Star dispatches

Invisible plastic

What happens when your garbage ends up in the ocean

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Introduction

On board the SSV Corwith Cramer, north of Bequia, Caribbean Sea

In the old-fashioned sense of the word, plastic means something that can change into something else. It's pliable, transformative, maybe metaphoric, certainly shifty. In the modern sense, plastic is a substance made from crude petroleum engineered into chains of molecules so freakishly long that they are both supple and unbreakable.

Unknown at the beginning of the last century, uncommon until after the Second World War, plastics now permeate everyday life in ways we barely keep track of. We use these man-made molecules to wrap and carry food, mass produce juice and water containers, fashion intravenous bags and syringes and polar fleeces, insulate homes, make car parts and air bags and baby carriers, record music and even create artificial human hearts. It's been said, with only a touch of exaggeration, that plastics make modern life possible.

And while some of these plastics are made to be useful for years, many are one-use wonders designed to be tossed away. The problem is that the very characteristics that make plastics versatile also make them immortal. While other materials eventually get broken down by bacteria or other processes into the minerals that made them, plastics don't. They live on, breaking down only into smaller and smaller pieces of themselves.

Much of that plastic ends up in landfills, and scientists are increasingly worried about its effects on groundwater, human health and wildlife. But a vast amount also ends up in the ocean, making ever larger tracts of indestructible plastic trash in the great, living basins of the sea. The most famous, but not the only one or even necessarily the biggest, is the Pacific garbage patch north of Hawaii that news outlets have focused on in recent years. But scientists have found plastic litter in every single part of the ocean no matter how far from human civilization, from the floor of the Arctic Ocean to the surface of the waters surrounding Antarctica to the deepest reaches of the abyss, where it acts like a sponge soaking up toxic chemicals we have also dumped in the sea.

A sea turtle after swallowing a plastic bag. *(Photo: Star file photo)*

The pieces range in size from the microscopic to the alarmingly large, like the debris from Japan's 2011 tsunami that will continue to hit North America's shores in the coming months. Most, though, are smaller than the fingernail on your pinky. And they are not just in the water itself. Plastic bottle caps and lighters are present in the bellies of dead albatross chicks on the planet's most remote islands, six-pack rings from beer cans are wrapped around strangled seals' necks and shopping bags are vomited from the stomachs of foundering sea turtles. Tiny bits have even been found in the circulatory systems of mussels that have eaten it instead of plankton.

And every single bit of plastic that has entered the ocean over the past 60 years is still there and will remain there, save the few pieces we humans happen to have cleaned up from beaches or dragged up in nets with scientific tows or recovered from dead wildlife. As more and more of the stuff is amassed in the sea, scientists are on an escalating mission to figure out how this strange plastic invader is affecting marine life.

Just how bad is it?

1 On Board the SSV Corwith Cramer

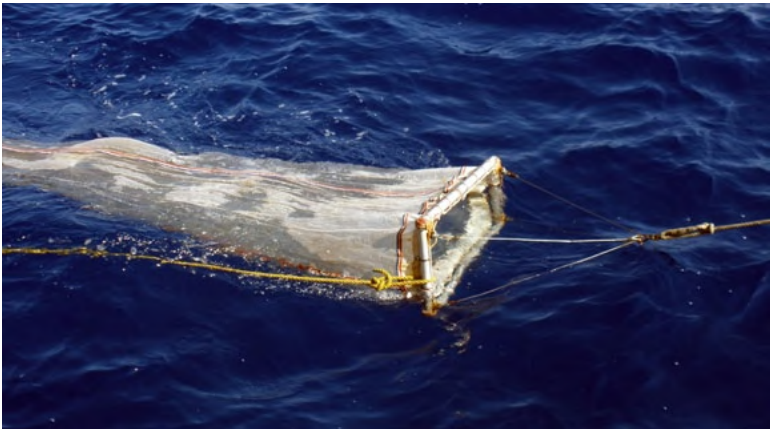
Scientists are fond of saying that knowledge begins with counting. Here on the SSV Corwith Cramer, a brigantine-rigged tall ship, we're trying to add to the growing body of knowledge about how much plastic is where. I've joined this expedition during its short stopover in the former whaling powerhouse Bequia, the largest Grenadine island, after hopping on a plane in wintry Toronto with only a backpack, sunscreen and some heavy-duty rain gear. I've spent several years and lots of time on ships looking at other ways we've damaged the sea, but don't know much about the risks from plastics. I'm here to learn.

The Corwith Cramer is the perfect place to start. The ship and its predecessor have been collecting and counting ocean plastics along the same path of the Atlantic Ocean for 29 years, the longest span of continuous counting anywhere in the world and their findings have been key to understanding the global trends in plastic ocean garbage. The ship is owned by the Sea Education Association (SEA) of Woods Hole, Mass., a program that offers university and college students semesters at sea.

The 15 student scientists and 13 mariners and professional scientists on board arrived in Bequia the day before me, sailing nonstop for 27 days from Maine across the North Atlantic subtropical gyre — one of the ocean's vast rotating swirls of water — to the sweltering Caribbean. Now, the sails are up again and we're back out in the open ocean. Up on deck in the science cabin, the two students who are writing their term papers about plastic are showing me what they've found so far.

The SSV Corwith Cramer *(Photo: Roman Shor /Sea Education Association)*

In front of me is an astonishing array of vials, laid out in a precise plastic-tray grid that reminds me of a super Sudoku puzzle. With one exception, each vial contains the results of a single metre-wide net or "tow" with a small-gauge filter dragged along a nautical mile beside the ship. Alexandra Uribe, 20, an undergrad at Dartmouth College, an Ivy League school in Hanover, N.H., is holding up the vial from tow 21 and she hands it to me. In the relentless morning sun I see that the vial is shot through with a fragment of a black fishing line. A crumple of blue fishing line lurks mid-vial. Multiple grains of dried-out, brittle plastic the size and shape of rice settle on the bottom. Plastic flakes of an indiscriminate colour stick to the vial's sides.



The "tow", a metre-wide net with a small-gauge filter (Photo: Leslie Peate/ Sea Education Association)

All in all, there are 177 separate pieces of plastic from tow 21, collected a couple of weeks ago in the South Sargasso Sea in the thick of the North Atlantic subtropical gyre. The plastic didn't come onto the ship alone. Like the other 40 or so twice-daily tows conducted so far on this voyage, tow 21 also captured plants and animals whose birthright it is to swim and float on the top of the ocean. These can include water striders, larvae from lobster, eel, squid and octopus, not to mention fronds of the sargassum seaweed so common in this part of the world.

The vial from tow 21 doesn't contain the worst of it. The one conducted half a day before it — tow 20 — captured more than 3,200 pieces of plastic. It took the student scientists the better part of a dozen hours to count everything, and many vials to contain it all.

And those are just the pieces visible to the naked eye. Along with fishing line, flakes, rice-shaped pieces and some shards, the tows are collecting plastic pieces so small the students need a microscope to find them. Christina Maruyama, 20, from Colorado College in Colorado Springs, is sitting at a long metal counter next to the table with the tray of vials, peering through a microscope at another grid. She's been here for hours and will be hunched over the microscope for many hours more.

I look into the lens. There, near the centre of the image, is a tiny filament. Maruyama and Uribe have stained the sample with a rose-coloured dye that will only stick to living matter. This piece isn't rose and that means it's one of those long petroleum polymers. Plastic.

"It's very upsetting," says Uribe. "It's just so small and you can't see it. But you know it's not supposed to be there."

Maruyama nods in agreement.

"We're in the middle of the ocean and we're still finding remnants of human activities," Maruyama says, gesturing to the wide, rolling sea. "It's one thing when you see a huge floating bucket — it's from only one place. When you see 3,000 pieces, they're from 3,000 different places."

And, as Uribe points out, they could be from last week or from 30 years ago. No one can tell.

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The concern over ocean plastics started in the early 1960s, a scant decade after the materials began to be mass produced. All of a sudden, the fallout of imperishability became clear: plastics started showing up in the beached carcasses of seabirds whose stomachs were filled with the stuff.

After that, scientists began to watch for plastic accumulation on beaches and in the intertidal zones. They've tracked a sharp increase over the past four decades.

By the early 1970s, scientists had also started to notice more and more plastic floating on the surface of the Atlantic Ocean.

Within a few years, fine nets set in the ocean and towed anywhere on the high seas were coming up with plastics, with most of it concentrated in the five subtropical gyres — continent-sized, shifting vortices of water bound by currents that make up more than 40 per cent of the planet's surface. Those conducting the tows included student scientists with the SEA program on their voyages from North America to the Caribbean. By 1987, Jude Wilber, one of the SEA scientists, had put the findings together in a landmark paper, revealing that the number of plastic pieces in the northern Sargasso Sea had quadrupled in just 15 years.

But the concern intensified when Charles Moore, a citizen scientist from California and founder of the Algalita Marine Research Institute, happened on what was later dubbed the Great Pacific Garbage Patch north of Hawaii. On his way back from a yacht race in 1997, he sailed through the massive North Pacific subtropical gyre and saw a plastic soup of debris as far as the eye could see. It appeared to have gathered there from all over the planet, just as oceanographers had predicted years before, based on their understanding of the ocean's current and wind patterns. Moore, the author of the recent book *Plastic Ocean*, has returned to the patch with other scientists for years now to gather more information.

Charles Moore, founder of the Algalita Marine Research Institute
(Photo: Matt Cramer/Courtesy Algalita Marine Research Institute)

One key question: What is the ratio of plastic to plankton in the gyre? In 2001, Moore published his stunning revelations in the academic journal Marine Pollution Bulletin.

By dry weight, there was about six times as much plastic as plankton in the gyre. His decision to oven-dry the plankton before weighing it has been called into question, since plankton are mainly water by weight, but the results attracted intense news coverage and fired the public imagination.

I've given hundreds of public talks on four continents about my research into the ocean's changes, and in every single one I've been asked anguished questions about the Great Pacific Garbage Patch. It's become a symbol of humanity's reckless pollution of the planet, a sign that goods we thought were thrown away can come back to haunt us, undying as ghosts.

2 Of Sea and Science

Shipboard life is getting back to normal after the three-day break on Bequia. The students on board are not just budding scientists, they're also learning the ancient arts of the mariner. During this final phase of their six weeks at sea, they are in charge of sailing the 134-foot-long ship in three teams of five with watches around the clock. Neither deckhands nor mates are allowed to give advice even when asked, unless there's an emergency. That means the students must know which of the 10 sails to set or strike in the right combination to keep the ship steady, how to haul on ropes and tie knots, and which way to steer to keep to the course set by the captain, Terry Hayward, who has ultimate responsibility. Deftly, these students are doing things most of us see only in pirate movies.

I think of the ancient mariners who took to the sea in ships like this hundreds and even thousands of years ago. In a way, they were early scientific explorers, just like the students on board today. Going to sea has always been a time-honoured way of finding things out, of seeing the world in ways nobody but a sailor can. And like science, sailing is bound by inflexible rules. Things must be done the same way, time after time. Knots must be tied as they have been for uncounted generations. The compass has precisely 360 degrees and 32 points. Breakfast is at 6:20 a.m., not 6:21. You take notes in the same way, using just the same language, as everyone who ever did it before you.

The keys are rigour, predictability, replicability. On a ship, it's what keeps you alive. In science, it's what makes your findings valid: Somebody else has to be able to do what you did and make the same finding.

I'm acutely aware right now of how difficult it is to be at sea. The ship is constantly lurching from side to side and I find myself grabbing wildly for something stable. The students and staff adapted to this weeks ago. But this is my first time on a tall ship and I am seriously off kilter. I don't get sea sick, unlike the other new passenger Nansha Medard, a fisheries observer from the St. Lucia government, who has taken to her berth and is unable to eat. But my headaches are severe and nausea is never far away.

And then there's the heat. It's sticky and insistent. Medard is used to that. But there was snow on the ground when I left Toronto and I'm suffering badly. On deck, you can catch the breezes and sometimes rain to cool off, if you can ever get out of the blistering sun. But down below, where the single-bed berths ring the galley tables and line the hall, stacked two high, the air is deadly still and the heat has an unpleasant personality all of its own. This business of being at sea is not easy.

And there are perils. Another of the world's tall ships, the vintage 1960 HMS Bounty built for the Marlon Brando movie *Mutiny on the Bounty* and used in a couple of the *Pirates of the Caribbean* films, sank in October off the coast of North Carolina as it tried to avoid Hurricane Sandy.

Its captain, Robin Walbridge, was lost at sea and the body of crew member Claudene Christian was recovered. The loss sent shock waves through our crew. It occurs to me that it's an act of faith every time we set foot on a ship and sail into the open ocean. We are foreigners here, here on sufferance of forces we barely comprehend. No wonder it's tough to find answers to scientific questions at sea.

I go up on deck to chat with Chuck Lea, the expedition's ponytailed chief scientist. He reminds me of a thin version of characters the actor John Goodman plays: an acerbic wit who takes nothing at face value. An oceanographer, Lea fell in love with squids decades ago and began a quest to understand the mysterious inner workings of the water's currents and gravitational forces so he could understand how they affect marine life. The subject still fascinates him. He's spending part of this journey gathering information about the very deepest waters we're passing over, sending his equipment as far down as he can to record temperature, salinity and a host of other information.

It's hot and bright up here on deck, nearing noon with little cloud cover and less shade. The seas are calm. There's no hint of the ferocious waves that sank the Bounty just a few days before. We're chatting over the whine of a metal wire carefully unwinding to lower some of the instruments into the deeps. There are ropes cordoning off the area from the rest of the deck, warning the unwary that the moving wire could sever a limb. Lea has spent a great chunk of his life on ships and still marvels at how hard it is for humans to live on the water, much less do science on it or begin to understand it. "We're hopelessly terrestrial in everything we do," he says, counting the length of line to see how deep his instruments have gone. He thinks that's one of the reasons the ocean has such a hold on the collective human psyche. It's mythical. It's the other.

I look at the water surrounding us on all 360 degrees of the compass. The ocean is the main medium of life on the planet. It controls the carbon, oxygen and nitrogen cycles — the very building blocks of life — not just for itself but for the land masses too. It's where most of the planet's creatures, alive and extinct, evolved. Ninety-nine per cent of the planet's living space is here, below the ship's rudder, while only a single per cent is in the thin band of air we breathe on the Earth's surface. That thin band is packed with life, including 7 billion humans and our plastic habit. Yet despite our long search to understand it, the sea is nearly as profound an enigma now as it was when the Greeks believed it was Poseidon's domain.

Lea points out that many of the most basic natural history observations — the things we take for granted as we roam on land — are impossible in the sea. On land, you can look around and say: "The brown squirrel eats a nut from the oak tree." But in the ocean, hardly any of that direct observation is possible. Most of the time, we drag creatures out of the water and examine them dead on a dissecting table, or put live animals in tiny aquaria. From time to time, we put on scuba tanks and descend 40 metres and sometimes more to look around, but for only a few dozen minutes. We can build submersibles that will take a very few of us a little deeper for a little longer before we have to bolt for the surface. We can even construct remote operated vehicles and send them yet further to find things out. But we've barely penetrated the surface.

As Lea notes, we still haven't figured out how the sperm whale feeds, and it's the sea's most storied animal. And that's despite the scientific focus on the ocean's big creatures, the ones we can actually see from time to time. And despite the fact that those big creatures like whales, fish and seals, have made many people wealthy over the centuries. For sea life with a direct commercial value gets studied more than, say, a water strider insect.

Trying to understand the energy flow in the ocean and its chemistry is harder still. Lea's been around long enough to remember the breakthroughs in oceanography in the late 1960s and early 1970s when some of the first satellites showed thermal pictures of the sea. It led to a revolution in the spatial understanding of the ocean, from seeing it as undifferentiated mega bodies of water, to discrete regions often just a few hundred kilometres across. Understanding that most of the live activity in the ocean is bacterial and viral was another, far more recent leap, he notes. The breakthrough there was the round-the-globe sailing odyssey of the American geneticist Craig Venter. During his voyage, he scooped up microbes from the top layer of the ocean and smashed them up into their genetic bits, just as he had when he sequenced the human genome. In 2007, he unveiled more than a billion new genes from an unknown number of unidentified and unclassified marine creatures.

Standing on the deck, listening to Lea, I realize that getting to the bottom of how plastics are affecting the ocean system, including the animals and plants that live in it and creatures like us who feed on them, goes far beyond some of the basic questions we've begun to answer. Even the counting is spare. We do not have a good count of how much plastic is where, much less how it got there and when. If you add up all the sampling done over the past decades, it amounts to a nearly invisible thread over minuscule parts of the ocean's surface. The deeps — so immense that they beggar the imagination — remain essentially unexplored for plastic. Occasionally some pictures that have been taken from above over the years for other scientific reasons have inadvertently revealed plastic garbage on the sea floor.

It's hit and miss, truth be told. Yet even this sparse and random documentation is showing huge increases in plastic concentration in different areas of the ocean.

And what if you go beyond the counting? What's the systemic impact of all that plastic? At this point, it's hard to tell. The problem with plastic garbage is that it goes to the heart of all the other oceanic unknowns. If we don't understand, for example, how plankton really function in the sea, how will we know how microplastic garbage is affecting them?

Liann Correia, 22, third assistant scientist on board, has come up on deck to help the students send a high-volume pump into the ocean where it will collect cyanobacteria from huge amounts of water. These blue-green algae, a type of bacterial plankton, are relatives of the creatures that figured out how to convert the energy of the sun into food 3.5 billion years ago, giving off oxygen to the atmosphere as an accidental waste product. As the cyanobacteria adapted, the atmosphere slowly shifted to support oxygen breathers, including, eventually, us. In other words, we're here because they are.

And now those same creatures are competing for space in the sea with plastics engineered from crude petroleum, which is, in effect, the fossils of their own ancestors from millions of years ago. With unknown consequences.

Figuring out those consequences is like a huge, global, communal scientific brainstorm, Correia says. She points to the students running this ship.

"It goes back to why we're out here. It isn't science or sailing," she says. "We're teaching the students to make decisions. The biggest thing for people to understand about plastic is what it is and where it comes from so they can make informed decisions about what they do and what they use. It's all about how we make decisions and why."

Plastic flotsam drifts in the ocean (Photo: Lindsey Hoshaw/Courtesy of Algalita Marine Research Institute)

3 The Reach of Plastic

Plastic's reach is extraordinary. In less than a single human's lifetime, plastics have become inescapable, replacing huge amounts of paper, metal and glass. In 1950, the entire plastic production across the planet was about half a million tonnes. Plastic was so novel that in 1957, the French philosopher Roland Barthes published an essay about it after having seen an exhibition in Paris, calling it "in essence, the stuff of alchemy."

"At the entrance of the stand, the public waits in a long queue in order to witness the accomplishment of the magical operation par excellence: the transmutation of matter," he wrote, adding prophetically: "Plastic is wholly swallowed up in the fact of being used; ultimately, objects will be invented for the sole pleasure of using them."

Today, we take the process of making plastic for granted. By 2011, yearly plastic production had grown to 280 million tones, a jump of 4 per cent in a single year.

One scientific paper reckoned that almost as much plastic was produced in the first decade of our century as was made throughout the 10 decades of the last. It's very big business, the third largest manufacturing industry in the U.S., with yearly shipments of $380 (U.S.) billion.

And while Barthes may have thought of plastic as alchemical, in fact, it is simply chemistry — fossil fuels put to a different use. Roughly 4 per cent of all the petroleum used anywhere in the world over the course of a year goes to make up the raw building blocks of plastics. Another 4 per cent of the world's yearly fossil fuel consumption is used up in the energy it takes to make the plastics themselves.

That's 8 per cent of the world's fossil fuels a year, the most prized and controversial modern commodity, used solely for plastics. And much of that, thrown away after a single use.

The chemical engineer Anthony Andrady of North Carolina State University in Raleigh, N.C., an independent plastics consultant who is a world expert on ocean plastics, says the process of making plastic is pretty simple. You take crude oil or gas monomer molecules and do a special reaction to make them into giant man-made polymer molecules. The polymer's length is what makes it unique and useful.

It also makes it indestructible except by high-heat incineration. There's just no biological mechanism to break it down into its original minerals. That would only happen if the enzymes from microbes could convert it into food or something else useful. So when you get mould on your orange, that's a microbe making a nice lunch out of your fruit. The problem with plastic is that because it is such a new, man-made invention, no microbes or enzymes exist yet that recognize it as food. They just don't have the equipment. Give them a few hundred thousand years and they might develop it.

Andrady says it's the same with humans. We didn't evolve to eat, say, Styrofoam, a type of plastic. We could consume it, but we wouldn't get energy from it that we could use. We don't have the equipment. He's quick to add that plastics could be made from other substances that would biodegrade: a handful exists already but they make up less than 1 per cent of global production. It is also possible to make petroleum-based plastics that could biodegrade. But so far, we haven't created them.

These polymer molecules eventually get made into nurdles, tiny beads of plastic that are the raw, pre-production material used to make a whole raft of goods. Globally, about 35 per cent goes to make packaging, Andrady says. In Canada, where the plastics industry was worth $17.6 billion in 2011, it's 39 per cent. Another

33 per cent goes for construction in Canada and about 14 per cent to the automotive sector. Proportions are similar in Europe, one of the world's plastic powerhouses. It's a relentless cycle: ever more plastic is produced but there's no way of returning it to its original mineral components. It's the perfect recipe for producing the kind of garbage that never goes away.

That fact is not lost on consumers, many of whom, the world over, have lobbied for a ban or a surcharge on plastic bags to limit their proliferance. Toronto's politicians, in a fit of global counter-culturalism, reversed the city's policy of forcing vendors to charge for plastic bags in favour of a total ban due to begin January 1, but then, overturned that ban, despite the fact that the original policy had led to a dramatic decline in the use of plastic bags.

Globally, about 10 per cent of municipal waste weight is plastic, destined to live on forever. In Canada, it's 9 per cent by weight and between 14 and 20 per cent by volume.

Apart from using less, one obvious solution to the continual buildup of plastic is to recycle it. That means accepting the fact that it's a polymer forever, but a valuable one, and re-forming it into something else plastic. But recycling rates are still spotty. In the U.S. only 8 per cent of total plastic waste is recovered for recycling.

In the European Union, it's 57 per cent and growing by 7 per cent a year.

In Europe, more than half the recovered plastic is incinerated for the energy it can produce, because plastic is, at base, both a fossil and a fuel. While industry associations in Canada report that plastics recycling has increased and they know that Canadians are eager to recycle given the option, it's difficult to find out what proportion is actually re-used.

Andrady got interested in ocean plastics because he grew up in Sri Lanka, an island country in the Indian Ocean. He used to enjoy going back home to walk on the beach and eventually noticed that the beach had become more and more polluted with plastic trash. As a chemical engineer, he already knew how plastics were made and how valuable they are. But the plastic junk on the beach propelled him to dig deeper — to try to understand how the stuff got there and how long it would remain. His research has been sobering.

Nobody knows exactly what proportion of discarded plastic ends up in the ocean. Teams of scientists are trying to figure it out right now. But it's clear that all over the world a great deal of it gets into the sea, washed there by rivers, floods, or tsunamis, thrown there from beaches, blown by the winds or hurricanes, dumped off boats and ships. Andrady calculates that nearly every bit of plastic that has entered the ocean over the decades is still there and that much of it has sunk from the surface to deeper waters. He says the tows that scientists like those on the Corwith Cramer conduct across that narrow track of the surface are just collecting the tip of the proverbial plastic iceberg.

While lots of public commentators are worried about the big stuff — like all the plastic garbage heading to North America's beaches from the 2011 tsunami in Japan — Andrady's worried about the little bits.

Some of it entered the sea already small, like nurdles, known in scientific circles as "mermaid's tears" because they have shown up in such volumes in plastic tows. The plastics industry, stung by public outrage over the quantity of nurdles found in the ocean and conscious that lost nurdles are also lost income, has started sweeping up nurdle spills in recent years. It's one of the few ocean plastics success stories and has led to a sharp decline in the number caught in scientific counts.

Other tiny particles end up in the ocean through the laundry cycle. Clothing made of polyester, nylon and other plastics sheds microthreads of plastic by the boatload with every wash. One study showed 1,900 microfilaments of plastic get swooshed out of a single piece of clothing with every wash.

Debris suspected to be from the Japanese tsunami on Long Beach, Tofino, B.C. (Photo: Jonathan Hayward /CP)

All of it ends up in the ocean. Another growing source is the tiny beads of plastic used in cosmetics as skin exfoliants. And plastic sand is now used more and more in place of real sand in resurfacing brick and stone. Large pieces of plastic that enter the ocean break down into micropieces by being dashed about by waves or made brittle by heat and sun. Many end up so small as to be invisible to the naked eye.

Andrady's biggest concern with microplastics has to do with chemical toxins. Toxins, such as DDT or persistent organic pollutants, are present in ocean water in mild concentrations, carried there by the air or dumped directly into waterways. But through the unbreakable laws of chemistry, plastics act like sponges to absorb those toxins. That's because their chemical makeup is similar to plastics and they like to dissolve into them, Andrady explains.

In some cases, they've got as much as a million times as much toxic content as the waters around them.

In one sense, that's a bonus. At least the chemicals are removed from the water. But in another sense, it's terrifying. The tiny chemical-laden plastics masquerade as food for zooplankton, which take up the chemicals along with the plastic. In turn, the plankton get consumed by bigger marine animals and the toxic chemicals move up the food chain. Do they sicken the creatures that eat them? Unknown. Do they eventually get into the human body? Another unknown.

Plastic found after a tow. *(Photo: Skye Moret/Sea Education Association)*

Andrady pauses. The thing is, he says, that there's a huge potential for widespread, dramatic ill effects on the ocean system — and perhaps humans — that we haven't been able to calculate. It could be catastrophic or gradual. We don't know its potential severity. We don't know how long it will take to kick in.

Most people still don't know what really happens when they toss a piece of plastic away, he says. But when he talks publicly about the issue, he knows he taps into widespread distress about it.

Back on the deck of the Corwith Cramer, Lea has been thinking about that public distress. It's searingly metaphoric for us, he says. Ocean plastic pollution is not one of those issues you can just blame on other people or on big corporations. We've been trained in recent years to think about pollution as a global economic and energy issue. But this one is far more personal than that. With this, all you have to do is run your workout gear through the wash and you're pouring plastic in the ocean.

"There's nobody to blame but us," he says. "You just look in the mirror every morning and you're the polluting bastard."

4 Climate Change in the Ocean

Every day on the dot of 2 p.m., students gather for a lecture on the quarterdeck of the Corwith Cramer. Now, the trip is nearing its end and I'm giving the very last talk before the students begin to present their findings tomorrow. The topic: the other, non-plastic problems in the ocean.

We've all just finished a drill to test our sea rescue skills. I was totally sucked in, believing for five heart-pounding minutes that there really was a man overboard. I was looking around trying to figure out who we lost, surreptitiously wiping away a tear.

But everybody's here now, both students and staff. Lea and I have rounded up some big sheets of paper and fat markers so I can write down the numbers. I'm feeling the weight of responsibility. They've just spent nearly six weeks out here at the mercy of this primal planetary element, trying to figure out their narrow slices of how it works and how it's changing, soaking in its power, taking it deadly seriously, like they just did for the safety drill.

Humans have wrought dangerous changes to this seemingly immutable sea. And these young people are going to have to grapple with the broader issues of ocean change beyond their current study on plastics. So I begin, wielding the markers, telling them about the research I've done and written about on other vessels with scientists in many other parts of the world.

There's the obvious change: Over the past 50 years, we've harvested vast amounts of fish and other sea life from the global ocean, and have crashed the populations of every single large fish in the sea. The fewer the fish, the harder it is for fish to come back. Taking that much life out of the ocean impairs its potential for recovery by impairing water quality and other ecosystem functions.

But we've also changed the ocean's very chemistry in three fundamental ways, each of them related to fossil fuels. Scientists refer to these as the evil troika because together, they are so much worse than any one on its own.

We've polluted huge swathes of the coastal waters with synthetic, fossil-fuel-based chemical fertilizers that run off the fields and into the rivers and cause algae to reproduce like crazy. When those algae die, they fall to the sea bed where bacteria decompose them, using up the water's oxygen in the process and creating huge dead zones with little or no oxygen. The ocean already has 407 of these breathless zones where life can't exist and some of them are thousands of square kilometres in area, like the one in the Gulf of Mexico. The number is growing.

Then there's the direct effect on the ocean from the burning of fossil fuels to power our economy over the past 250 years. That burning puts carbon-based gases into the atmosphere, where some of them collect. Today, there's 40 per cent more carbon dioxide in the atmosphere than before the craze for coal, gas and oil began and it's accumulated so fast that there's been no time for adaptation. If we keep increasing these emissions at the same rate we have been, there will be twice as much by the middle of this century.

Like a polar fleece, that extra carbon holds heat against the body of the planet instead of letting it dissipate higher up, and that destabilizes climate patterns, leading to droughts, floods, more hurricanes, higher sea levels and shifting patterns of rain and snow. Both the droughts across the North American Midwest and Hurricane Sandy are just the types of things you'd expect from this planetary destabilization.

For years, scientists thought the ocean, so much bigger than the atmosphere, was too vast to be affected by the chemical changes in the atmosphere. They thought it would simply soak up some of the carbon dioxide gas and heat and dissipate them. But about a decade and a half ago, they realized they were wrong. There was just too much carbon dioxide.

As a result, the ocean has warmed up because it has absorbed about 80 per cent of the extra heat the carbon is trapping against the surface of the Earth. It has also become more acidic from the carbon dioxide gas it's absorbed.

Carbon dioxide reacts chemically with the water, molecule by molecule, to produce carbonic acid. The ocean has absorbed so much of the gas — roughly a third of the extra emitted over the past quarter millennium from burning fossil fuels — that it's turning the ocean toward the acid, or sour, side of the pH register. It's a process called ocean acidification. Today, the ocean's surface waters are about 30 per cent more acidic than they were before we started burning fossils. By the middle of this century, if the burning continues at its current rate of growth, the surface waters could be 150 per cent more acidic than they were at the start.

I'm acutely conscious that most of the people on this deck will still be alive then. Some of them are looking shocked.

The consequences of ocean acidification are dire and irrefutable. More acidic water means the creatures that need to use calcium and carbon to build shells, teeth, coral reefs and bones won't be able to do it as easily. That's already happening in parts of the ocean where scientists are seeing scampi claws snap off and crab shells bleed calcium into the sea. Eventually, the ocean will become acidic enough to actually corrode the shells, reefs and teeth of some creatures. Recent studies are showing that sea life of all sorts will have trouble maintaining its own internal chemistry in a more acidic sea. Summer flounder have been shown to lose cartilage and sustain liver and muscle damage, for example. Baby sea creatures are expected to suffer more than adults. Washington State's oyster fishery has been hit hard because oyster larvae have trouble surviving in the altered seas.

Coral reefs around the world, already suffering from hotter waters, more cyclones and overfishing, are now on a watch list for total extinction. The eminent Australian coral reef biologist Charlie Veron has estimated coral reefs could vanish in as little as 20 years. That would give them the dubious honour of becoming the first global collapse of an ecosystem due to carbon destabilization. Already the southern part of the Great Barrier Reef, the planet's largest reef, which is visible from space, has seen its hard coral cover diminish by half in just 27 years.

For the sea and for its sister medium, the atmosphere, this is a strange and unstable time with few precedents. Already, the ocean is more acidic than it's been in 55 million years and the concentration of carbon dioxide in the atmosphere is higher than it's been for tens of millions. The chemical parameters of both sea and air are way outside those of the world we evolved in.

It has scientists running to the fossil record to see what happened last time the Earth was like this. Many of them are now examining the Permian extinction from 252 million years ago for clues to today. Then, 95 per cent of the planet's species perished, the biggest of the five mass extinctions in the planet's history. It's known in scientific literature as "the great dying." The trigger for the die-off was the massive infusion of carbon dioxide into the atmosphere from the series of volcanoes that created the Siberian Traps geological formation in modern Russia.

But the killing mechanism was the ocean. It rapidly turned breathless, warm and sour, just like today. The chemistry of the sea killed off creatures it had once supported and with them, creatures of the air, with only a few survivors to reboot the book of life. Scariest of all? A recent analysis has shown that we humans today are putting carbon into the atmosphere more quickly than those volcanoes millions of years ago.

This whole picture, with its deadly prognosis, has emerged only in the past decade or so.

I've been writing all these numbers down on the sheets, shouting over the wind on the quarterdeck. By the time I'm done, the papers look like a chronicle of the unremitting math of extinction. There's a single technical question on carbon and then, stony silence.

Lea leaps into the breach, lobbing some easy questions and joking to break the tension. Still, resolute silence from the students. Is it despair I'm reading in their faces? Determination? Resistance? Anger? I can't tell.

Later, when it's over and the other students are letting loose on deck with games to celebrate the birthday of one of the deckhands, Aaron Milstein, 28, of Northern Essex Community College in Massachusetts, marches over to me and looks me straight in the eye. "Thank you," he says.

5 The Lesson of the Yellow Rope

The trip is almost over. The students have handed in their term papers, given their on-board presentations, received their scientific grilling from Lea. He's hard to impress. They're still on round-the-clock watches in charge of sailing the ship and the final push to finish the semester is showing. Some of them look like the walking dead. When they finally sleep — I can see them in the berths around the galley tables through the day — they lie motionless, as though in a coma.

I've been sleepless now for nearly a week, lying awake and sweating in my berth night after night, staggering up on deck in the wee hours of the morning to cool off, sluicing myself down with water. The skin on my right foot has broken down for some unknown reason in the heat and is disintegrating hour by hour. The only thing that seems to hold back the advance is to immerse it in vinegar, and so I've cadged some from the steward and am sitting on deck in a sliver of shade soaking my foot in an abandoned plastic yogurt tub.

We're heading for the U.S. Virgin Islands and the students are already in mourning that their tightly-knit group will break apart. Between the classes on shore before they set out to sea and the six week voyage, they've been together for two and a half months, relying on each other to survive, devoid of privacy, bonding.

I'm still trying to figure out where the problem of plastics in the ocean ranks, given all the other man-made assaults on the sea. Research on it is even newer than the research on acidification.

I think back to an interview I did a couple of weeks ago with Miriam Goldstein, one of a small but growing cadre of scientists devoting their careers to the issue. She's a newly minted PhD from Scripps Institution of Oceanography in California, who's already published a raft of papers on the plastics in the North Pacific subtropical gyre. Her latest shows that there's 100 times more tiny plastic trash in the gyre now than there was four decades ago. It's such a dramatic increase that one species of water strider is laying more eggs, using the mini plastics as a floating base, something Goldstein calls a "strange indirect effect." The question of whether more of those eggs reach adulthood is unanswered. As is the question of whether this is good or bad.

I pressed her on this, playing devil's advocate: Does it really matter that there's so much plastic in the ocean?

At first she runs me through the basic logic. We know that before the Second World War, there was no plastic in the ocean because it hadn't been produced or discarded in the volumes we see now. We know that today, plastics are causing widescale changes to a huge portion of the ocean, including supporting creatures to live where they once did not, and that the phenomenon is disproportionately affecting the five subtropical gyres that make up more than 40 per cent of the planet's surface. Those same gyres are critical to the planet's carbon cycle and nobody's sure how plastics will affect that.

"There's just a huge amount of plastic in the ocean over thousands and thousands of miles," she says. "It's very disturbing. It does not belong in the ocean."

The big losers we know of so far are the seven types of ancient sea turtles, nearly all of which are endangered. They eat plastic bags, which then block their bowels and kill them.

On the other hand, some creatures, like the water striders, seem to be colonizing plastic. Certainly microbes are, even in the gyres, which don't normally support much life. Perhaps those microbes will attract algae, which will attract algae-feeders, which in turn will attract fish. What if that alters the cycle of life in those gyres? It could add up to massive changes, she says.

But, I ask again, is that good or bad?

It's the wrong question, she snaps back. Journalists always want winners and losers, she says, and I'm missing the point. What's at stake is that life depends on predictability. We and other living creatures need chemical and biological cycles and climate patterns that do roughly the same thing century after century, millennium after millennium.

This, she points out, is a change. A big one, and unprecedented in the whole history of life on the planet.

Goldstein is right, I'm realizing, back on deck, shifting my foot around in this plastic tub full of vinegar. And as other scientists have pointed out, of all the man-made problems of the ocean, this is one that's relatively solvable.

I recall the interview I did with the oceanographer Kara Lavender Law, another of the bright young global specialists in ocean plastics. She works for SEA and has been on lots of their voyages. In 2010, she wrote one of the seminal papers on plastics based on data the SEA students have been collecting over the years.

It showed no increase in plastic bits along the ship's route from North American to the Caribbean over the 23 years to 2008, but no decline either. It's an unexplained contrast to Goldstein's paper that showed such a large increase in the Pacific gyre. Law is based in New York state and in preparation for this trip on the Corwith Cramer, I drove from Toronto to Rochester to interview her. Over lunch, she laid out the whole scientific picture for me.

We talked a lot about possible solutions and one of her comments has stuck with me through this whole voyage.

"In my mind," she told me, "it's a waste management problem."

I think now of what she said. We can't remove most of the old plastics that are already in the sea. But I realize that, with a few policy tweaks, we could keep out a lot of the new ones. There are already basic design improvements that use less plastic in packaging, for example, such as water bottles. And the giant European company Unilever, maker of Dove and St. Ives products, announced in January that it will ban the use of plastic microbeads from its face exfoliants and other products by 2015.

Kara Lavender Law *(Photo: Roman Sher/Sea Education Association)*

Some chemists are pushing to develop more green plastics, designed on a molecular level to biodegrade. Some clothing designers, including Patagonia, are examining whether it's possible to make fleece-wear that would not shed plastics in the wash.

More plastics recycling would obviously help and so would enforcing the rules that prohibit dumping plastics at sea. Here on the Corwith Cramer, as on other seafaring vessels, all the plastics are kept separate and will be disposed of on shore, unlike the foodstuffs that get tossed overboard every day. And there would be side benefits from recycling. Making new plastic uses fossil fuels, both as raw material and as energy in production. Reusing plastic polymers saves fossil fuels and reduces the carbon dioxide emissions that are also damaging the ocean. One study showed that recycling old plastic bottles to make new ones saved 27 per cent of the emissions.

The philosophical hurdle to get over — for the plastics industry and the public — is to stop thinking of any plastics as throw-away, to harvest far more of the old as the raw material for the new. It would take seeing the big picture.

We have a ways to go. Our species has a history of seeing conveniently small shards of the picture. In my sweaty hours on board, I've been reading about the Caribbean by the historian Eric Williams, the first prime minister of Trinidad and Tobago. *From Columbus to Castro* tracks the money trail and social consequences of the cane sugar and slave trade that followed European settlement here. It's a tale of intractable horror, torture, death and greed, all for the taste for sweets. It seems incredible to me, as I read it, that European society could not see through that.

But the money from sugar at the time was so easy, so dazzling, that it justified all the cruelty and oppression. Williams talks about sugar as the cocaine of the era, except, of course, it was legal. Slavery was just part of a mathematical equation to the sugar sellers, just a line item on the budget, not a moral issue. Until, finally, the markets died because beet sugar was cheaper than cane sugar, and slavery pushed on to new crops in the Americas and eventually, long after, became a moral issue and was fought and banned.

It makes me think of our reliance on fossil fuels. Climate destabilization is already causing hardship globally for tens of millions a year in catastrophic events. The drought in the Horn of Africa can be directly attributed to atmospheric and ocean changes linked to the carbon dioxide load. Tens of thousands are dead. Millions have lost their homes. It's a similar picture with the floods in Bangladesh and other catastrophic events around the world. Australia has become so hot its meteorologists had to add two more coloured bars to maps — deep purple and pink — to indicate temperatures above 50 degrees Celsius. And, as the scientists are realizing to their horror, worse planetary conditions are around the corner unless we pull back from pouring carbon into the atmosphere and ocean.

We already know how. We have all the technology and the alternate forms of non-polluting energy we need to make the switch.

But, of course, the money from petroleum is so easy, so dazzling. At this point, it's hard to link driving my Honda to Rochester with someone starving in Somalia. The line is winding and humans have trouble following it. It's easier just to look ahead to the next bend in the road. It's the same with ocean plastics and waste management. To most of us, they seem like separate issues. And they seem so huge and intractable anyway. But sometimes, the big systemic problem and personal action coalesce rather magically into one. Sometimes the lesson that needs to be learned comes in the shape of humble nylon rope.

A few days ago, while I was helping Lea and the students reel one of their instruments back up onto the ship from deep in the Caribbean, we spotted something bright yellow snagged on the machine. When it got to the surface, we recognized thick plastic multiple-ply rope, the kind you use for camping or tying a canoe to the roof of your car.

All the students and even the hard-bitten staff gathered around, amazed, and started hauling on it, muscles straining, faces red. The captain stood at attention, too, and we all wondered what on Earth could be attached to the line: Treasure? A body? Fishing gear? The hauling went on and on. Finally, the captain ordered that the yellow rope be hooked to a small engine and a pulley and brought in that way. We stood there for more than an hour, burning in the blazing sun, as the machine laboured away, pulling in hundreds of meters of plastic yellow line, length after length tied together in clumsy knots.

Captain Hayward finally unsheathed his knife, over the moans of the students, and cut the line. It was dragging the ship off course and we had to move on. But there on deck was a massive pile of yellow plastic, coils and coils of it, more than anyone had ever seen in one place, that we, the adventurers of the Corwith Cramer, had, by some quirk of fate, taken out of the sea.

Assistant scientist Liann Correira pulls on the yellow rope (Photo: Sea Education Association)

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