EMERGING DISEASES

HOW KITTY IS KILLING THE DOLPHINS

The pathogens of land animals are spreading to the oceans, threatening otters, seals, whales, coral and other sea creatures

By Christopher Solomon

The detective story always do, with a ring was on the line. He A few days later he having found another. coming "again and Miller recalls. "At the were getting four a piled up, so did the

DOMESTIC CATS carry a parasite, *Toxoplasma gondii*, that has sickened dolphins found stranded in the Mediterranean Sea.

had begun, as they
ing phone. A biologist
had found a corpse.
called a second time,
Soon the calls were
again," Melissa A.
highest point, we
day." As the bodies
questions.

Christopher Solomon, a former reporter for the *Seattle Times,* writes frequently on the environment and the outdoors for the *New York Times, Outside* and other publications.

Miller is a wildlife pathologist and veterinarian. The dead were California sea otters, a threatened subspecies of sea otter that today numbers fewer than 2,800 along the state's central coast. In all, more than 40 sick and dying otters washed ashore during that terrible April 2004 episode—an astounding number in such a short time.

Miller spent many days with her hands inside the dead animals, looking for what went wrong. She was stymied. During their last breaths, many had shaken with seizures. Autopsies showed extensive neurological damage. Finally, a pattern emerged of severe brain inflammation. Hunched over microscopes, Miller and her colleagues finally fingered a surprise killer. The opossum did it.

More precisely, the culprit was *Sarcocystis neurona,* a single-celled parasite that is related to malaria, whose primary host is the Virginia opossum. Yet *S. neurona* is a terrestrial disease, and opossums are natives of the Appalachian backwoods, not the American West. How could this parasite be scything through sea otters in the Pacific?

Further gumshoe work teased out a tale too strange for fiction. People moving from east to west in the early 1900s helped the opossum travel to the San Jose area. The invasive animal thrived and eventually spread north into British Columbia. Infected opossums shed *S. neurona*'s sporocysts, hardy reproductive structures, in their feces. Miller and her associates surmised that a big, late-winter rainstorm washed a load of sporocysts downstream and into the waters just off Morro Bay, Calif., where they were taken up by filtering razor clams. Otters then gorged on the clams.

Although disease agents such as canine distemper virus had previously migrated from land to sea and killed thousands of seals, this case was the first documented mass killing of marine mammals by a land-based parasite.

We are all familiar with diseases such as rabies that can make the jump from nonhuman animals to humans. Yet what about a jump in the other direction? In the past decade ocean researchers have found a disturbing trend: we are making marine life ill with human diseases, as well as those of our pets, livestock and wildlife that have hitched a ride with us. Scientists have even coined a new term—pollutagens (polluting pathogens)—to describe the land-based bacteria, fungi and parasites flowing into the seas. Transmission is happening worldwide and is sickening and killing marine mammals such as harbor seals, sea lions and porpoises, not to mention those hapless California otters.

Frequently the examples are bizarre, even jarring. In 2010 scientists reported that a strain of *Salmonella* Newport, which is normally associated with birds and livestock, most likely killed a newborn killer whale that had washed ashore in Ventura County in California—and orcas swim at a distance from the coast, presumably far from pollution. In South Carolina, Atlantic bottlenose dolphins have been found carrying the "superbug" methicillin-resistant *Staphylococcus aureus* (MRSA).

Our diseases are making more than just mammals sick, evidence shows. In 2011 scientists genetically linked the pathogen *Serratia marcescens*—which causes meningitis and is responsible for the white pox epidemic that has wiped out 90 percent of the Caribbean's elkhorn coral—to human sewage. It was the first time that a human disease had been shown to infect a marine invertebrate.

This notion that land-based pathogens are moving seaward is so novel that scientists are still trying to grasp its scale and severity—and how new the issue really is. Some argue that our beleaguered oceans face more pressing problems, such as acidification. Others, however, say the breakdown of barriers be-

IN BRIEF

Pathogens from people, cats and other land animals are entering the oceans and attacking sea mammals. A parasite from opossums is killing California sea otters; a parasite from cats is killing dolphins.

Although data are still new, these "pollutagens" seem to be on the rise. Furthermore, drug-resistant bacteria from humans have been found in sharks and seals, raising the chance that the bugs could mutate and reinfect humans, who might be ill equipped to fight them. **Thoroughly cleansing** wastewater and expanding wetlands that buffer land from sea could lessen the pollutagen threat.

PRECEDING PAGES: SHERI L. GIBLIN *Getty Images (cat);* HIROYA MINAKUCHI *Getty Images (dolphin)*

tween land and sea could allow pollutagens to sicken or kill a wide array of ocean life. The trend could also give pathogens a way to mutate and reinfect people; after all, we work and play in the sea and eat many of its creatures. We need to better understand what is happening and to take actions—which sometimes can be quite simple—to help the ocean's creatures and, in turn, ourselves.

CAT POOP SICKENS DOLPHINS

ALTHOUGH THE SPECTER of pollutagens seems frightening, researchers first have to determine how recent and widespread the problem is. The most studied terrestrial pathogen currently affecting sea animals comes courtesy of America's favorite house pet, the cat. *Toxoplasma gondii,* a relative of *S. neurona,* is a protozoan parasite—a single-celled organism. *T. gondii* completes its reproductive cycle inside felines and has adapted so that it can invade and thrive inside the tissue of other creatures. Up to one quarter of the U.S. human population aged 12 years and older now carries *T. gondii,* with few to no ill effects, although pregnant women are warned against cleaning out the cat box because the parasite can cause birth defects. Today *T. gondii* has invaded sea life worldwide, from Miller's California sea otters, to dolphins that have become stranded in the Mediterranean Sea, to the critically endangered Hawaiian monk seals, of which few remain. "It truly is a cosmopolitan disease," says Stephen Raverty, a veterinary pathologist at British Columbia's Animal Health Center and a leading sleuth of pollutagens.

How can Whiskers be responsible for that ailing Guadalupe fur seal in Mexico? Credit the parasite's remarkable instincts for survival. In just 10 days a newly infected cat can shed up to 100 million *T. gondii* oocysts—tiny egglike structures—in its feces, says Michael Grigg, chief of the molecular parasitology unit at the National Institute of Allergy and Infectious Diseases. When an infected cat poops in the garden or an owner flushes used kitty litter down the toilet, the oocysts enter the environment. Persisting in soil or saltwater is no sweat for these sturdy structures. "In the lab, we store them in dilute sulfuric acid," Grigg says. "For up to 10 years they'll remain infective." In theory, just a single oocyst ingested, say, from the meat of a clam can infect a sea animal. Multiply that by some 70 million pet cats and 60 million feral felines in the U.S. alone, and the threat looms large. (Humans do not contribute to the problem directly, because they do not pass the oocysts through their feces.)

Even though *T. gondii* can kill outright, Grigg says that more often it weakens creatures with "kind of a chronic, smoldering infection." The infection can flourish when an animal is stressed by illness or an environmental problem such as sewage spills. Grigg's work in the Pacific Northwest, where much of the pollutagen research is centered, has found that more than half of dead raptors and more than one third of dead seabirds examined had the *T. gondii* parasite. "That was much higher than we had envisioned," he says.

When sea animals get more than one such disease, the "cocktail" is even more lethal than either pathogen on its own. A 2011 study of 161 Pacific Northwest marine mammals ranging from a sperm whale to harbor porpoises that had either become stranded or died found that 42 percent tested positive for both *T. gondii* and *S. neurona*.

The problem sounds alarming, but it is hard to tell definitively whether pollutagens are indeed on the rise "because we don't have any background data," Grigg acknowledges. "Is this just better detection?" Until 10 or 15 years ago, scientists never thought to examine sea mammals for land-based pathogens. Now the hunt is on, and Miller, for one, has seen too many dead California sea otters to hedge anymore. She says 70 percent of the otters have *T. gondii,* which they can get only from the rear end of a feline. "I don't think there is any question that this is

SEA OTTERS found beached and dying on California's shore had brain inflammation from *Sarcocystis neurona,* a parasite carried by the Virginia opossum.

STEVE AND DAVE MASLOWSKI Getty Images (opossum); MARC SHANDRO Getty Images (otters)

increasing," she says of pollutagens. *T. gondii* was found recently in beluga whales in Arctic waters thought to be pristine, a dubious first.

ORCAS VAPORIZE GERMS

HEIGHTENED INVESTIGATION has expanded the rogue's gallery of ocean interlopers. A few years ago researchers in the Pacific Northwest wondered whether the thin, frothy film on the surface of seawater in Puget Sound, called the sea-surface microlayer, was contaminated—and whether those contaminants might be making orcas sick. When the killer whales surface to breathe, they vaporize this layer and then inhale it deeply into lungs that have few sinus protections. A significant number of orcas that have died over the past few decades have had respiratory ailments.

To investigate, scientists in boats chased the endangered whales to capture whale breath in petri dishes dangling from a stick. They also dipped dishes into the microlayer.

What grew in the petri dishes surprised them. In both kinds of samples, researchers found bacteria that did not seem to belong, including "significant human pathogens," according to the resulting 2009 study. They found strains of *Salmonella*. They found a rare bacterium, usually originating in sewage, that causes pneumonia in humans. They found *Clostridium perfringens,* a bacterium responsible for foodborne illnesses. In all, the researchers recovered more than 60 different pathogens "that are probably all terrestrial," says J. Pete Schroeder, the study's lead author and a marine mammal veterinarian now at the San Diego–based National Marine Mammal Foundation. "We've found stuff I've never even heard of, and I've been a veterinarian for more than 40 years," Schroeder says.

Schroeder's group did not directly link the contamination in orcas and in the microlayer to orca deaths. Yet orcas along the Pacific Northwest today are stressed by everything from cruise ship noise to declines in their preferred chinook salmon—which weakens their immune system. "The bacteria are out there, lying in wait for just the right set of circumstances, which is an immunocompromised animal," Schroeder says.

Scientists are increasingly worried about drugs entering the ocean, too, be it caffeine or estrogen in birth-control pills. In a study published in February, for instance, researchers at Umeå University in Sweden found that perch that swam in waters laced with the anxiety-moderating drug oxazepam left their schools to look for food on their own, a risky behavior because schooling protects them from predators.

DRUG-RESISTANT BACTERIA ALSO THRIVE

LAND-BASED POLLUTAGENS swimming in the sea are not the only concern. Some of the bugs are resistant to medications, which could be especially bad news for humans. A few years ago researchers at Woods Hole Oceanographic Institution and their colleagues concluded an unprecedented, three-year study of 370 live and dead marine animals found from the Bay of Fundy to Virginia. Surprisingly, three out of four animals had at least one antibiotic-resistant bacterium, and 27 percent had bacteria resistant to five or more antibiotics. Most of the bacteria found also live in humans. The booby prize went to a harp seal; it harbored bacteria that were resistant to 13 of the 16 drugs tested, according to research leader Andrea Bogomolni, including antibiotics used in agriculture, such as gentamicin, or for domesticated animals, such as enrofloxacin.

HARBOR SEALS that died off Washington State's coast were infected with *Neospora caninum*, a parasite that causes infectious abortions in British Columbia's dairy cows.

Resistant bacteria have been found to reside in sharks off Belize and Louisiana. Further, Raverty has recovered *Escherichia coli* and *Enterococcus* from the intestines of dead harbor seals off the Pacific coast that were resistant to all eight common livestock antibiotics that he and his colleagues screened for. "Even on land we don't see that level of resistance in the same bacteria recovered from livestock," he says.

Some naturally resistant bacteria can be found in the environment, of course. And again, the data are so recent that it is hard to know if the levels of resistance are steady or rising. As Bogomolni puts it, "What's normal?" Still, scientists suspect that something is out of whack. They think marine mammals are encountering antibiotics and antibiotic-resistant bacteria from plumes of ill-treated human sewage and from the effluent from large farms, where livestock antibiotics are often overused.

For example, people who consume the widely prescribed antibiotic tetracycline excrete a whopping 65 to 75 percent of it unchanged, Raverty says. A 2008 investigation by the Associated Press found that in the U.S. alone millions of pounds of pharmaceuticals are flushed down the drain annually by individuals, hospitals and nursing homes. Everything from anticonvulsants to sex hormones were found in the drinking water of at least 46 million Americans. If wastewater is not properly treated, such compounds can find their way to the sea.

Drug-resistant bacteria coursing through the ocean is worrisome for several reasons. A surfer or fisher with an open wound or someone who gulps water while swimming could get an infection that is hard to treat, Raverty says. And as Bogomolni points out, the harp seal he examined was mistakenly caught in a fishing net, which means that "you're getting your food from the same place that that animal is getting its food."

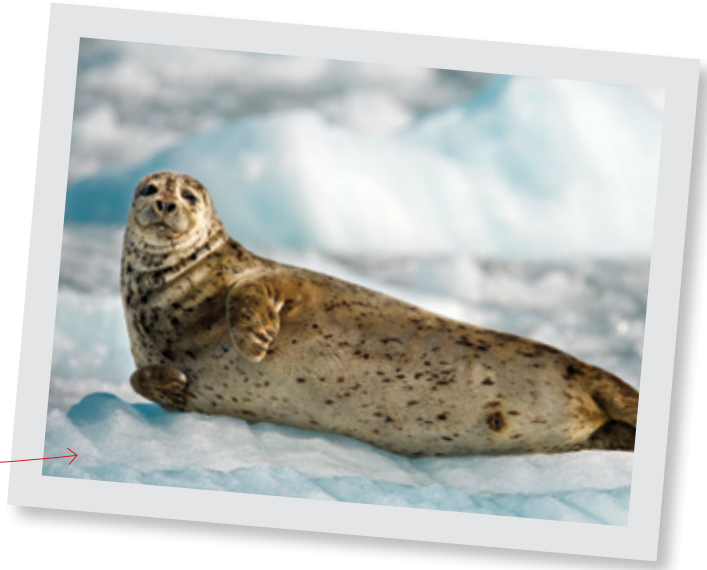
Another concern is that sea mammals could serve as swimming petri dishes, nurturing and transforming diseases—particularly viruses—until they reemerge among humans as something even more difficult to defeat. Viruses (which are unaffected by antibiotics) can mutate rapidly. In 2010 researchers at the Hubbs-SeaWorld Research Institute in San Diego and their colleagues discovered astroviruses in several marine mammals—

ANTHONY LEE *Getty Images*

star-shaped viruses that are a leading cause of viral diarrhea in young children and weak adults.

More sinister, perhaps, the investigators found that human and marine mammal astroviruses may have recombined (joined together) to form a new kind of virus. Although Hubbs-SeaWorld scientist Rebecca Rivera cautions that the virus is not about to sweep the land, she says the discovery highlights how sea mammals could throw an unforeseen curve back at humans. In 2011, for instance, 162 New England harbor seals died in a pneumonia outbreak. The seals, according to a study last year in the journal *mBio,* had contracted an avian flu virus that had "acquired mutations that are known to increase transmissibility and virulence in mammals"—including, possibly, humans.

Others worry about human viruses going into hiding until they can return with a vengeance. In 2000 researchers discovered that harbor seals in the Netherlands had acquired the same influenza B virus that had circulated among humans four to five years before, says Albert Osterhaus of Erasmus Medical Center Rotterdam, a top influenza scientist. Such a "reservoir" of human illness could return from animals, when our immune systems are more vulnerable to them, and infect us all over again.



PATRICK ENDRES *Getty Images*

Still, some scientists are not alarmed. Michael Moore, a well-regarded whale researcher at Woods Hole, who has participated in some of the studies, says the seas right now face other enormous challenges: ocean acidification, the "huge, huge problem" of marine mammals becoming entangled in fishing nets. "I don't see a tidal wave of new zoonotic agents coming back across the land-sea margins as being the same level of concern," he says. As for humans getting sick, "most of us have pretty darned good immune systems," says Moore, who has handled hundreds of ill and dead sea animals. If there had been any major threat from marine life, he points out, "I'd have been dead many times over."

WETLANDS TO THE RESCUE

WHETHER MARINE POLLUTAGENS are increasing or are just more prevalent than we knew, the way to reduce their presence is to figure out how they are getting into the ocean. Researchers have a pretty good idea. Humans have increasingly knocked down traditional barriers between land and sea. When people move to new habitats, they "get rid of wetlands, which are great natural kidneys for pollution," Miller says. And our increasingly dense landscape of streets, drains and pipes often whisks runoff directly into the sea. Both trends leave nature with little chance to grab sketchy water and let it soak into the seafloor along the shoreline, where it can be buffered and filtered. Ever resourceful, the bugs have taken advantage. Changing the environment "has given them opportunities to find new homes and be amplified," Grigg says. "This is evolution happening," and we are contributing to it.

Bringing our critters wherever we go has hastened the problem, whether cats, dogs, opossums—or cows. A few years ago sea otters, sea lions and harbor seals started stranding and dying along the coast of British Columbia and neighboring Washington State. Raverty and Grigg found them infected with *Neospora caninum,* a protozoan parasite that is the chief cause of infectious abortion in British Columbia's dairy cattle.

The problem, Miller says, is fixable—and not by killing all the house cats. Communities should preserve wetlands that cleanse runoff before it reaches open water. Large waste lagoons at animal farms must be prevented from leeching into streams and rivers that lead to the sea. Simple measures can often suffice. One study showed that adding a grassy strip between dairy fields and a riparian area dramatically reduced the number of pollutants entering the waterway.

As for cats, scientists are working on a vaccine against *T. gondii*. Until a practical one is created, the otter's future may be in our hands. Miller says cat owners should keep their pets indoors so they do not poop outside and should spay and neuter them to keep unwanted felines from proliferating. All of us should make smarter use of antibiotics and not toss extra medications down the drain. The best way to dispose of old drugs is through programs such as the National Take-Back Initiative or others that any local pharmacy can recommend.

Communities should also require better scrubbing of human and animal sewage. We need to filter our wastewater, Grigg says, because "chlorine is insufficient." Miller still recalls her elementary school teacher saying, "Dilution is the solution to pollution." Now our own effluents "are coming back to haunt us, as well as the animals who are downstream," she says. "Luckily, small steps can cumulatively make a big difference." If saving a sea otter is not sufficient inspiration to better clean up our own waste, then saving ourselves from a mutant pollutagen may be. SA

MORE TO EXPLORE

A Protozoal-Associated Epizootic Impacting Marine Wildlife: Mass-Mortality of Southern Sea Otters (*Enhydra lutris nereis*) due to *Sarcocystis neurona* Infection. Melissa A. Miller et al. in *Veterinary Parasitology,* Vol. 172, Nos. 3–4, pages 183–194; September 20, 2010.

Polyparasitism Is Associated with Increased Disease Severity in *Toxoplasma gondii*–Infected Marine Sentinel Species. Amanda K. Gibson et al. in *PLOS Neglected Tropical Diseases,* Vol. 5, No. 5; May 24, 2011.

Human Pathogen Shown to Cause Disease in the Threatened Elkhorn Coral *Acropora palmata*. Kathryn Patterson Sutherland et al. in *PLOS ONE,* Vol. 6, No. 8; August 17, 2011.

More information on sea otter diseases: **http://seaotterresearch.org**

SCIENTIFIC AMERICAN ONLINE
For a list of specific antibiotic-resistant bacteria found in sea mammals, see **ScientificAmerican.com/may2013/drug-resistance**