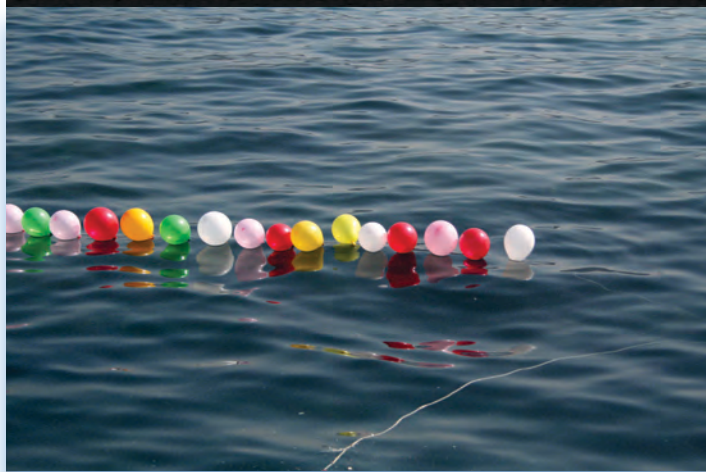


What happens to plastics that end up in the ocean?



Follow the balloons

Tons of plastic end up in the ocean every year—trash bags, cups, beach toys, fishing line, bottles, and balloons. Scientists at the Sea Education Association and Woods Hole Oceanographic Institution investigated what happens to plastics in the ocean.



Courtesy of Kara Lavender Law, SEA

Trolling for plastic debris

For more than 20 years, SEA students and crew have gathered plastic particles with nets during semester-at-sea cruises in the Atlantic Ocean and Caribbean Sea.

Plastic Particles Permeate the Atlantic

You've heard about the Great Garbage Patch in the Pacific Ocean. Well, the Atlantic certainly isn't pristine when it comes to plastic.

In two major studies published in August 2010, scientists at Sea Education Association (SEA) and Woods Hole Oceanographic Institution (WHOI) analyzed plastic debris skimmed over the past decades from the surface of the Atlantic Ocean. They found that plastic was widespread throughout the western North Atlantic, primarily in fragments measured in millimeters, the size of pencil erasers or smaller.

Chemical analyses of the debris revealed more intriguing findings and posed new questions:

- Since 1986, the global production of plastics has skyrocketed, but the concentration of plastics in Atlantic surface waters has remained about the same. If the amount of plastics entering the oceans has also skyrocketed, what processes might be removing some plastics from surface waters?
- Debris in the surface ocean contained few particles made of certain types of plastic that are abundant on land, specifically polyethylene terephthalate, or PET, which most beverage bottles are made of. What is happening to that plastic?

- The plastic particles showed evidence of being coated with living organisms. Are microbes or other tiny life forms digesting the plastics, causing them to sink, or are they sticking to the particles and being carried through the ocean like sailors on rafts? (See page 22.)

For their studies, the scientists took advantage of a remarkable dataset collected in an unorthodox way. Every year since 1971, SEA, a nonprofit organization based in Woods Hole, Mass., has been taking undergraduate students aboard its ships every year for a 12-week SEA Semester program. Thirteen years later, it began a standard practice for its students to sample along the same track each year, towing nets along the surface twice a day to collect biological samples and ocean debris. This unprecedented effort resulted in roughly 64,000 pieces of plastic collected by 7,000 undergraduates from 6,100 net tows since 1986. It was a scientific treasure trove that researchers could tap to reveal long-term trends in ocean plastics over a wide area of the Atlantic and Caribbean Sea.

"I passed SEA on my way to WHOI every day and never knew they had this extensive, long-term stockpile of data," said WHOI marine chemist Chris Reddy. "When I found out, I started salivating, and we began collaborating to mine it."



Courtesy of Kara Lavender Law, SEA

Painstaking plastic picking

After each net tow, students picked out, weighed, and measured plastic particles trapped in the nets. Between 1986 and 2008, some 7,000 students collected roughly 64,000 pieces of plastic from 6,100 net tows.



Tom Kleindinst, WHOI

Broken down into bits

The vast majority of plastics collected in the Atlantic Ocean were not large bottles, but particles measured in millimeters. The plastics were broken down by waves and chemical reactions driven by sunlight—and perhaps by something else (see page 22).

A brief history of marine plastics

In 1997, Charles Moore brought widespread attention to the problem of plastics in the ocean when he crossed the North Pacific Gyre in his catamaran *Alguita* on the way back home to California from Hawaii. He found surprisingly large amounts of plastic debris (sometimes hyped in the media as an island of floating plastic as large as Texas that you can walk on for miles and miles). He became an important advocate for cleaning up the oceans.

But high concentrations of plastic debris were first reported from the Atlantic Ocean, specifically the Sargasso Sea, by two WHOI scientists, Edward J. Carpenter and K.L. Smith Jr., in 1972. Aboard WHOI's research vessel *Atlantis II*, they collected, counted, and weighed all the plastic pieces collected in a net with a 1-meter-wide mouth that was towed at the ocean surface.

Carpenter and Smith calculated concentrations of 50 to 12,000 plastic particles, collectively weighing up to 1,070 grams, per square kilometer. The highest numbers were obtained at about 34°N latitude in the Sargasso Sea. Later work showed that plastic debris was widespread throughout the northwestern Atlantic, and that densities could be much higher.

For its routine plastic sampling, SEA incorporated methods comparable to those used by the WHOI scientists in the early

1970s—tow a 1-meter-wide net through the surface and collect, count, and weigh the plastic particles trapped inside. But SEA scientists standardized the speed and duration of the tows (30 minutes at 2 knots, or about 3.7 kilometers per hour). One tow generally covers 1 nautical mile, or 1,850 square meters. The volume of water filtered through a net during a tow is staggering—about 122,000 gallons, or 2,000 bathtubs full of water.

By 1987, one SEA scientist, R. Jude Wilber, wrote in *Oceanus* magazine: “It is virtually impossible to tow a ... net through the surface waters of the Sargasso Sea and not catch plastic debris of some sort.”

In the center of the gyre

Assessing 22 years of data collected by SEA ships (initially the *Westward* and later the *Corwith Cramer*), the researchers found that more than 60 percent of the tows contained detectable plastic debris. Average densities rivaled those reported from the Great Pacific Garbage Patch, ranging from 1,400 pieces per square kilometer in the Caribbean to more than 20,000 pieces per square kilometer in the Sargasso Sea.

The research team—Kara Lavender Law from SEA, Skye Morét-Ferguson and Giora Proskurowski, who held joint

appointments at SEA and WHOI, Reddy and Emily Peacock from WHOI, and Nikolai A. Maximenko and Jan Hafner from the University of Hawaii—reported their findings in the Aug. 26, 2010, edition of the journal *Science*.

The plastic debris reached its highest density between about 22°N and 38°N latitude; the highest value recorded during the 22-year period was 580,000 pieces per square kilometer at 24.6°N east of the Bahamas. Eighty-three percent of all the collected plastic debris came from this area, known as the North Atlantic subtropical gyre. The region is bounded by wind-driven currents, such as the Gulf Stream, which flow clockwise around the gyre.

The findings supported a numerical ocean model developed by co-author Maximenko, who suggested that Ekman dynamics—a net movement of water to the right of the prevailing wind direction in the Northern Hemisphere (and to the left in the Southern Hemisphere)—would tend to concentrate floating material in the center of the gyre.

Where do the plastics end up?

The *Science* study also showed that even though global production and disposal of plastic in the U.S. municipal waste stream both increased significantly between 1986 and 2008, “it is very surprising to find that the concentration of plastic at the surface is not increasing,” Law said. If plastic entering the ocean has also increased, “this means that there must be some process removing it from the surface of the ocean.”

“We still haven’t figured out this missing plastic problem,” said Reddy. But in a first attempt to try, he, Morét-Ferguson, Law, Proskurowski, Peacock, and Ellen Murphy of WHOI analyzed the size, mass, and material composition of 748 samples of plastic collected on SEA cruises between 1991 and 2007. Their study, published in the October 2010 issue of *Marine Pollution Bulletin*, offers new insights and raises new questions about what happens to plastics in the ocean.

The scientists found almost no ocean debris made from PET, although this type of plastic is found all over beaches, primarily in plastic bottles. PET (pronounced “Pete”) has a density greater than seawater.

“Can PET float for a little while and

then sink?” Reddy asked. “Does the PET ever get off the beach? Where is all the PET going?”

The vast majority of plastic debris collected at the sea surface was made of polypropylene and polyethylene, which are less dense than water. But their densities were higher than expected based on their chemical properties alone. The scientists suspect that water turbulence and chemical reactions sparked by sunlight probably are breaking these plastic pieces into fragments too small to be captured by sampling nets, and perhaps are changing the density of the plastic itself so that it sinks.

There is also evidence that “there is biological growth on these plastic pieces,” Law said. “It’s possible that because of that growth, the plastic becomes so dense that it sinks out of the surface layer.”

The researchers’ chemical analyses showed that many plastic pieces have measurable amounts of nitrogen, even though nitrogen is not a component of the polymers that make up plastics such as polypropylene,

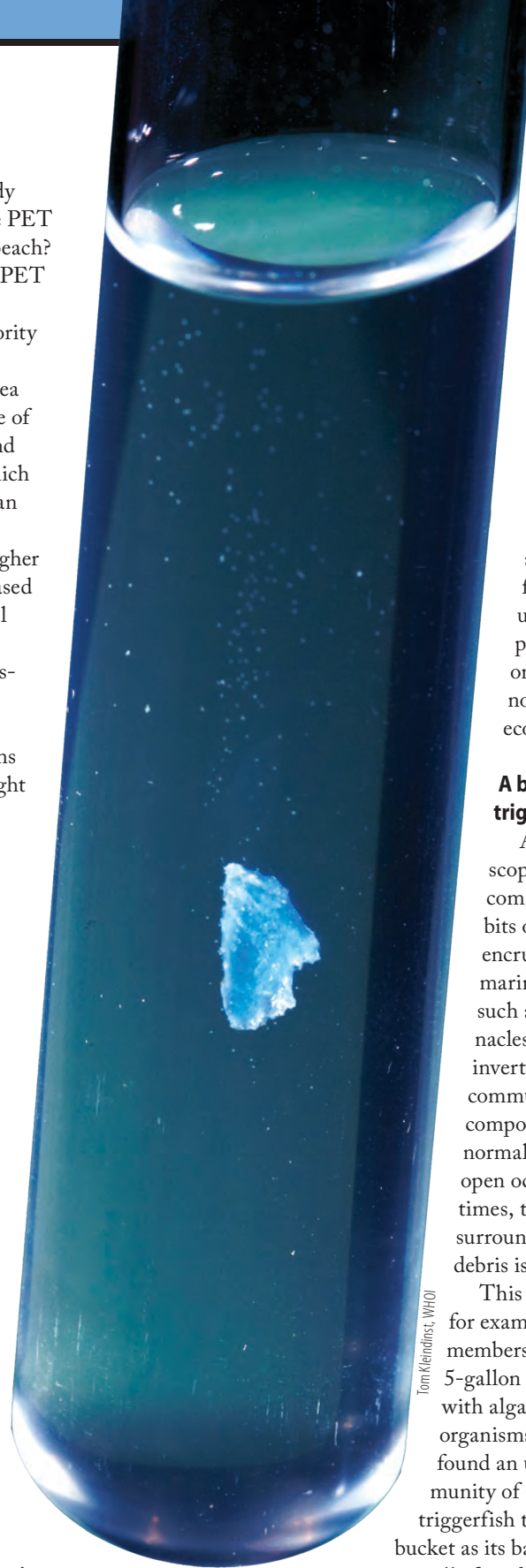
polyethylene, and PET. That nitrogen could only have come from living organisms. Microbes may be taking up residence on the floating plastic debris, perhaps taking advantage of a new source of food, or perhaps using the plastic pieces as substrates on which to form novel microscopic ecosystems.

A bucketful of triggerfish

As for macroscopic life, it is common to find bits of plastic debris encrusted with marine organisms, such as algae, barnacles, and other invertebrates. Some communities are composed of species normally found in the open ocean, but other times, the community surrounding the plastic debris is unexpected.

This past summer, for example, SEA crew members encountered a 5-gallon bucket carpeted with algae and other small organisms, but they also found an unusual community of about two dozen triggerfish that used the bucket as its base. Triggerfish are generally found in coral reef communities, but in this case, they were

WHOI chemists analyzed bits of plastic collected at sea to discern what types of plastics are going into the ocean and what happens to them.



Tom Klendinst, WHOI



Each individually bagged bit of plastic collected from the North Atlantic is a piece of the puzzle to learn how the ocean is responding to the flood of plastic it has received in recent decades.

Tom Kleindinst, WHOI

found more than 1,000 miles from the nearest reef. One triggerfish caught in the net along with the bucket had more than 40 pieces of plastic in its digestive tract.

Plastic debris may block food passages or accumulate in marine organisms, but what happens to it after their death is yet another scientific mystery.

“We know that the plastic is being con-

sumed by organisms at a variety of scales, from plankton all the way up to fish and larger organisms,” Law said. “But we have no idea how much they eat. We don’t know what happens to it after they eat it—whether it stays in the organism itself or whether it gets eliminated with other waste.”

The answers to these questions may depend on developing a reliable way to measure the age of plastic debris.

“We still don’t know how old many of these pieces of plastic were,” Reddy said. “Trying to figure out some kind of time stamp would allow us to figure out how long it takes for the plastics to get into the ocean and how long they stay there. And then, do they last forever? Or do they keep breaking into small pieces and sink down to the bottom of the ocean?”

Red and yellow areas show where high amounts of plastic were found. About 83 percent of all the plastic debris was concentrated in the North Atlantic subtropical gyre (marked by the black contour line). Strong currents such as the Gulf Stream flow clockwise around the gyre. Inside the contour line, water moves slowly.

A novel collaboration

Reddy said the two studies—in fact, the entire decades-long sampling effort—represent a substantial accomplishment for the SEA staff whose primary role is teaching, not research.

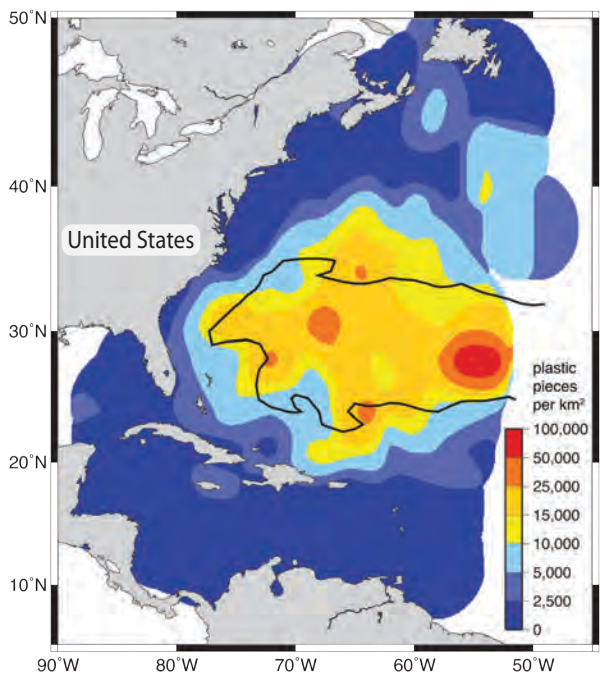
“The several thousand SEA Semester undergraduate students who helped collect and count plastic debris over the decades have been important contributors to this work,” said SEA President John Bullard. “They have gained a much fuller understanding of the oceans and the role humans play both in the present and the future.”

The National Science Foundation supported the research to analyze the plastic data, but Law said that collecting the necessary data and monitoring oceanic conditions over long time periods are too expensive for traditional government funding sources to undertake.

“I don’t believe you could have designed this in a government-funded research capacity—there simply wouldn’t have been anybody willing to commit that much money to sustain a time series that repeated itself every single year for 22 years,” she said. “In the end, it’s tuition dollars and donor dollars that funded this research.”

—Dave Lawrence

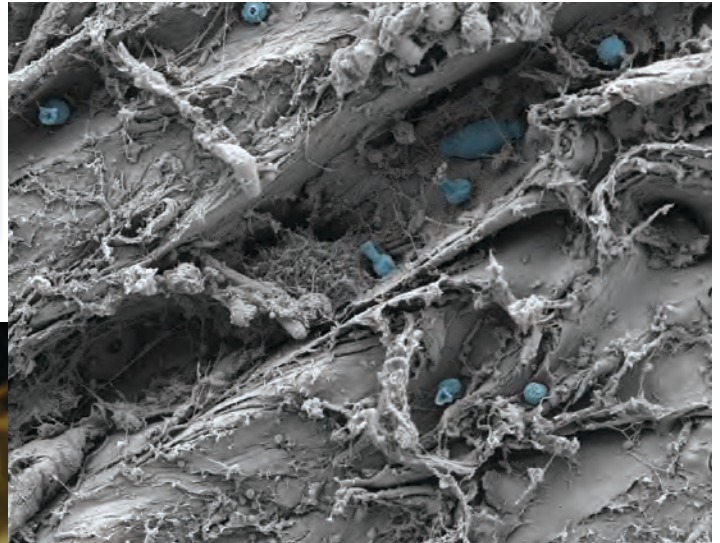
Figure 2



Courtesy of Chris Reddy, WHOI

Revealing Brave New Worlds on Floating Plastic Debris

This is a close-up of a remnant of a plastic trash bag collected from the Atlantic. Tracy Mincer, a biogeochemist at WHOI, zoomed in even further and found curious things happening on the surface of this plastic particle.

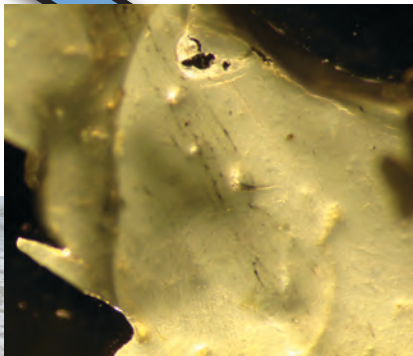


Tracy Mincer, WHOI

Magnified 10,000 times by a scanning electron microscope, this teensy bit of plastic that was floating in the ocean reveals organisms (colorized in blue) nestled in surface nooks and crannies. Patches of stringy-looking substances secreted by organisms festoon the plastic like party streamers.



Tom Kleindinst, WHOI



Tracy Mincer, WHOI

Mincer and colleagues are asking many questions as they investigate this heretofore unknown realm.

Are these organisms using plastics as a source of food and decomposing it? Do the plastic bits offer the organisms convenient rafts to proliferate and migrate more extensively? Is the plastic more useful to certain species than others, potentially creating new oceanic ecosystems?

Scientists know that microbes hitchhike on floating seaweed, Mincer said, but the microbes he is seeing on the plastics are different. Many have not yet been identified. So the first step is finding out “who” is living on the plastics.

Mincer rinses the bits of plastic with copious amounts of ultra-filtered, sterile saline solution to remove the cells. Linda Amaral Zettler, a scientist down the road at Marine Biological Laboratory in Woods Hole, then extracts their DNA and identifies specific gene sequences in the hodgepodge of genetic material. These telltale sequences will help her and Mincer identify the organisms residing on the plastics.

With that information, the scientists can begin to explore

what the organisms are doing. Plastics are made of petroleum-based hydrocarbons, and many microbes are capable of metabolizing those compounds to extract life-sustaining carbon. In the process, the microbes could help biodegrade plastics.

Different types of plastics are made of different compounds, Mincer said, so it stands to reason that different plastics could harbor distinctive microbial populations with different “enzymatic tool sets” to break down the plastic.

Other microbes may exploit plastics not as floating banquets, but instead for transportation or refuge, he said. Some may take advantage of more buoyant types of plastic to keep themselves near the surface and sunlight they need for photosynthesis. Others may use less-buoyant types to lie low in the water. Either way, putting lots of plastic so rapidly into the ocean raises the possibility of unanticipated changes to marine ecosystems.

“This idea is completely unexplored,” Mincer said, “and the ability of the ocean and life in it to adapt is always amazing.”

—Lonny Lippsett