Now scientists studying Chesapeake Bay fisheries are beginning to apply new scientific tools that promise to help them learn more about what blue catfish and other predators are eating. They are using DNA sequencing, a technology used by police on TV shows like "CSI: Miami" to identify samples taken from crime scenes based on their unique genetic signatures. This technique can also yield clues about a different kind of remains — decomposed fish taken from blue catfish stomachs.

A Genetic Library

One of the scientists doing this work is Matt Ogburn of the Smithsonian Environmental Research Center (SERC), in Edgewater, Maryland. The marine ecologist is interested in how communities of fish interact with their environment and how their dining habits change as they grow older and larger and move around. Because blue catfish are voracious eaters and their populations are rising in the Chesapeake, they are a potentially useful species to study.

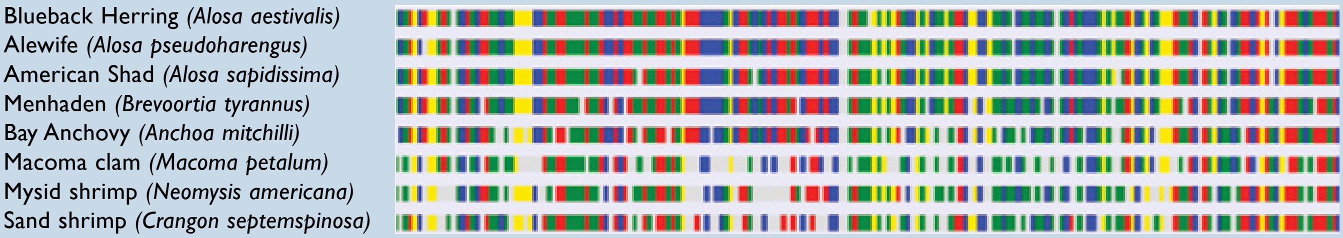
Ogburn and his colleagues suspected that DNA sequencing was a more reliable way of cataloging catfish stomach contents than the traditional method, which relies on appearance. A trained biologist has to recognize the prey species by characteristics like body shape or, for crustaceans, pieces of shells left behind in the stomach.

Using DNA sequencing can offer a more precise method. Biologists use a particular technique called genetic barcoding because it's something like scanning the unique code printed on a label on a grocery-story product. This approach is possible because of a discrete, single stretch of DNA, a gene called COI, for "cytochrome c oxidase subunit 1." COI was selected as a useful gene for DNA barcoding animal species because it is very nearly unique for many species of animals, including the smaller fish and invertebrates (animals without backbones, such as worms) that predator fish in the Chesapeake like to eat. Biologists can take the remains of an animal — even one partially digested in a catfish stomach — determine the sequence of its COI gene, and compare the sequence to a library of known COI sequences to discover which species the flesh came from.

Ogburn has used a library called the Barcode of Life Database (BOLD) developed by biologists worldwide for this purpose. But the SERC scientists knew it needed some updating before they could use it to study Chesapeake Bay predators and prey. The database contains COI sequences for nearly 12,000 species of fish, including many native to the estuary. In many cases, though, the individual fish from which those gene sequences were originally derived were caught in another region of the world. Ogburn and his colleagues knew that might complicate the job of identifying stomach contents of Bay predators. That is because within a single species, genetic sequences can vary slightly across regions. A COI sequence of a small fish appearing in the BOLD database might differ from the sequence of the same species found inside the stomach of a catfish in the Chesapeake.

The researchers, including SERC biologist Robert Aguilar, set about to plug that information gap by starting a new project called the Chesapeake Bay Barcode Initiative. In 2011, they began obtaining specimens of fish and invertebrates caught in the estuary, determined the COI sequence for each, and contributed the information to the BOLD database. So far, they've found COI sequences for more than 220 of the Bay's 315 fish species.

CSI for Fish Stomachs



These portions of a DNA segment *(above) show unique signatures of eight species of fish and invertebrates. Scientists can use this segment, named COI, to identify prey species in the stomach contents of larger predator fish, such as blue catfish, living in the Chesapeake Bay. Each color represents a separate "letter" in the genetic code contained within the DNA (except for gray, which represents a gap in the sequence). Species that are closely related tend to have sequences that are more similar than do species that are less closely related. Robert Aguilar (left), a biologist at the Smithsonian Environmental Research Center, helped develop a library of these DNA segments.*
GRAPHIC, CHESAPEAKE BAY BARCODING INITIATIVE, SMITHSONIAN ENVIRONMENTAL RESEARCH CENTER; PHOTOGRAPH, NICOLE LEHMING

The work has created a resource that can be used for other kinds of fisheries research in the future.

Dining Choices of Blue Catfish

With that improved tool in hand, Ogburn's team wanted to know which method was more reliable for identifying stomach contents, genetic barcoding or the traditional technique of examining appearance. The team compared both methods to analyze contents from 319 blue catfish caught in four tidal freshwater areas in Maryland — the Patuxent River, Marshyhope Creek, the Sassafras River, and Swan Creek.

It wasn't much of a contest: the SERC researchers identified the species of only nine percent of tissue samples by observing morphology but 90 percent using genetic barcoding. The latter represented 23 different fish species, a sign of the blue catfish's wide-ranging palate. The researchers even found an unexpected piece of tissue — from a black cormorant. Ogburn speculates that the blue catfish scavenged upon the bird's carcass after it wound up in the water.

Not everything in a fish's stomach is easily identifiable using genetic techniques, especially the remains of invertebrates. These animals, such as mysids (small crustaceans) and polychaetes (worms), can make up a large portion of the diet of some predator fish. But there are gaps in the DNA library for these species. So far Ogburn and his colleagues have determined DNA sequences for only 250 species of the larger Bay invertebrates while the number in the estuary is estimated to total more than 1,000. The species of each invertebrate has to be correctly identified through other techniques before researchers can label it with its DNA code, and identifying invertebrates, which are small, can be time-consuming and tricky. That is why the SERC study of blue catfish, published in 2017 in the journal *Environmental Biology of Fishes,* covered only the fish species they ate and not invertebrates. George Mason University researchers are conducting a pilot study using DNA barcoding to determine what kinds of invertebrates are eaten by predator fish in the Potomac River.

Maryland Sea Grant has also funded research to develop this kind of technology. Rose Jagus, a molecular biologist, and graduate student Ammar Hanif used DNA barcoding to analyze the stomach contents of menhaden, an important prey species for striped bass. The researchers used a DNA sequence other than COI that is unique to a species of phytoplankton that menhaden eat.

A Next-Generation Genetic Tool

Given the limitations of DNA barcoding, it is unlikely to replace visual observation of stomach contents any time soon. Examiners can often see enough detail about partially digested fish and the bones and shell left in the stomach to assign particular samples to at least a broad taxonomic grouping, such as a genus or family, if not a particular species. Those details have given resource managers important information about what predator fish are eating in the Chesapeake Bay.

But emerging genetic techniques offer scientists a complementary, powerful, and efficient way to study the estuary's fisheries. In contrast to DNA barcoding of a single tissue sample at a time, an approach called "next-generation sequencing" can quickly identify all of the species in a

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Guess Who?, from p.15

fish stomach in a single laboratory test run. This is a quicker method than analyzing individual items one by one. The next-generation method should also indicate the relative abundances of prey species within a stomach, such as whether the predator recently ate more menhaden or more bay anchovies.

The same approach can also be used to examine other important questions in fisheries biology, like whether a water sample from a particular river contains DNA of an endangered, rare fish like river herring or sturgeon or an invasive species like blue catfish. That information could help inform managers about where to focus their efforts to protect the endangered fish and reduce the populations of unwelcome, invasive fish.

Next-generation sequencing has not yet been used to study Chesapeake Bay fisheries, but progress to date suggests that it and more traditional DNA barcoding have a lot of promise, Ogburn says. "It's been an exciting area to try to push into. It's producing new opportunities for new kinds of research. We're always looking for ways to get better data, to get it more efficiently, and to answer important questions for management or conservation."

— *Jeffrey Brainard*

New Watershed Restoration Specialist Will Serve Northern Maryland

Kelsey Brooks is the newest regional watershed restoration specialist for Maryland Sea Grant Extension, serving Baltimore City and Baltimore, Carroll, and Harford Counties.

Brooks is working with communities, citizen groups, and local governments to help improve water quality in the rivers, streams, and creeks that flow into the Chesapeake Bay.

Sea Grant's team of five watershed restoration specialists educate Maryland residents about practical measures they can take. For example, the specialists help communities to secure funding to install projects that reduce stormwater runoff, which carries excessive amounts of nutrients into the Chesapeake where they have fostered the development of low-oxygen "dead zones."

For information about watershed restoration planning and projects in your area, please visit the Maryland Sea Grant Extension watershed specialists' webpage: bit.ly/CleanwaterMD

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