

A Sri Lanka navy soldier walks over mounds of debris from the *X-Press Pearl* on May 27, 2021.

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# GRAPPLING WITH THE BIGGEST MARINE PLASTIC SPILL IN HISTORY

The wreck of the *X-Press Pearl* unleashed a record **1,680 metric tons of plastic pellets** on Sri Lanka's coast in 2021. Scientists want to understand more about the effects of this poorly studied type of marine pollution

KATHERINE BOURZAC, C&EN STAFF

# In brief

**In 2021, a cargo ship caught fire and sank** off the coast of Sri Lanka. The ship carried various chemicals, including 1,680 metric tons of plastic pellets called nurdles. Scientists are studying the accident, the largest known marine plastic fire and spill, to help advance our understanding of the environmental effects of this kind of pollution. Still, many unknowns remain about the ship's cargo and its impact on the environment. The accident's aftermath is playing out in Sri Lanka, where economic and political challenges present hurdles for local scientists and may complicate efforts to ensure compensation for environmental damages.

## n May 20, 2021, a fire started on a cargo ship off the coast of Colombo, Sri Lanka. At home under COVID-19 lockdown, the country's environmentalists and scientists watched media reports showing the ship spewing yellow and black fumes, and they worried that the *X-Press Pearl* would spill its oil into the sea.

But a few days after the ship caught fire, it became clear that the *X-Press Pearl* disaster was bigger than an oil spill. The ship was carrying more chemicals than its 348 metric tons (t) of bunker oil. Of the 1,486 containers on board, 81 held dangerous goods. The cargo included caustic soda, nitric acid, and fertilizer. The ship was also transporting polymers, including 1,680 t of plastic pellets, about 70 billion of them, each about 5 mm wide. These pellets, also called nurdles, are the raw materials that are melted and molded to make many plastic products.

On May 25, explosions were heard on the ship, and containers began falling into the ocean. Piles of plastic pellets meters deep engulfed the nearby Sarakkuwa beach. There was so much plastic that "you could not see the sand," says Muditha Katuwawala, founder of the environmental organization the Pearl Protectors. "It was really scary." The accident is the worst ecological disaster Sri Lanka has ever faced and the worst marine polymer fire and spill in history. The largest previous pellet spill released 150 t into the waters of Hong Kong in 2012. In the wake of the *X-Press Pearl* accident, thousands of dead animals, including turtles, lionfish, and dolphins, were beached on the shores. Fishers lost their income, compounding the economic challenges of the pandemic. Meanwhile, the environmental and health risks posed by the chemical and polymer spill are still uncertain.

"This was an extreme incident, but it's not an isolated one," says Therese Karlsson, a science and technical adviser at the International Pollutants Elimination Network (IPEN).

Plastic pollution is ubiquitous. Nurdles and other plastic pollution can be found on just about every beach in the world. But little is understood about the chemistry, movement, and evolution of plastic pollution over time—crucial details for chemists who want to untangle its environmental impact. The *X-Press Pearl* spill offers a chance for chemists to learn more about this common contamination.

The Sri Lankan government has until June 2 of this year, 2 years after the ship sank, to file a claim in international court for damages against the ship's insurance company. And the disaster is still unfolding, with consequences that may not be seen for years, scientists say. "There's an acute phase and a chronic phase, the visible damage and the invisible," says Meththika Vithanage, an environmental scientist at the University of Sri Jayewardenepura.

#### THE INCIDENT AND CLEANUP

The X-Press Pearl first reported problems on May 11, when the ship, operated by X-Press Feeders, was in Qatar's waters. The crew reported to Hamad Port that a container was leaking nitric acid. The port denied them help off-loading the container, and the ship moved on to Hazira Port in Gujarat, India. On May 15, the Indian port also refused to help. According to a website that X-Press Feeders established to share incident information, both ports responded that "there were no specialist facilities or expertise immediately available to deal with the leaking unit." The X-Press Pearl





continued on.

On May 20, the *X-Press Pearl*, then anchored off Colombo, sent a Mayday call. Fumes were seen coming from the ship. A fire had started. The ship burned for days, releasing an estimated 8,000–13,000 t of air pollution. Firefighting ship crews from Sri Lanka and nearby India tried unsuccessfully to extinguish the fire with foams and water.

On June 2, the flames had died down enough that authorities tried to tow the boat farther away from shore, but it sank. By June 17, the ship had lodged on the seabed. It has remained there since, though workers began salvaging it in mid-November of last year and plan to recover the wreck in the first quarter of this year, according to the company's website.

Ship fires used to originate mostly in the engine, but now many are chemical fires that start inside cargo containers, says Claudio Bozzi, a maritime law expert at Deakin University. And chemical fires on this scale are extremely challenging to put out, especially when it's not clear what's burning.

The risk of this type of fire is increasing as more ships sail with ever more cargo, Bozzi says. IPEN's Karlsson notes that about 90% of the world's goods are transported by sea. According to the insurer TT Club, ship fires occur about twice a month, and major fires happen once a month. "These ships are so large that any accident becomes catastrophic," Bozzi says.

X-Press Feeder's incident information website reports that "it is too early to tell how the fire started"; as of press time, the company's public relations firm had not replied to a question about the cause of the fire.

The leaking nitric acid is a possible cause, Bozzi says. Nitric acid is a strong



Currents carried nurdles from the X-Press Pearl wreck around Sri Lanka's coasts. This graphic shows nurdles spotted by citizen scientists between May 29 and July 11, 2021.

oxidizing agent that can ignite combustible materials, including wood and oil. He wonders whether the nitric acid container was stowed properly. To easily spot and address problems with a container of hazardous material, people should store it near a door or on the deck, not deep in the hold, he says. But port workers are not always aware of what hazards are on board and may not be properly trained on how to arrange cargo on these ships, he says.

The initial cleanup effort after the accident was massive, involving 18,973 people by June 14, 2021, according to a United Nations Environment Programme (UNEP) report. Once government efforts had cleared away much of the visible spilled plastic and other wreckage, such as twisted and burnt metal containers, the beach cleanup got a lot harder.

Over time, the plastic pieces started to blend into the environment and became harder to identify. Adding to the challenge was their varied color, shape, and size. Besides unburned nurdles, the debris includes a spectrum of burnt plastic, also called pyroplastic, that can be charred gray or orange or charcoal-like. Pyroplastics can also appear rocklike or resemble wood. Burnt plastic is brittle and readily fragments into smaller pieces. Some pyroplastic from the wreck is made up of nurdles that fused into larger pieces that look like seaweed or other organic matter.

The job of sifting through this hard-tospot plastic has now mostly fallen to volunteers, the Pearl Protectors' Katuwawala says. The Pearl Protectors has built handheld sieves for sifting the nurdles from the sand. Volunteers use them on cleanup days, and the Pearl Protectors leaves them on beaches for visitors to use on their own.

But the beaches are dynamic. One day a beach will be clean; the next, the movement of the tides and the waves might have brought up a batch of nurdles. Katuwawala says he has seen the plastic pollution move into the water and then get buried in sand during monsoon seasons, only to come back up later. "It's not like you can clean one place and then it's done," he says.

Indian Ocean currents wrap around Sri Lanka. Six weeks after the spill, researchers documented severe nurdle pollution along 40% of the 340 km of coastline stretching from Kalpitiya to Matara in the south (*Mar. Pollut. Bull.* 2022, DOI: 10.1016/j. marpolbul.2022.114145). Colombo is in the middle of that length of coastline. A citizen science mapping project called Nurdle



Tracker Sri Lanka has recorded nurdles as far as the country's east coast.

#### THE IMPACT

Whatever caused the fire on the *X*-*Press Pearl*, its aftermath spilled out into the waters around Sri Lanka and onto its beaches. Sri Lanka has so far received \$7.85 million in compensation from the ship's insurer. The government says this money has been used for cleanup efforts and to compensate fishers for lost income.

The spill disrupted fisheries around Sri Lanka. The University of Sri Jayewardenepura's Vithanage says she saw "luminous green" water in the Negombo Lagoon, a major fishing area. Such green water is a sign of an algal bloom, something she had never previously observed in this region. Algal blooms can kill fish and contaminate them with toxic compounds. The bloom could have been caused by urea carried on the ship.

The accident occurred during the prime fishing season, says Hemantha Withanage, director of the Sri Lankan environmental advocacy group Center for Environmental Justice. The CEJ's representatives interviewed local people, most of whom reported lost income after the accident. A joint report by the CEJ and IPEN recounts that some fishers found their nets damaged after the accident and observed nurdles in fish's stomachs, gills, and mouths.

Other marine species were also affected by the spill. Most of the world's sea turtle species visit the Sri Lankan coast at some point in their life cycle, and the disaster's impact on turtles has been particularly stark—the *X-Press Pearl* was anchored in a turtle migration path. Over 600 turtles were found beached in the months after the disaster, some with broken shells and others with burns. Vithanage says that for every beached turtle, it's likely another five turtles have died at sea.

The accident happened at the start of the monsoon season, when currents run to the north and pelagic fish, which normally live farther out to sea, enter coastal waters to spawn. This timing means there could be a drop in fish populations in coming years.

Wildlife was likely harmed by intense heat from the fire, explosions, and even sound waves. The UNEP report also points to chemical risks. There were 1,040 t of caustic soda and 25 t of nitric acid on board, both of which are water soluble. But both are much denser than seawater and may have sunk to form corrosive plumes on the seabed. These plumes could inflict chemical burns on wildlife such as turtles and dissolve animal carcasses. "We might not have seen some of the damage" for that reason, Vithanage says.

There are also questions about the exact contents of the ship and what happened to them during the fire. If the 210 t of methanol listed on the *X-Press Pearl's* manifest spilled instead of combusted, it would have floated on the water and created a cloud of toxic vapors that would have been harmful to fish and posed particular risks to turtles, dolphins, and other animals coming up for air, according to the UNEP report.

Another unknown is the 9,700 t of epoxy resin carried in 349 containers. The ship's manifest does not indicate whether the resin was liquid or solid. Liquid epoxy could have formed a toxic plume on the seabed and traveled with the currents, burning swimming and stationary animals and plants, according to the UNEP report. UNEP recommends finding more information about this part of the cargo,



A dead fish with nurdles in its mouth, photographed on May 31, 2021

such as the epoxy's material safety data sheet, to evaluate the risks. As of press time, company representatives had not responded to questions about the epoxy resin.

## PLASTIC POLLUTION QUESTIONS

While reactive chemicals from the spill may have caused acute environmental damage, environmentalists and researchers are also concerned about potential long-term issues caused by the *X-Press Pearl's* spilled plastics, which may persist in the environment for a long time.

Most news about plastic pollution focuses on end-of-life issues—for example, what happens after we throw away a plastic bottle or bag. But plastic can also leak into the environment earlier in its life cycle. About 230,000 t of







A Pearl Protectors volunteer uses a sieve to clean plastic debris from a beach at Moratuwa, Sri Lanka.

nurdles is released into the environment every year. "Nurdles are one of the most well-recognized plastics in the ocean," says Christopher Reddy, a marine chemist at the Woods Hole Oceanographic Institution (WHOI). "If you throw a net off a boat and trawl, you'll get a nurdle."

A handful of other large-scale nurdle spills are known, but they are orders of magnitude smaller than the 70 billion nurdles released by the *X-Press Pearl*. Several spills occurred in 2020 alone. That year, an estimated 731 million nurdles were spilled into the Mississippi River; an unknown tonnage was spilled off South Africa's coast; and 13 t was spilled from a container ship in the North Sea. The scale of spills on the open ocean is more mysterious. Plastic is not considered a hazardous material, and international law does not require shipping companies to report all containers lost at sea.

The X-Press Pearl disaster gives scientists a unique opportunity to address some of the biggest questions about plastic pollution: How does it break down over time, what kinds of chemicals does it leach in the process, and how do those chemicals affect the environment? In the case of a spill like in Sri Lanka, "you have that provenance of where and when plastic entered the environment," WHOI materials scientist Bryan James says. "You can do forensics, track it. You can estimate the baseline of what it is and how it changes over time."

One particular issue scientists want to address with the Sri Lanka spill is what happens when plastic gets burned.

As the ship burned, some nurdles were released in relatively pristine form,

Hundreds of dead turtles were seen on Sri Lanka's beaches in the months after the X-Press Pearl shipwreck.

maintaining their white color; others hit the ocean seared orange, flecked with gray ash, or fused to form rock- or seaweed-like black shapes. Chemists want to know how these changes could affect what molecules the nurdles release into the environment. Potential toxic compounds might include ingredients in the pellets themselves, molecules absorbed from other spilled cargo, or chemicals created during the fire.

Environmental scientist Vithanage has been documenting changes in nurdles washed up on Sarakkuwa beach near the shipwreck. Before the accident, she had sampled sand and nurdles (at the time quite scarce) from the beach. She's been regularly sampling there since a few days after the accident, gathering nurdles from the surface of the sand and digging for them a meter deep. She's seen the pellets wear down and shrink over time. She's observed the nurdles get buried in the sand and come back up. Her ability to assay organic chemicals in and on the nurdles is limited by the equipment in her lab, she says. But she's been testing them for metals.

Vithanage tested for lithium after learning that the ship's cargo included a container of batteries. Her group found high levels of lithium in the water and on the nurdles (*Sci. Total Environ.* 2022, DOI: 10.1016/j.scitotenv.2022.154374; *Mar. Pollut. Bull.* 2022, DOI: 10.1016/j. marpolbul.2022.114074). Her team also found high levels of chromium, which Vithanage believes may have come from coatings on the shipping containers. Exposure to chromium can slow plant growth, damage tissues in aquatic animals, and cause organ failure in people.

According to the cargo list, most of the nurdles on board were made of polyethylene, but that tells chemists little about their composition and what additives might be present. The CEJ collaborated with IPEN to test for toxic organic compounds in the recovered nurdles. The team found ultraviolet sensitizers, bisphenol A, and polycyclic aromatic hydrocarbons (PAHs), which are carcinogenic.

The PAHs either are from the ship's fuel or are a by-product of plastic combustion, Reddy says. WHOI data in a paper currently under review show that some of the spilled nurdles have higher levels of PAHs than have ever been reported for ocean plastic. Reddy says it's not clear whether these chemicals would be bioavailable. There has been very little research on how PAHs interact with pyroplastics. These carcinogens might cling tightly to the plastic's surface, or they might shed into the sea or onto people's skin.

Another reason that chemists are studying pyroplastics is that when plastic is burned, the chemistry gets more complex. Purdue University environmental engineer Andrew Whelton has studied this complexity in the context of plastic water pipes. In 2018, a wildfire in Santa Rosa, California, led to benzene contamination in the city's water supply. Benzene was created when the plastic pipes burned, and the chemical persisted in the water system. Acute exposure to benzene can depress the central nervous system; chronic exposure can be carcinogenic and cause blood problems such as anemia. Organic molecules like benzene cling to plastic, an effect that's more pronounced in salty water.

Without knowing the chemical details of the nurdles and other plastics carried on the *X-Press Pearl*, scientists can't say what might have been released into the ocean. As a benchmark, Whelton says, consider that for every gram of high-density polyethylene that is burned, 0.8 µg of benzene gets released.

Whelton says more research is needed on how the plastics were transformed by the fire and what materials were released into the water. But this information is hard to come by.

#### Nurdle accounting

Plastic pellets like the tens of billions of nurdles spilled by the X-Press Pearl are the raw materials used to make many products, including plastic bags and beverage bottles. In 2019, Jace Tunnell, director of the Mission-Aransas National Estuarine Research Reserve at the University of Texas Marine Science Institute, and his team used the weights of pellets found in the environment and of sample products to estimate the number of nurdles that compose each item. The numbers are estimates because the density and chemistry of both nurdles and products can vary.



Sri Lanka's Marine Environment Protection Authority (MEPA) has convened a scientific committee to gather information about the accident's environmental impacts. The committee submitted its report to the government in January as this article was going to press. C&EN contacted MEPA and members of the scientific committee with questions about what kinds of samples were gathered, what testing was being done, and what data they had collected on marine animal mortality. Committee members were reluctant to talk given MEPA's stipulation that all findings must be kept secret ahead of potential international court filings.

Reddy and colleagues at WHOI are

extensively testing a small volume of samples shared with them by Asha de Vos, executive director of Oceanswell, a nonprofit conservation research and education organization in Sri Lanka. When the ship caught fire, she contacted Reddy because he had experience working on oil spills, including the *Deepwater Horizon* disaster. She shared samples taken from Pamunugama, a beach just south of Sarakkuwa, 5 days after the fire started.

Those samples and others now sit in WHOI's labs. At WHOI, James dons gloves and pulls plastic bags and glass jars full of debris from a refrigerator. One piece of agglomerated and incinerated plastic looks like a stack of toasted nori. Some of the burnt plastic bits look like fragments of wood or stones. The WHOI scientists have jars of white, orange, and gray nurdles sorted for study—they want to know how the degree of burning affects their chemistry and toxicity.

When probed with high-resolution mass spectrometry, most of the clean, white nurdles from the beach look similar—like high-density polyethylene (ACS *Environ. Au* 2022, DOI: 10.1021/ acsenvironau.1c00031). The burnt plastics are a widely varied group, with no nurdle an exact chemical match for its brethren. The WHOI group found long-chain hydrocarbons normally seen in petroleum, a mix of incomplete combustion products, degradation products of antioxidants, and more.

James and WHOI toxicologist Mark Hahn have studied the pellets' potential for acute toxicity during zebrafish development, a standard animal model to test toxicity. They

placed pellets of different colors indicating different levels of burning—in the water with zebrafish embryos. They didn't see acute toxicity in these studies.

The team then looked in more detail, assaying how exposure to chemicals leached from the plastic pollution affects human cells. They used solvents to coax relatively high levels of organic chemicals out of the different types of plastic pollution and then assayed whether they activated gene-expression-regulating proteins called transcription factors in the cells. Their goal was to identify biological pathways that might be activated by exposure to the plastic and assess whether burnt and unburned plastic from the spill had different effects.



Woods Hole Oceanographic Institution (WHOI) researcher Bryan James holds a piece of pyroplastic from the *X-Press Pearl* disaster. Burnt plastic can resemble seaweed, wood, and other organic matter naturally found on beaches.

Researchers at WHOI have sorted nurdles spilled from the *X*-Press Pearl by color to study how different degrees of burning in the ship's fire changed the chemistry of this plastic.

The results are preliminary, but James says the team observed the activation of metabolic and endocrine pathways, as well as one associated with oxidative stress. Compared with material leached from pristine pellets, the burnt-nurdle cocktail had much stronger and more wide-ranging effects on cells. James says it's not clear yet what this all means, but the WHOI team is expanding the tests to a cell model of marine life.

This kind of solvent-based leaching is not intended as a direct mimic of what happens to plastic pollution in the natural environment, Hahn says. It's a kind of sped-up, worst-case scenario. "We're getting things out of the nurdles that wouldn't necessarily come out naturally," he says.

The complexity of the plastics spilled from the *X-Press Pearl* is already overwhelming, Hahn says. "When you add on top of that combustion, photodegradation—it's a wicked problem that's not going to be easy to solve," he says.

## THE HURDLES

Scientists in Sri Lanka face not only this wicked problem but also logistic challenges. For example, there aren't any facilities in the country capable of doing the kind of chemical analysis needed to detect trace levels of many kinds of harmful chemicals in beached fish. The country does not have extensive infrastructure for collecting environmental data or the necessary lab equipment to analyze them. And the country is facing an economic and political crisis, which means dealing with the environmental disaster is not a high priority.

Protesters frustrated with the country's economic situation forced Sri Lanka's president to step down in July. The cost of food, fuel, and other necessities has continued to rise. As of September, inflation in the country reached a record 69.8%. As a result, costs for scientists traveling from study site to lab to home are high.

Vithanage notes that all debris from the accident, including nurdles, is considered evidence for court proceedings. It must be turned over to MEPA for storage in a central facility that is managed by a different agency. Getting permission to do research on the nurdles is time consuming because of bureaucracy and the need to coordinate between multiple government offices, she says.

On Jan. 11, Sri Lanka's Daily News reported that MEPA had turned over its report on the damages caused by the X-Press Pearl disaster to two other government officials. The paper reported that Urban Development and Housing State Minister Arundika Fernando said the country is "waiting to receive compensation amounting to US\$ 6.5 billion for the damage caused to the coastline and coastal environment of this country due to this accident." But the government must do more than wait-Sri Lanka has until June 2, 2 years after the X-Press Pearl sank, to file for damages in Singapore's courts. In the same article, Fernando stated that they plan to do so. As of press time, MEPA chair Dharshani Lahandapura had not responded to C&EN's query about the status of the report and its contents.

"There's no compensation scheme in place for an accident like this, no mechanism to guarantee restitution," IPEN's Karlsson says. "These accidents have massive impacts on coastal communities, and they have to bear the brunt of the cleanup and the consequences."

Bozzi, the maritime law expert, says there's no question that the *X-Press Pearl*'s owner carries liability for the spill and associated damages. "The burden of proof will be identifying and calculating the damages that need to be paid," he says.

International shipping regulations ensure compensation for oil spills. When oil is spilled, "you don't have to prove it would cause environmental damage; it's just assumed that it does," Bozzi says. That's not the case for other kinds of spills, he says, "even though other forms of pollution are becoming more common." He says many maritime regulations were written before microplastic pollution was even recognized, so these rules need to be revised.

Karlsson also hopes that the world can learn from the X-Press Pearl disaster and that international shipping laws can be updated before the next time something like this happens. For example, the International Maritime Organization's Hazardous and Noxious Substances (HNS) Convention would ensure liability and compensation for damages from hazardous materials other than oil. But the conditions needed for the convention to take effect-including ratification by 12 countries—have not been met. Only 8 countries have signed the protocol. The HNS Convention would not cover plastic. but it does include other chemicals that were on board the X-Press Pearl.

And the next spill may be sooner than later. "With the increasing size of ships, increasing complexity of cargo, there will continue to be spills and accidents and continued risks to human health and the environment," Karlsson says.

Meanwhile, chemists are digging in for years of research on the spilled nurdles' environmental impact. Reddy, Vithanage, and other chemists hope research on the disaster can help advance scientific understanding of the environmental effects of plastic pellet pollution and serve as a case study for how to handle such spills in the future.