Swimming Sentinels: Climate Clues from Stranded Marine Mammals

by

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ABSTRACT

From skinny sea lions on beaches in California, to hundreds of enormous dead whales in the fjords of Chile, scientists have been recently puzzled by a spate of dead and dying marine mammals. These events are so complicated— influenced by disease, biotoxins, ecosystem changes, and human interaction—that their cause can appear impossible to untangle. Yet a growing body of evidence strongly suggests that climate change has a hand in them all. This thesis examines marine mammal stranding events of the past and present to show how climate change will, and already has, impacted marine mammals, and how these events could serve as proxies for broader ecosystem changes in the years to come. By paying attention to whales and dolphins, seals and sea otters, we may be able to learn something about our planet, and how its changes will impact its most abundant mammal: us.

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Introduction

Dino was born during an unusually hot and sunny July, on a craggy island thrusting out of the Pacific. His world consisted entirely of black volcanic rocks and crashing blue surf and his mother's milk when she came back from fishing trips—at least for a little while. When he was four months old, just as Dino should have been weaning off of milk, his mother left again. This time she didn't come back.

Dino got hungry. His instincts told him to swim, to search for fish himself. But when he splashed out into the Pacific, there were no fish to be found.

Not long after, Dino was spotted on a beach on the California coast, the sharp angles of bones visible beneath his thick fur. He was so weak that he could no longer swim for himself. A passerby called for help, and shortly after his world changed again: it became a chain-link pen with a concrete floor and deep pool in its center, all to be shared with half a dozen other Northern fur seal pups. Some of the pups slipped into the pool to splash around when they were feeling bored. Some were too exhausted to move at all.

Like him, Dino's roommates had been forced out to sea when their mothers disappeared into the Pacific. They were tiny balls of fur and bone, like stuffed animals relieved of their stuffing. The pups had been arriving in record numbers over the past months to Sausalito's Marine Mammal Center, a rehabilitation center located just outside of San Francisco. Each and every one had been found stranded on a beach somewhere in the area, hungry and unable to swim, and brought in after being spotted by a human who happened to be nearby.

By the end of 2015, the Marine Mammal Center had taken in over 100 Northern fur seal pups. This was more than triple their former rescue record from 2006, and more were arriving every day.

Dino and his fellow northern fur seals are just the latest species of pinniped (the suborder that includes seals, sea lions and walruses) to strand on California beaches over the past three years. First came one of the state's most iconic species, the California sea lion, which began arriving into the center—all skinny and underfed pups, like Dino—in August 2013. Their influx has continued unabated for over two years. August 2015 saw the start of a spate of strandings by Guadalupe fur seals, a threatened species. The following November, the Northern fur seal strandings began in a flood.

The Marine Mammal Center had expected a busy season in the build up to the new year; 2016 was forecast to be an El Niño year, and the warm water that builds up off of California during this phenomenon has historically been associated with an increased stranding rate. But what happened broke nearly every record in their forty-year history, bringing in a total of 1,747 animals in one year. In addition to the effects of El Niño, in 2015 west coast seals and sea lions faced the largest and longest bloom of toxin-producing algae ever seen in the region, an event that left hundreds of them poisoned and with severe neurological effects.

Still, according to scientists, neither of these occurrences are solely responsible for putting Dino and thousands of other seals and sea lions on California beaches. The reason for their arrival comes from a much larger mystery, one that scientists are still trying to solve.

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Dino is unquestionably cute. Even if he had been eating normally, he would be tiny, no larger than a beagle. There is something about his giant, dark wet eyes and pointed snout that indeed evokes a dog, albeit one with tiny ears, long whiskers, and flippers that give him an adorably awkward, rolling gait on land. Perhaps because of this resemblance to one of our favorite companions, seeing Dino in distress—starving, skinny, unable to swim—elicits a visceral response. Humans respond to marine mammals strandings like no other, laboring to keep animals alive or push them back into the water.

Some of this has to do with big dark eyes and floppy flippers and seemingly unimpeded energy, the very things that draw volunteers to linger by Dino's pen and emit an "aww" as he slips in and out of the pool, chasing tossed frozen fish. Yet there's a depth to our relationships with marine mammals that goes beyond seeing them as sweet or cuddly. Massive sperm whales that wash up on beaches receive the same compassion for their suffering, despite bulky, square heads, sharp teeth and unnervingly black eyes. We now know that many of these species have self-awareness, language, names, and familial bonds; that they teach one another, sympathize with pain and suffering, and carry complex cultures through generations. We have begun to realize that they are a lot like us.

Like humans, marine mammals confront a planet that is changing around them every day. We call it climate change, a global shift driving by our success as a species. In some places, it's a visible phenomenon: we see it in droughts, extreme storms, seawater pushing up through sewers and crashing over jetties. But how these changes percolate through the complex webs of ocean ecosystems is not so obvious. Our understanding of how the ocean is changing is clouded by its complexity; we must rely on other proxies to judge its health. As top predators, highly susceptible to even small shifts in their environment, marine mammals make good stand-ins. And to many, he increasing incidence of marine mammal strandings is a sign that our ocean's vital ecosystems have already begun a wild teeter out of stability.

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"Right now is just not a good time to be a marine mammal," said University of Indiana veterinary pathologist Kathleen Colegrove. "There have just been strandings back to back."

Colegrove has seen this reality firsthand. In 2010, she led the pathology response when whales and dolphins started stranding in the northern Gulf of Mexico following the *Deepwater Horizon* oil spill. She had barely finished studying that event when she was called on in 2013 to help examine a mortality event in the eastern US that left hundreds of bottlenose dolphins dead—and, almost simultaneously, asked to look into why California sea lions were stranding on the opposite side of the country, an event she's still looking into today.

Colegrove was brought into each of these investigations by the National Oceanic and Atmospheric Administration, which, among many things, is in charge of investigating marine mammal strandings. With our sympathy for marine mammals comes a feeling of responsibility; we want to help these animals when they're sick and dying, and if we can't, we demand that someone figure out what's gone wrong.

Though humans have recorded marine mammal strandings since the age of Aristotle, the modern era of stranding research truly began in 1992. After several high-profile stranding events, in '92 the National Oceanic and Atmospheric Administration formally initiated the Marine Mammal Health and Stranding

Response Program, created to track large-scale marine mammal mortality events and investigate their causes. Part of this program's responsibility is deciding which stranding events warrant federal investigation. If the stranding fits three qualifications—"is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response"—NOAA calls the stranding an "Unusual Mortality Event," or UME.

The UME classification brings helpful research funding to the stranding event, but that doesn't mean that they become any easier to solve. Take, for example, Colegrove's investigation in the Gulf of Mexico into the cetaceans found dead in the smear of oil *Deepwater Horizon* left behind. Colegrove suspected from the start that the oil had something to do with so many dead mammals. She was able to link the lesions in the animals' lungs and adrenal glands to exposure to hydrocarbons in oil, and proved that the most mortalities and the most severe cases occurred in the footprint of the oil spill. These results were published in two separate PLOS One papers.

And yet, despite all of this evidence, NOAA still classifies the 2010 Gulf of Mexico UME as "undetermined."

This is, perhaps, the most unusual thing about unusual mortality events; many of them will never be definitively solved. Of the 62 events that NOAA has declared in the US since 1991, exactly half have been attributed to one of four causes: infectious disease, biotoxins, ecological factors, or human interaction. The other 31 events remain undetermined.

Over five years after the oil spill, cetaceans in the northern Gulf of Mexico are still stranding at an above-average rate; 46 washed ashore in April 2016. Until these numbers drop back towards what is considered normal, this investigation will stay open.

If things do return to normal in the Gulf, the marine mammal working group that makes these calls may decide that the evidence Colegrove has found is not, in fact, enough to call this marine mammal stranding event human-caused. Unusually cold weather and a bacterium called *Brucella* are also being investigated as potential sources of the lesions. If the evidence at hand is not able to prove one cause over the other, this UME may remain in the ranks of the undetermined.

"It's been exhausting the past five, six years to be involved in [UME investigations]," Colegrove said. The complexity that she faced in the Gulf of Mexico case is not unusual. In fact, it's the normal. Ocean systems link so many different and varied factors, all mingling invisibly beneath the waves, that identifying a single thread to pull is most of the battle.

I: Disease

It was the start of summer 2013, a humid and hazy July, and just as a heat wave began to wash over the east coast, it happened like someone had flicked a switch. One day, the beaches were clear; the next, they were scattered with dead and dying bottlenose dolphins.

They appeared in New York first, in startling numbers—five, ten, a dozen per day. Most of the animals were already dead and in various states of decomposition. Any still alive when they reached the beach did not survive for long. As the summer progressed, the dolphins turned up further and further south, in

New Jersey, Virginia, Georgia. By December, the mortality event had reached central Florida, stretching down most of the east coast, and the number of dead was in the hundreds.

For beachgoers, it was a horrifying interruption of summer activities. For marine scientists, it déjà vu. They had been waiting for this for 25 years.

In the summer of 1987, the east coast had witnessed an almost identical event: bottlenose dolphins started to strand themselves, first in New York before progressing south over the course of months. Most of the dolphins were dead or close to death. The event was so dramatic it prompted the National Marie Fisheries Service to create a working group on marine mammal strandings—and sparked the discussions that would create the US Marine Mammal Health and Stranding Response Program five years later.

The dolphins that showed up dead in 1987 had lesions in their cardiac and pulmonary systems, ulcerations, and damage to the respiratory tract, trachea and esophagus. These telltale lesions were exactly what scientists saw when they faced the eerily familiar scene over two decades later.

On August 8, 2013, NOAA declared the strandings an Unusual Mortality Event. It more than fit their qualifications. The average stranding rate for bottlenose dolphins in New York in July from 2007 to 2012 was six animals. Between 2013 and 2015, that average jumped to 47.

As the strandings moved down the east coast, the hardest-hit states sometimes found themselves confronting up to 30 animals per day, more than any facility was equipped to handle. Volunteers were called in from all over the country to help.

"People were reaching a pure exhaustion standpoint," said Deborah Fauquier, a NOAA veterinary medical officer. "This event, we really tried to concentrate on fresh animals, which give the best samples, to decrease the burden. [Volunteers] try to do everything, but they are limited, you have to sleep, you have to eat."

The entire operation was soon placed under the Incident Command System, or ICS, the emergency response system used for national disasters like Hurricane Katrina. The system offered organization and consistency that proved vital in sorting out what had caused the massive spate of deaths.

"We really wanted to do a good job to determine the cause of death," said Blair Mase-Guthrie, NOAA's regional stranding coordinator for the Southeast US. "That was the problem in 1987-88, there wasn't a consistent way in collecting data. Here was our chance."

By late July 2013, tests confirmed what scientists had suspected. Just like in 1987, the Atlantic bottlenose dolphins were dying of a disease called cetacean morbillivirus.

Cetacean morbillivirus is a relative of the virus that causes measles in humans. And like humans, dolphins can develop antibodies to protect themselves against this virus. Yet they can only do this if they're exposed to the disease regularly. For some reason, these dolphins hadn't been. Morbillivirus had vanished from the bottlenose population since the end of the 1988 epidemic.

"In the 1987-88 event, half of the animals [in the Atlantic population] died, and everyone else that survived was immune," explained Fauquier. "But over the next 25 years, there was no new influx of virus into the population—it didn't look like the coastal stock was being exposed again. Everyone was naïve when the virus came back."

Morbillivirus can only be passed between animals through close contact: either by physically touching each other or sharing body fluids, such as exhaled breath at the ocean surface. This means that the strain of morbillivirus that caused the 2013 outbreak did not come from within the species, or the disease would have appeared cyclically over the years, in a few naïve – or unexposed -- animals at a time.

So where did the 2013 outbreak come from? Investigators believe that an outside carrier species must have passed morbillivirus back to the bottlenose dolphins, suddenly, after years of waning immunity. Both pilot whales and seals are known to be carriers. But what caused the two species to interact after twenty-five years of separation?

"It could have been an environmental factor that makes these species mix, something that could bring species closer together than they would have been," says Fauquier. "Perhaps resources were congregated so they all decided to eat the same thing." Shifting currents or changing temperatures may have pushed fish all into the same place, or made them extremely limited. All of a sudden, two species that normally do not mix found themselves sharing the same waters and hunting the same prey, to disastrous results.

In tracing the source of this virus, we see how our warming planet muddies the waters. Even when scientists can trace a mortality event to its cause, the events that led to that cause may be hidden by the systems through which they run. And with marine mammals, that root may hide within the bodies of the animals themselves.

II: Biotoxins

"You can't get tissues back from an exploded whale back to the lab in time for them to mean anything." says Kathleen Colegrove.

There are many incident-specific reasons why a stranding event may remain unsolved. As Colegrove saw in the Gulf of Mexico in 2010, and Farquier and her peers did in the Atlantic in 2013, scientists find themselves with a mountain of variables to consider—including the fact that, because whales decompose and build up gas so quickly, some of the scientists' samples become explosive before they can be studied.

"This is wildlife we're looking at, so they're not coming in with just one disease," Colegrove said. For example, she said, while a stranded animal might have traces of a biotoxin in its system, it could also have a viral infection and signs of cancer at the same time. "As a pathologist, more than finding one cause, I have to say, which can I rule out?"

Marine scientists have learned this the hard way. Ask one of them about a mortality event that sticks in their memory, and they will likely tell you about the year that California sea lions started having seizures.

It was 1988– the International Year of the Ocean– and the headlines screamed bad news: GORE AND CLINTON IN MONTEREY; BUT OCEAN NOT SO BLUE. While then-president Bill Clinton and his vice president Al Gore were attending a conference in Monterey, a CNN camera crew filmed and broadcast footage of something strange and terrible: a pregnant female sea lion that had a seizure and died on live TV.

Sometime in mid-May, California sea lions began washing up on shore, unable to swim or hunt for themselves. The sea lions were mostly females, young and fat and well-fed. None of them had any major diseases or infections. It was approaching pupping season, and a number of the animals were pregnant. Yet these seemingly healthy young animals were lethargic and disoriented; their muscles trembled, and their heads lurched from side to side when they lifted them; and in many cases, they suffered from seizures, which grew more frequent as the animals grew sicker and sicker.

The veterinarians at the Marine Mammal Center had treated a smattering of seizing sea lions before, and had assumed that those isolated cases were caused by poisoning from heavy metals, or petroleum, or a chemical spill. They had never seen an outbreak like this. Between mid-May and mid-June that year, 70 California sea lions and one northern fur seal showed up on the beach with severe neurological symptoms, many of them in bursts of dozens of animals at a time. Before the end of 1998, the center would care for 245 sea lions with these symptoms.

"We had to rent a U-Haul and pack all these animals in," said Francis Gulland, the head of veterinary science at the Marine Mammal Center, who has assisted with nearly every major marine mammal stranding in the western US over the past three decades. "We had no idea if this was a new viral epidemic, if it was contagious, so should we keep the animals separate? Or if it was because of some chemical spill? We just had no idea."

Faced by these many unknowns, the Marine Mammal Center started their investigation by keeping their seizing patients in quarantine, concerned that their condition could spread to others. That didn't last long as the sick sea lions continued to flood in; after a few days, they switched instead to isolating any animals that had come in before the latest victims, keeping the new arrivals together. Meanwhile, the sea lions were treated with fluids and antibiotics, medicine to reduce brain swelling, and diazepam, lorazepam, and phenobarbitone—the same medicines used to treat human epileptics—to control the animals' worsening seizures. At the same time, MMC team tested the animals' blood for lead poisoning, their spinal fluid for inflammatory cells, and their brain fluid for depleted levels of cholinesterase, which would indicate chemical pollutant poisoning. All of their tests came back negative.

Yet, even as newspaper articles highlighted the mysterious nature of the sea lion disease, two researchers began to follow a hunch that the animals' condition might actually be something that had been seen before.

Chris Scholin, a researcher investigating toxic algae species at the Monterey Bay Research Institute (and today the institute's president and CFO), had spent a frustrating set of days in late May placing unanswered calls. The U.S. Fish and Wildlife service and the California Department of Fish and Game were closed for Memorial Day Weekend, so Scholin left his fears on their answering machines: he had noticed, through a set of RNA-detecting probes he was developing, a spike in the numbers of a particular species of algae in the unusually warm waters of Monterey Bay.

Scholin managed to get through to Francis Gulland on Monday morning, just before she received a second call—this one from a first-year graduate student at UC-Santa Cruz named Kathi Lefebvre, who was studying how biotoxins moved up the food chain through fish. Both Scholin and Lefebvre shared with Gulland the same theory: her sea lions didn't have a disease—they had been poisoned by an algal toxin, called domoic acid.

Domoic acid comes from the bottom of the food chain, produced naturally by marine algae belonging to the genus *Pseudo-nitzschia.* Though this acid was first discovered in Japan in 1959 (and took its name for the Japanese word for seaweed, *domoi),* both Scholin and Lefebvre had learned about it from more recent—and more frightening—events.

In November and December 1987, 107 people in places throughout Eastern Canada showed up in emergency rooms with a similar set of symptoms: initially, "incapacitating" headaches, nausea, vomiting, diarrhea and stomach cramps—and soon afterwards, disorientation, confusion, memory loss, and even seizures. Within three weeks, three elderly victims died, either from septic shock or pneumonia. Another died three months after leaving the hospital. Examinations of brain tissue from three of these victims revealed necrosis—cell death—in many of the patients' neurons. Many of those who recovered from the 1987 event experienced short-term memory loss, sometimes severe, for years after the incident.

The patients from the Canadian outbreak varied widely in age, health levels, and demographics, but they shared one thing in common: they had all eaten blue mussels cultivated from Prince Edward Island shortly before falling ill. On December 17, 1987, chemists identified domoic acid, produced by a *Pseudo-nitzschia* species that the mussels had filtered out of the water, as the guilty neurotoxin.

Still, Scholin and Lefebvre's suspicions weren't proof.

"There had never been reports of domoic acid effecting marine mammals, so at that point we thought, okay, maybe," Gulland said. She began to call up marine researchers all over the country—chemists, algal researchers, marine ecologists, veterinarians—to ask if they would analyze sea lion blood and tissue samples for a range of potential diseases and toxins, including domoic acid. According to Mark Busman, a chemist who was working at the NOAA Ocean Service Laboratory (since renamed to the Hollins Marine Lab) in Charleston, South Carolina, Gulland's requests were more like calls to action: anyone on the other end would "drop everything they were doing to contribute."

Before long, they started seeing domoic acid everywhere. In Santa Cruz, Lefebvre's biological tests found domoic acid in the animals' feces, and beneath a microscope, she could see in the feces what looked like thousands of tiny needles—green-and-transparent striped strings of diatoms, called frustules, created by chains of *Pseudo-nitzschia.* Lefebvre called them the "smoking gun."

In Charleston, mass spectrometry tests on sea lion tissue and excrement also confirmed the presence of domoic acid. The same tests on their stomach contents—filled with small filter feeders like anchovies and sardines—found the acid there, too. In Monterey Bay, Scholin's RNA probes tracked *Pseudo-nitzschia australis* as it bloomed in a thick band that clung to the shore in and around Monterey Bay. At the bloom's peak, samples from Monterey Bay contained 130,000 *P. nitzschia australis* cells per liter of seawater.

"The person that was really at center of putting the narrative to the whole story was Francis," Busman said of Gulland's tireless efforts. "I don't think anybody would have made sense out of the deal without her. I never saw a sick sea lion, I was never on the west coast, all I saw was boxes of samples. We contributed our own part to the story, but the real synthesis of the story was totally Francis Gulland."

As the summer of 1998 waned, the number of afflicted animals slowly dwindled as the *Pseudo-nitzschia* bloom died off. At the Marine Mammal Center, the overtaxed team was able to nurse some of their patients into a healthy enough state to be returned to the wild. But not all. Many of the sea lions that survived the UME were left permanently disoriented, unable to forage or navigate, and prone to seizures for the rest of their lives.

But even after the outbreak was solved, one mystery remained. *Pseudo-nitzschia* species were previously a fairly common, but mostly harmless, presence off the California coast. With hindsight, scientists now know that the rare cases of seizing marine mammals before 1998 had likely been feeding on fish that were caught in isolated blooms of *Pseudo-nitzschia*. There's even evidence to connect domoic acid to an incident of bizarre avian behavior in Monterey in 1961, which inspired a visitor named Alfred Hitchcock to produce a movie called *The Birds*. Yet this is nothing compared to what domoic acid has become: one of the most common causes of marine mammal strandings, and particularly pinniped strandings, on the west coast.

But why, precisely, did *Pseudo-nitzschia*'s grasp on the west coast become a stranglehold? Why did everything change in 1998?

III: Ecological Factors

Though he'll never know it, Dino the northern fur seal shares something in common with the domoic acid-poisoned sea lions that beached in the International Year of the Ocean.

In normal years, pinnipeds in California are the top of a food chain that starts with something very, very tiny: water-borne nutrients, dissolved in seawater carried from the seafloor to the surface in cold, turbulent currents. This process is called upwelling, and normally it happens all along the California coast. The nutrients brought to the surface by upwelling feed phytoplankton, microscopic photosynthesizing organisms that bloom on the ocean's surface. They, in turn, feed animal plankton called zooplankton, which then feed the fish that seals and sea lions love.

"All environmental conditions, especially around here, are being influenced by upwelling," explained climate researcher Isaac Schroeder. "So you get good upwelling conditions, you get good productivity, and good pup weight—it's kind of like a chain. The phytoplankton's happy, the zooplankton's happy, everybody's happy."

Schroeder works at NOAA's Environmental Research Division in Monterey, where he investigates the role of climate in events like the 2015 pinniped strandings. He and his coworkers spend much more time examining data sets than dying seals, but they're at the forefront of figuring out exactly what might have led Dino, and hundreds of other seals and sea lions, to end up skinny and hungry on the California coast.

By tracing this event backwards, the first, immediate cause seemed apparent in the animals' condition: for some reason, the pups hadn't been eating. But why?

In early 2014, environmental signs began to indicate that something unusual might be something brewing out in the Pacific. Two patches of anomalously warm water began growing off the west coast—one along Baja California, and another clinging to the Pacific Northwest, soon to be dubbed the "Blob." Both signaled the first phase of the atmospheric phenomena dubbed El Niño. El Niño years are never good for marine mammals. With the approach of an El Niño comes a weakening of the Pacific trade winds, which normally blow from east to west. Normally, these winds push warm water away from the western U.S. and summon cold, nutrient-rich water to the surface. Without them, warm, nutrient-depleted water was beginning to slosh back towards the west coast.

On the surface, the growing El Niño seemed an obvious culprit for the pinniped strandings from 2013 onward. As it happens, 1998 was an El Niño year. Like Dino, the seizing sea lions of that year spent many months living in abnormally warm waters before they ended up on the coast.

In the 1998 case, the El Niño created the exact conditions—high temperatures and limited nutrients—in which *Pseudo-nitzschia* thrive. These algae can tolerate such conditions much more comfortably than other species, allowing them to out-compete other algae and dominate the ecosystem. This environment may have allowed the algae's populations to grow to unprecedented levels. Even after the 1998 bloom died, it left behind a large enough base of survivors that each warm season since has only strengthened *Pseudo-nitzschia*'s hold.

Despite the ongoing presence of this algae, the connection between El Niño and Dino is not quite as clear.

In 2012, a team from NOAA's National Marine Mammal Laboratory conducted their annual visit to San Miguel Island, a sea lion rookery off the California coast that the laboratory has used to monitor California sea lions for over 40 years. When the team weighed the year's newborn pups, they were surprised to find they were underweight, despite the fact that upwelling—and, in theory, the ecosystem that should be feeding plankton, fish, sea lion mothers and their pups—was normal. In fact, in 2013, the year that these same pups started stranding on California beaches, upwelling off California was the highest recorded in decades.

NOAA's Environmental Research Division was left to try and unwind this paradox. By January 2016, the team had narrowed down to what they called three options.

The first possibility is a purely Malthusian one: the sea lion population has grown too large, causing too much internal competition for fish. Indeed, sheltered by the Marine Mammal Protection Act, the population of California sea lions has skyrocketed from 10,000 animals in the 1950s to approximately 300,000 animals today. Some wildlife biologists believe that the sea lions' decline, and the fact that it began well before El Niño conditions caused the stranding of other pinnipeds, indicates that they've reached the carrying capacity of their ecosystem.

Option two flips the beneficial effects of upwelling on its head. Bograd has theorized that the high levels of upwelling that were seen over the past few years have actually been *too* strong—that the strength of these currents from the seafloor could have transported nutrients far offshore, out of the reach of sea lions' limited foraging range.

The final option suggests that something has happened to the sea lions' usual food, fatty fish like sardines and anchovies. Curiously, research has found that even in years where there was good upwelling off California, the populations of these fish—once overwhelmingly abundant—stayed low.

"That's a big issue—even if you have really good upwelling, really good productivity, you just simply don't have enough fish because they've been fished out or they've declined for other reasons," said Elliot Hazen, a NOAA research ecologist. In other words, if the number of fish being born is not greater than the number of fish dying, being eaten, and being removed by the fishing industry, really great nutrient availability doesn't help very much.

This option carries different weight depending on who you talk to. Geoff Shester, the Program Director of Oceana's Pacific Team, believes that declining fish populations are the reason that seals and sea lions started stranding in 2013—but he places blame for UMEs primarily in human hands. He believes if chronic overfishing created an ecosystem that can't support both humans and pinnipeds at the current level of exploitation.

"I just think, from a sea lion's perspective, would there be so many deaths and starvations if there were four times more fish out there when there are now?" Shester said. "There probably would have been a stranding due to lower fish, but we made it so much worse. The stranding we're seeing is way worse than it would have been."

The story of California's missing fish is the one that NOAA is currently sticking to. The current explanation for the past three years of strandings is that the sardines and anchovies are still out there, but that they have moved further north or offshore than usual. NOAA hasn't yet decided on a mechanism by which this apparent movement has happened, and the investigation remains ongoing.

However, NOAA has acknowledged that the Pacific sardine population is in danger. For the 2015-2016 fishing season, and for the first time in the fishery's history, the harvest limit for Pacific sardine will be zero. For the next year, commercial fisherman will not be legally allowed to catch a single sardine.

In truth, what NOAA has developed are three accounts that are all potentially viable, and all equally inadequate. Each is thick with the complexity that we've come to expect from marine mammal events, layered with the if-then statements that makes tracing a starving sea lion back to its source so close to impossible.

"They kind of blur together," said Steven Bograd, a NOAA climate and ecosystems scientist, said of the scenarios his team had developed. He acknowledged that it was possible that all three scenarios could also be occurring, in some form, at the same time. "The last three years, it's never really gone back to normal."

Taken together, each attempt to explain the predicament of Dino and his fellow stranded mammals confronts two simple truths about the ocean: it is an extremely complicated system, and lately, it is one that is not behaving as we expect. In such a system, a particular marine mammal mortality event may be a red herring. One stranded seal – even a spate of them -- is a tempting puzzle, a sad mystery we can't help but try and solve. But such inquiries should not obscure the larger question we really should be investigating. Instead of focusing solely on what has caused these events, we need to examine what they portend—what marine mammal strandings can tell scientists about the fate of our rapidly warming planet.

The El Niño event currently sweeping across the ocean has been a boon to some and a bane for most. Yet for scientists, El Niño could turn the Pacific into a laboratory. Its warm waters and unpredictable weather work something like a global warming simulator—painting an image of what a future with a constantly warmed ocean might look like.

"Basically, these El Niños kind of serve as a test bed for what we're likely to see more of in the future," said NOAA's Hazen. "Because if you think of it, El Niños are kind of like a blip in the record. But if you have this low scale warming... those blips will be more extreme. You'll be passing the threshold for what many of these species can do."

Seen that way, the 1998 El Niño - domoic acid outbreak serves as a kind of demonstration of what climate change can set off in an ecosystem. The large blooms seen during that years served as stepping stones for *Pseudo-nitzschia* in the region, creating enough algal mass that large numbers of cells could hitch a ride on local currents and settle down in strange new lands.

"What I find profound now, is ever since [1998], I have continued seeing domoic acid and how this toxin moves through the food web," said Kathi Lefebvre. She is now a supervisory research biologist for NOAA's Northwest Fisheries Science Center, and the PI on a joint NIH-NSF project developing a biomarker to indicate chronic exposure to domoic acid. As Lefebvre sees it, what happened with *Pseudo-nitzschia* locally is a revealing episode for how the effects of climate change can propagate through an ecosystem.

"The initial story from 1998 was a big deal, but it has just in some ways it's a bigger deal now than it was back then," said Mark Busman, the NOAA chemist who helped trace down domoic acid's root in the strandings. "It's just not news anymore."

Over time, the 1998 El Niño has produced changes on a grand scale, blurring the geographic boundaries that scientists once knew. In May, a new bloom of *Pseudo-nitzschia* began off the shores of California. Though it started like any other, this bloom would eventually stretch from Santa Barbara Channel in the south all the way to Alaska. It became the largest and most severe blooms to occur in the region, and in Monterey Bay and off the coast of Oregon, produced some of the highest concentrations of domoic acid ever seen.

Chris Scholin was once again among the scientists that investigated the 2015 bloom. He found himself unnerved by how similar the bloom was to what he saw in 1998—and yet how much worse the event was in its scale.

"We had an underwater vehicle running transects along the bay, and you could see this thick layer of these cells—imagine a sub-surface blanket," Scholin described. "And yet it's kind of this insidious threat. You can't really see it or smell it or anything, but these animals crawl up out of the water and are clearly poisoned."

As a result, 220 California sea lions and 4 Guadalupe fur seals came into the Marine Mammal Center with domoic acid toxicity, arriving from locations all over the state of California. Up the coast, in Washington State, a sea lion was filmed having a seizure, the furthest north that neurological symptoms of domoic acid toxicity have yet been found. Domoic acid has also been suggested as a possible culprit for the deaths of 45 large whales that washed up on the shores of Alaska between May and December 2015.

The effects of this bloom didn't stop at the shoreline. In early June, NOAA closed the multi-million dollar Dungeness crab fishery in California, Oregon and Washington, due to high levels of domoic acid. The closure, which lasted until April of the following year, had a disastrous impact on local economies.

And in Alaska, in waters previously thought to be too chilly and too ice-covered for most of the year for toxic algae to really thrive, Lefebvre recently found detectable levels of domoic acid in every one of 13 species she sampled from 2004-2012. Ten of the 13 species also had detectable levels of saxitoxin, another toxic algal byproduct. Algal bloom had been seen in these northern waters before, yet they were rare, short-lived; Lefebvre's study was the first to confirm that the algae have become established enough to concentrate in top-of-the-food-chain predators.

"From my perspective, it's a scary and concerning situation," Lefebvre said. "Because I was there in 1998, and it had never been observed in marine mammals before. The question now is, are these toxins moving further north, and having impacts on the food web? And the answer is most likely yes."

The last way climate change operates through domoic acid is on the subtlest, most insidious scale: working domoic acid slowly into the bodies and brains of all who ingest it. Francis Gulland has observed an increasing incidence, over the past seventeen years, of animals with *chronic* exposure to domoic acid: small amounts of the substance consumed year after year, as small blooms have regularly occurred off the coast. These animals often have much more subtle neurological symptoms, such as normal health sporadically punctuated by seizures, or general memory loss, which sets in over the years as domoic acid binds to a few neurons at a time, particularly in the hippocampus—a vital, seahorse-shaped section of the brain that contributes to memory formation, spatial navigation and information processing.

This degradation was documented in a 2008 study by the Marine Mammal Center, which examined the hospital's records for sea lions hospitalized for domoic acid toxicity between 1998 and 2006. The research found that while the number of acute cases did not show an increasing trend, the number of chronic cases increased significantly each year. Unlike animals with acute toxicity, which tend to strand on shore at the same time, chronic cases show up throughout the year following a bloom. Even after a bloom is over, the toxins from these algae linger in the ecosystem. Gradually, such exposure can cause the hippocampus to shrink as these neurons die.

Sea lion brains react to domoic acid toxin in some subtly different ways from human brains. Yet the slow disintegration of memory and the partial seizures we see in sea lions are similar to how the human brain reacts when exposed to this toxin.

"I think that's much more of a concern to human health," Gulland says. "If [domoic acid] levels are over 200 parts per million, then that seafood is unavailable for humans. Here in California there was no crab this winter because of this, it was closed. But now it's open again, because the levels are down to about 50 parts per million. Well, that's still domoic acid."

The rise of domoic acid since 1998 is just one example of how climate change plays out. It doesn't work in simple, cause-and effect sequences, but in complex, layered ways that transform the ecology of a system. Harmful algal blooms have become a part of the California ecosystem, and one that is not going away anytime soon.

"It's a little bit like bad weather, or like tornadoes," says Scholin. "You might not be able to predict if next year will be a good or bad year, but the threat is there. I would say it's not a question of if it's going to happen again, it's a question of when and where and how bad."

In the same fashion, a warmer ocean will allow the spread of bacterial species to higher latitudes. Just as the Atlantic bottlenose dolphins experienced in 2013, viruses and parasites will spread to species that have never encountered them before. The categories that NOAA has laid out for a UME will likely become harder and harder to fit, the "undetermined" cases more and more common. *The question now may be whether all cases now fit under the fourth category in NOAA's list: human interaction.*

Patagonia through the window of the survey plane spread out like a watery array of arteries, a puzzle of green cliffs and still blue fjords running in channels as far as the eye could see. It was June 23, 2015, and on board the plane, a team of scientists peered at the network of channels below them. They were looking for dead whales.

Two months before, Vreni Häussermann, a German scientist working at the Huinay Scientific Field Station in northern Patagonia, had discovered what looked like thirty large whales stranded onshore. Their massive bodies were turning pale pink as they burned and decomposed in the sun. The whales were scattered through the region between the Gulf of Penas, a west-coast bay that opened its maw to the Pacific, and Puerto Natales, a small city lying at the edge of the fjords on the border between Chile and Argentina.

Häussermann thought the whales looked like sei whales, 20 meter giants considered the fastest cetacean in the ocean—and a species that is endangered throughout its range. Yet from only a few aerial glimpses, Häussermann couldn't be sure, and she couldn't say anything definitive about *why* so many dead whales had appeared out of nowhere.

Häussermann decided to pool her resources with a fellow marine scientist, Carolina Simon Gutstein of the Universidad de Chile and Consejo de Monumentos Nacionales, to conduct a more thorough investigation. The pair started scanning satellite footage, looking for some clues about the deaths of the whales that Häussermann had spotted in the spring. In June, they boarded a small plane to conduct an observation flight of the region. What they found floored them.

Dead whales began appearing beneath the survey plane's wings, and the team onboard started to count. They passed Häussermann's original discovery of thirty whales in no time. Below the plane was not just the remains of a stranding event in the spring, but fresh bodies, whales that must have stranded in the past few weeks. By the end of June 23, Häussermann and Gutstein had counted 337 dead whales.

"It was an apocalyptic image," said Häussermann. "None of us had ever seen anything like it before."

In early spring 2016, an expedition organized by Häussermann and Gutstein was sent to the Gulf of Penas to sample the carcasses. The dead animals were, indeed, sei whales. The scientists suspected that their deaths likely had something to do with large algal blooms, known as red tides, which had been seen in the area—it made sense, since the huge numbers of deaths suggested a single, toxic substance introduced into the ecosystem.

When the expedition arrived, the scientists began cataloguing the hundreds of whales that had been reported months before. They were surprised to find that alongside carcasses and skeletons there were also freshly dead whales, three of which appeared to have died within the last few weeks.

Then, while moored in a cove called Caleta Buena, the team saw something they never could have expected.

"We could look forward to a nice, succinct solution to the puzzle," one of the mission leaders, Greg Landreth, wrote on the expedition blog. "Then, Nature threw us a curve ball."

On two separate occasions, they witnessed a group of orcas—killer whales—attacking sei whales in the cove. The orcas charged the sei whales at top speed, in groups of up to six animals, biting, fin-slapping, and even breaching out of the water to land on top of the sei whales. When the encounters were over, three more dead sei whales lay on the beach. It invoked a familiar refrain: nobody onboard had ever seen anything like it.

In January 2012, a group of NOAA scientists correlated domoic acid poisoning with abnormally aggressive behavior, both in wild sea lions—which were observed attacking swimmers—and rats in a laboratory setting. Could an intense enough algal bloom in Chile's coastal fjords drive orcas to kill sei whales in never-before-seen numbers? The link is a tenuous one, a conjecture; the expedition has not published any of the results of their investigation, and there have never been studies of domoic acid's effects on orca behavior.

Yet the attacks don't seem to be isolated events. The team had previously heard stories from fishermen about the orca attacks, and brushed them off as big fish tales—far from a potential explanation for the sei whale deaths. Yet at the close of the expedition, Landreth wrote that the orcas' involvement in the mass stranding was "now not only a possibility, but also a probability."

IV: Human Interaction

While marine mammal stranding investigations may resemble forensic investigations in many respect, their conclusions usually have none of the satisfaction that comes with catching the killer in the end. This is particularly the case when trying to pin a stranding on changes that occur on a global scale. Climate change leaves no DNA on its victims and has no gunpowder residue on its fingers; when it acts, it does so through a series of accomplices, moving subtly behind the scenes.

What we do know about climate change is beginning to amount to a circumstantial case. It's a case that tells us that the consequences of human-caused warming don't stop at what we can see. And as we act in response to the changes we have set off, we must consider that these actions move through cascades that will be, by their nature, both unpredictable and startling in their scale—so much so, that they can easily be called too complicated, too layered, to attribute to climate change.

Perhaps more than any other, the sei whale deaths in Chile show us how marine mammals can serve as proxies for these cascades. The region between Gulf of Penas and Puerto Natales is so remote that changes in its waters and in the nearby Pacific would be easy to miss. This is particularly the case if they occur on an invisible scale—such as the growth of algae beneath the surface, or the accumulation of toxins in the brains of local predators. Whatever changed, scientists likely would have missed it had Vreni Häussermann not spotted those first thirty whales.

Of course, seeing these animals suffer and die scares us. There is something particularly unsettling about the sight of hundreds of dead whales on a beach. Beneath their rubbery skin and strangely shaped bodies, it's easy to imagine that whales are not so different from humans; that their intelligence and sociality belies an inner life just like our own. It makes it hard to view their deaths in a clinical way, as a tool that we could use to monitor the health of our planet.

Yet taking on some responsibility for marine mammal strandings is a way of countering that fear. It means finding a level of control over changes that can impact every level of the ecosystem, visible and invisible, from tiny water-borne plankton all the way up to ourselves.

"It's a cautionary tale," Kathi Lefebvre says of marine mammal strandings. "We are also top predators, humans. And I can say this without a doubt— this warming planet is going to throw ecosystems out of balance. There's going to be big changes, and that's absolutely true; we can't predict exactly what these changes will be, but they will happen."

On the bright morning of January 7, 2016, Dino and sixteen other Northern fur seals were herded, blinking and confused, out of their pens at the Marine Mammal Center, into a set of waiting dog crates, and on to the back of a pickup truck headed north. Through the grates they watched the coast transform as it passed: rolling green hills and houses into the dappled shadows of towering forests, tiny roadside towns into still marshlands, all of which gave way to a single road winding up a set of breathtakingly high green cliffs. Below, the Pacific roared into the distance, deep blue. Their destination: a spit of land on Point Reyes National Seashore, lapped by the Pacific to the west and hugging a sheltered bay to the east. It was time for the pups to return to the ocean.

The trucks wound their way down through green fields until they reached what had once been a lifesaving station overlooking the bay and a sloping, pebbly beach. Several massive elephant seals were lounging in the sun, baying reproachfully, often sloughing their massive bodies into the water as the trucks backed down the beach and the crates were unloaded. The air was rich with salt and excitement, the pups' eyes wide as they stared out of the doors at the blue horizon.

After some shuffling of the human volunteers in charge, the doors were opened. Though it had been weeks since any of them had seen the ocean, the seal pups barely hesitated. Weeks of twice-daily feeding had made the pups back into tiny balls of fat, jiggling happily as they galloped down the sand and splashed into the ocean. They splashed and cavorted, rolling in the salt water with apparent glee as volunteers laughed and grinned and snapped photos.

For many of the humans watching, it was a day of accomplishment—nothing less than a happy ending. The truth is a little less cheery. As El Niño continues to steamroll the west coast, it's possible that some of these pups will end up right back in the Marine Mammal Center in the weeks and years to come.

Like a hospital seeing more patients, if Dino and his fellows are brought back into their care—regardless of the reason why—the Marine Mammal Center will once again treat them. When they deem these animals healthy, they'll bring them right back here and smile as they run back into the ocean. They will have accomplished a goal in doing so.

But in the end, what sort of ocean are we sending these pups back into?

Until very recently, marine mammal stranding events were seen as solitary incidents, disconnected from the fate of human beings and of the planet as a whole. A deeper look shows this is not the case. We share surprisingly similar brains and bodies, similar reactions to toxins in the ecosystem. We all find ourselves impoverished when fish vanish from our coasts or become permeated with toxins, when shifting weather patterns leave seals stranded just as they leave farmers without water.

If marine mammals are the canaries in the coal mine that is our warming planet, they've stopped singing.