Ocean Storms Create Oases in Watery Desert

Research Demonstrates that Mid-Ocean Eddies Pump Up Nutrients to Fuel Plankton Blooms

For two decades, scientists have puzzled over why vast blooms of microscopic plant life form in the middle of otherwise barren mid-ocean regions. In a recent research article in *Science*, a team including researchers from VIMS reports that episodic, swirling current systems known as eddies act to pump nutrients up from the deep ocean to fuel such blooms.

The report presents the findings of the EDDIES project, a multi-year study of eddies in the Atlantic Ocean. The project is led by Dennis McGillicuddy of the Woods Hole Oceanographic Institution (WHOI), and includes VIMS Associate Professor Deborah Steinberg, post-doctoral researcher Sarah Goldthwait, graduate student Bethany Eden, and research technician Joe Cope.

Members of the EDDIES team found that ocean productivity was surprisingly high when stirred by certain types of mid-ocean eddies. These huge swirls of water were teeming with diatoms (a type of phytoplankton) in concentrations 10,000 to 100,000 times the norm—among the highest ever observed in the Sargasso Sea, an otherwise barren mid-ocean region south of Bermuda.

McGillicuddy notes that "Past research has shown that the open ocean is far more productive than we could explain based on what we knew about nutrients in the water. Scientists have been trying to figure out where the nutrients come from to make these oases in the oceanic desert, and some of us hypothesized that eddies were part of the answer. The EDDIES project has validated that suspicion."

The Sargasso Sea, like other mid-ocean regions of the world, is warmer, saltier, bluer, and clearer than most other parts of the North Atlantic. Prevailing oceanographic wisdom has suggested that such open waters were mostly desert-like, unproductive regions populated by a few smaller plant species. Yet observations showed oxygen and other biologically important elements were being consumed at a higher rate than theories and models predicted. There had to be some natural nutrient source.

VIMS post-doctoral researcher Sarah Goldthwait tracks an ocean eddy while onboard the RV Oceanus *during the June 2004 EDDIES expedition to the North Atlantic.*

The EDDIES team found that eddies draw nutrients from the deep, thereby fertilizing surface waters and priming the ocean's "biological pump." Fed by this unusual upwelling, the phytoplankton population explodes. Steinberg's team found that this in turn attracts more zooplankton, small drifting animals that feed on the phytoplankton within the eddies.

"Eddies have a dramatic ripple effect on the open-ocean food web," says Steinberg. Her team found up to three times as much zooplankton within eddies as they did in surrounding waters.

They also discovered that the end result of this souped-up food web is a significant increase in the number of fecal pellets—zooplankton poop—sinking out of the eddies' surface waters toward the seafloor.

"Fecal pellets are heavier than phytoplankton cells and sink faster, thus making a more efficient biological pump," says Steinberg. "They're a more efficient way to get carbon to the deep ocean."

Pumping carbon to the deep ocean is important because it allows the ocean surface to soak up more carbon dioxide from the air, thus lowering the concentration of this greenhouse gas in the atmosphere. Carbon dioxide that is pumped to the deep ocean can remain there for thousands of years, contributing nothing to global warming.

In addition to WHOI and VIMS, the EDDIES team included scientists from the Bermuda Institute of Ocean Sciences (BIOS), Rutgers University, the University of Southampton (UK), the University of California-Santa Barbara, Humboldt State University, and the University of Miami.

In nearly six months of ship-based work in the summers of 2004 and 2005, the researchers employed a combination of remote sensing, video plankton recorders, electronic plankton nets, ocean drifters, tracers, and traditional measurements of water properties and current speeds.

They started with NASA satellite measurements of sea-surface height to locate eddies in the Sargasso Sea, south and east of the Gulf Stream in the North Atlantic. The 18-member research team then sailed into those eddies with the research vessels *Oceanus* (operated by WHOI) and *Weatherbird II* (operated by BIOS).

—By Stephanie Murphy of WHOI; adapted by David Malmquist of VIMS

Dickhut Puts Pollutants to Good Use

Bluefin tuna accumulate traceable amounts of organic pollutants in their tissues. Photo by Jon Lucy.

It seems unlikely that any environmental good could derive from the use of persistent organic pollutants such as PCBs and chlordane. But that's exactly what VIMS Professor Rebecca Dickhut is attempting in her latest research.

Dickhut, Chair of Physical Sciences at VIMS, is using these contaminants to help measure the degree of mixing between Mediterranean and western Atlantic stocks of bluefin tuna—a finding with important implications for management of the bluefin fishery.

The Atlantic bluefin tuna, *Thunnus thynnus*, is a highly migratory species that supports a fishery throughout the North Atlantic and Mediterranean. This lucrative international fishery is driven largely by the Japanese sushi market, where a single fish has sold for more than $150,000.

But the bluefin fishery is in trouble. ICCAT, the International Commission for the Conservation of Atlantic Tunas, reports a rapid decline in bluefin abundance during the last few decades due to severe over-fishing. The species was listed as endangered at the 8th Convention on International Trade in Endangered Species of Wild Fauna and Flora in 2003.

An important question in bluefin management is whether the bluefin population comprises separate western and eastern stocks, as early observations suggested. According to VIMS Professor John Graves, Chair of the US Advisory Committee to ICCAT, the two-stock hypothesis was founded on discontinuities in catches across the North Atlantic and the presence of two spawning areas, the Gulf of Mexico and the Mediterranean.

ICCAT manages the fishery based on the two-stock premise, with differing regulations on either side of the Atlantic. Catch limits for the Eastern stock (fished in the Mediterranean and eastern Atlantic) were recently reduced to 29,500 metric tons per year. The western stock, which has been subject to a recovery plan adopted by ICCAT in 1998, has much lower catch limits of around 2,100 metric tons per year.

As might be expected, the disparity in catch limits on either side of the Atlantic has led to contention between commercial fishing interests in the two regions, particularly in light of recent tagging and genetic studies suggesting that bluefins from the eastern and western Atlantic mix on the Atlantic fishing grounds.

Dr. Jens Carlsson, a post-doctoral researcher in Graves' lab, writes in a recent paper that "The extensive trans-Atlantic movements and lack of significant genetic differences between the putative populations of bluefin tuna have led researchers to question the validity of the 2-stock management approach."

Although Carlsson's studies of young bluefins support the two-stock approach by showing that genetic dif-

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ferences do exist between eastern and western stocks, continued uncertainty surrounding the species' population structure has led to a broad effort to further clarify the relationships among bluefin populations in the Gulf of Mexico, western Atlantic, eastern Atlantic, and Mediterranean.

Several studies, including Dickhut's project and a follow-on genetic study by Graves, are funded by the Large Pelagics Research Center at the University of New Hampshire, in partnership with NOAA's National Marine Fisheries Service.

The Center's grants reflect the science community's interest in developing novel methods of tracking tuna to supplement conventional tagging studies, which suffer from both high costs and low rates of recapture of tagged animals.

Dickhut's two-year study aims to clarify the stock question by measuring the ratio between PCBs and chlordane in bluefin tissues.

PCBs are manmade chemicals that were used in electrical equipment around the world starting in the 1930s. They were banned in the U.S. in 1977 because of evidence they build up in the environment and can cause cancer; an international manufacturing ban followed in the 1980s.

Chlordanes are a class of synthetic pesticides that were used in the US from 1948 to 1988 to treat field crops and control termites. The EPA banned all uses of chlordane in 1988 due to environmental and human-health concerns.

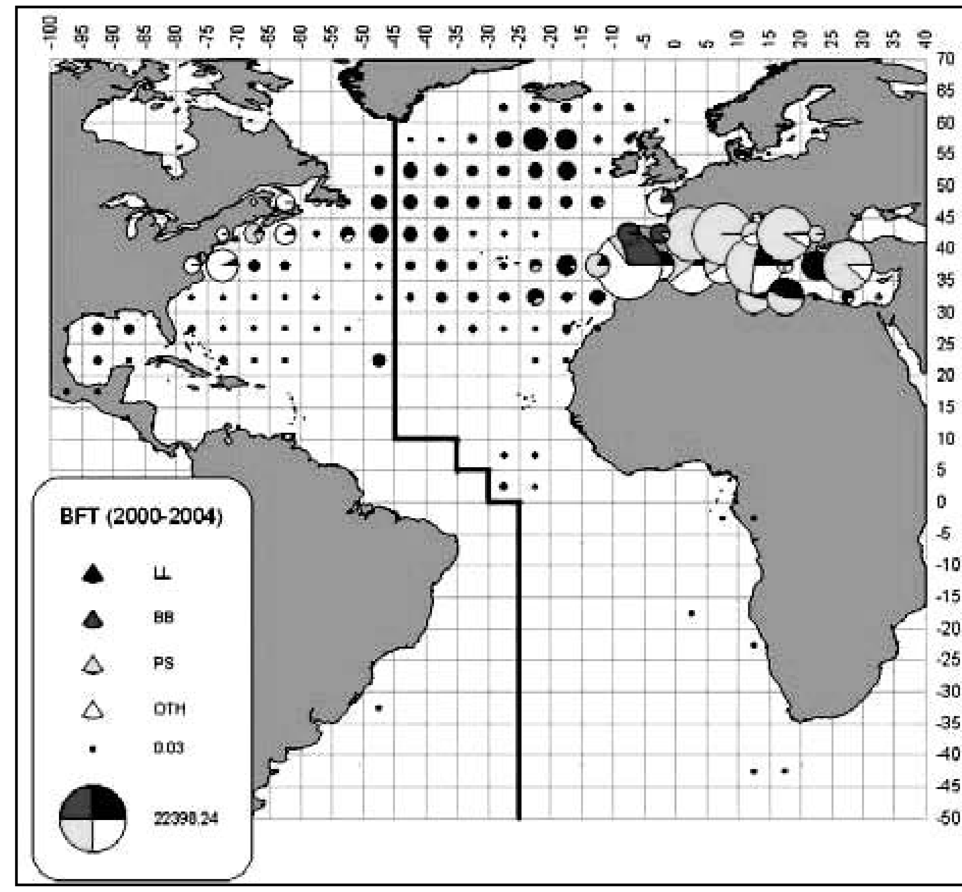
Both PCBs and chlordanes persist for decades in the environment, and can reach the open ocean through river runoff or the air. They accumulate up the food chain, reaching levels in bluefin tuna and other top predators that may be thousands of times higher than in water.

(These levels are of concern to human health, but have not led to any fish-consumption advisories for organic pollutants in tuna. The EPA did issue a mercury-based fish-consumption advisory for bluefin tuna in 2004.)

The key to Dickhut's investigation is that PCBs were used in both Europe and the US, whereas chlordane use was restricted to North America.

"The food web in the Mediterranean doesn't have much chlordane," says Dickhut, "whereas the food web along the US coast has a lot. So what we expect to see is differences in the ratio of PCBs and chlordane in animals from these areas. We're using the ratio as a tag, exploiting the difference in order to track these fish."

Her preliminary look at bluefin tunas from the Gulf of Mexico showed that they have a relatively low ratio of PCBs to chlordane, a finding that supports the prevailing notion that two Atlantic stocks consistently return to different spawning grounds.



Disparity in bluefin tuna catches between the western North Atlantic and Mediterranean from 2000-2004. Catch is in metric tons. Shaded circles indicate fishing gear: LL = longline, BB = bait boat, PS = purse seine. Figure from ICCAT.

"The idea," says Dickhut, "is that only Gulf of Mexico fish go back to the Gulf of Mexico [to spawn], and only Mediterranean fish go back to the Mediterranean, but any fish caught along the coast of Virginia or anywhere in the Atlantic could be from either side. We're trying to figure out how many fish from that side might be over here, and vice versa, by looking at stock mixing."

Dickhut has begun studying mixed stocks by sampling fish from the western Atlantic, including the coast of Virginia. The PCB-chlordane ratios in these fish are more variable, consistent with the idea that some may have migrated from the Mediterranean. None of these fish show the drastic difference one might expect given the lack of chlordane in Mediterranean waters, but Dickhut says this result really isn't that surprising.

"If a fish was feeding in the Mediterranean food web and incorporated that signal, but then swam across the ocean and started feeding here, it's chemical signal is going to start changing to look more like a fish from over here."

By using a mixing model, Dickhut's team has estimated that these fish had formed about 65% of their body tissues while in the Mediterranean, and 35% during their time in the Western Atlantic.

Dickhut's next step is to analyze tissues from Mediterranean bluefin tunas. She hopes to sample younger fish to lessen the possibility that they may have skewed their "native" PCB-chlordane ratios by spending time in western Atlantic waters.

Her team is also refining a new laboratory technique that will allow them to measure several different chlordane compounds. "We spent the summer getting a few other chlordanes to use as markers because we want to have multiple ratios to make our work more defensible," says Dickhut. "Our work is ongoing and hopefully we'll have a cleaner, clearer story with our new analytical method."

Staff members in the office of the late U.S. Congresswoman Jo Ann Davis (VA-1st Dist) visited VIMS in July to learn how VIMS scientists are working to conserve, develop, and replenish Chesapeake Bay and coastal resources such as oysters, blue crabs, sharks, scallops, and shad. The visit included a briefing on the VIMS-Industry Partnership, a tour of VIMS' Oyster Hatchery and new Seawater Research Laboratory, and a trip aboard the research vessel Pelican *to a VIMS observing buoy on the York River. Here, Dr. Stan Allen of VIMS' Aquaculture Genetics and Breeding Technology Center (far L) explains the oyster-rearing process as VIMS Dean and Director John Wells (2nd from L) and W&M Assoc. VP for Government Relations Fran Bradford (3rd from L) look on. Continuing to right are Davis Chief of Staff Chris Connelly, District Office Director Joe Schumacher, Legislative Director Mary Springer, and Legislative Assistant Brent Robinson.*

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ing the complex relationships between the deep ocean and the distribution of marine life."

The *Nature* study reports the findings of the ANDEEP project (ANtarctic benthic DEEP-sea biodiversity), a series of three expeditions to the Southern Ocean between 2002 and 2005 aboard the German research ship *Polarstern*. An international team from 14 research organizations investigated the seafloor to build a picture of this little known region of the ocean. They found more than 700 new species.

In addition to Dr. Diaz, VIMS graduate student Lawrence Carpenter also took part in the research.