"Marvelous. . . . Egan's book is an ecological page-turner."
—John Hildebrand, *Milwaukee Journal-Sentinel*

"This is a rollicking, eye-popping, scary, sad tour of one of the world's watery wonders, the Great Lakes."
—Stephanie Hemphill, *Agate* magazine

"With narrative flair, Dan Egan tells the story of how it is that we can be so shortsighted and negligent when it comes to something as wondrous and essential as our Great Lakes and yet so industrious and inventive in trying to undo our mistakes. This is essential reading for anyone concerned about the future of our natural world."
—Alex Kotlowitz

"In this beautifully vivid portrait of the Great Lakes, Dan Egan explores one of America's most essential ecosystems, reminding us that its story—one of both harm and hope—is ultimately our own."
—Deborah Blum

"A masterpiece. Dan Egan's epic story is one of those rare books that can change the world. Rachel Carson's *Silent Spring* sparked a national revolt against toxic pesticides. Egan's work could help save the world's biggest body of fresh water. Read it if you care about this country—and our planet."
—Tim Weiner

THE DEATH AND LIFE OF THE GREAT LAKES

Dan Egan

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Chapter 2

THREE FISH

THE STORY OF LAKE TROUT, SEA LAMPREYS AND ALEWIVES

If the basins that cradle today's Great Lakes were carved by glaciers, and if those massive depressions in the landscape only became lakes after the mountains of ice melted, and if those lakes then evolved isolated from the rest of the aquatic world, then here is an obvious question: Where did all the fish come from?

The answer is that the Great Lakes were not always disconnected from surrounding rivers and lakes. The glaciers that periodically smothered so much of North America during the last ice age waxed and waned over periods that stretched tens of thousands of years. Perhaps it is easiest to think of these pulsing ice sheets as a massive set of frozen waves crashing almost rhythmically, but at geologically slow speeds. Each wave started as the earth cooled to the point that a true summer never arrived in what is today central Canada and the northern United States. Piles of ice would grow snowflake by snowflake, millennia after millennia until they were ocean-sized expanses of ice, the largest of which stretched nearly two miles into the sky and spanned some five million square miles.

Each time one of these frozen waves came creeping down from the

north there were freshwater rivers dribbling off its "snout"—the transition zone where the glacier bumped into too much sunlight and too-warm breezes to stay solid year-round. The rivers flowing from these mountains of ice—and the lakes they fed and the grasslands and forests through which they flowed—gave refuge to the plants, animals and fish whose native ranges had been smothered under ice.

Then the climate would turn warmer and the ice sheet would pull back north, drop by drop, mile by mile, and the surviving plants, animals and fish that had been biding their time beyond the frozen zone followed the retreating ice northward to colonize the freshly exposed landscapes and lakes. And then the globe would grow cold again, a new ice sheet would press down into the middle of North America, and the fish and animals in its path would scramble once again for refuge.

Nobody knows precisely how many of these waves of ice plunged down from the north during the last ice age, which began about 2 million years ago and ended only when the last wave retreated barely 10,000 years ago; each time one advanced it scrubbed away the lakes, rivers and altered landscapes left behind by the previous one. But when the last wave pulled north, the massive basins it left behind filled with glacial melt. And these new Great Lakes were eventually populated with the hardy fish and other aquatic species that had been dwelling in the melted waters just beyond the glacier's reach.

The lakes in their early years were constantly shifting in shape, in size and in relation to adjacent waters during the ice sheet's stuttering retreat; the ice sheet began to shrink about 20,000 years ago but would then grow a bit again, and then shrink again in a two-steps north, one-step south fashion. There was a period when the lakes—or their predecessors—were linked to a freshwater sea northwest of today's Lake Superior that was bigger than all of today's Great Lakes combined. There was a time when a river flowed out of what is today Lakes Michigan and Huron and into a massive estuary of the Atlantic Ocean. Another river flowed from the southern end of Lake Michigan into the Mississippi River basin. Eventually these and other early links to waters beyond the Great Lakes basin dried up, and beginning about 2,500 years ago the lakes' sole continuous connection to the outside aquatic world was the river system that roared over Niagara Falls, coursed through Lake Ontario and then rushed down the St. Lawrence Valley and out to the North Atlantic. Species might be able to tumble over the thundering falls and out to the ocean, but the wide-open door for fish and other water-bound aquatic organisms to migrate upstream from the ocean (as well as from other inland waters on the continent) and into the lakes had been shut.

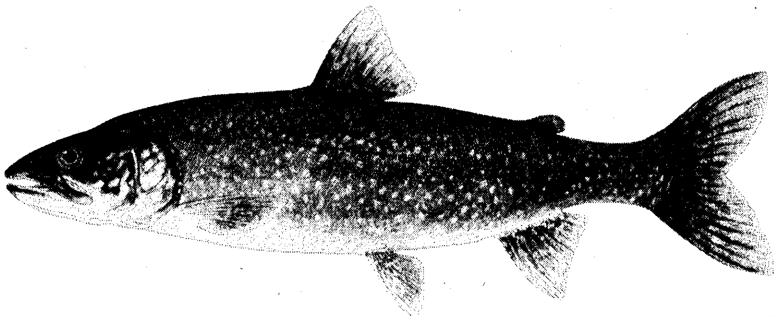
This left the four lakes above Niagara Falls largely separated from the rest of the aquatic world. The lakes might have sprawled across an area half the size of California, but in a sense they were as isolated as a one-acre pond in the middle of a forest until the early 19th century, when construction of the Welland and Erie Canal bypassed the falls and linked the lakes to the Atlantic Ocean. Pulling the Niagara plug that had protected the lakes for millennia triggered an ecological calamity best illustrated by the rise and fall of three species of fish—lake trout, sea lampreys and alewives. Their story shows how a delicate ecological tapestry that had been thousands of years in the making unraveled in just a couple of decades.

AT THE BASE OF THE FOOD WEB STITCHED TOGETHER AS THE upper lakes' river pathways to the outside world closed to migrating fish were phytoplankton. That plantlike life was gobbled up by tiny floating animals (zooplankton), which, in turn, provided meals for things like mollusks and crustaceans. Upon those larger critters feasted bait-sized fish like the ninespine stickleback, slimy and deepwater sculpins, as well as a minnow called the emerald shiner. The little fish sustained

the lakes' medium-sized fish, including perch, their larger cousin the walleye, and smallmouth bass. Also in the lakes' shallower areas lurked the giant sturgeon, which can live more than 100 years and grow to seven feet by rooting on the bottom for aquatic insects, crustaceans, mussels and the occasional small fish.

To call all this a food chain is an oversimplification. What gobbled what was not strictly linear; baby predators were often a meal for the same prey fish that those predators would have eaten had they survived to adulthood. Some fish species feasted on their own kind, and some of the big fish in this Great Lakes' web of life didn't favor little fish but instead competed with them for crustaceans and plankton. Whitefish, for example, could grow more than two feet long and swell to over 10 pounds on a diet that consisted mostly of bottom-dwelling organisms and crustaceans that migrated nightly up from the lakebed under the cover of darkness in search of plankton. In the same family as whitefish and occupying similar strands in the food web were more than a half-dozen closely related schooling species. The most well-known of these was commonly called lake herring but there were also several types of "chubs" with peculiar monikers like bloater, shortnose, blackfin, shortjaw and kiyi. Some of these foraging fish, collectively known as ciscoes, lived like mini-whitefish, schooling up to chase the crustaceans that migrated nightly off the lake bottoms. And chasing all these clusters of little fish were the yawning jaws of the lake trout—the spider in the Great Lakes' web of life.

The giant trout that can grow to a wolf-sized 70 pounds are in the same family as salmon but although the fish share the same ancestry, in many ways they could not be more different. Salmon hatch and spend their youth in freshwater rivers and streams and then descend to the ocean to feast for two or three years before returning to their native freshwaters to spawn once and die. Salmon can reach their maximum size—sometimes approaching 100 pounds—in just a few years by devouring schooling prey fish like herring. But salmon are a picky breed. If they can't find enough little schooling fish to eat during their short life, their own metabolism will burn them up; they will starve or become weakened and die of disease.



The lake trout, one of the hardiest and most recognizable native species in the Great Lakes.

Slow-growing lake trout are a beast of a different sort. They can live for decades, reproduce year after year, and are able to grow fat in the same conditions that would starve a salmon. Having evolved over millions of years to survive the frigid, relatively sterile glacier-fed rivers, lake trout eat just about anything they can find in the lakes—from plankton to insects to other fish—and are also nature-built to weather long periods of famine typical of such waters.

If their food supply hits a low cycle, lake trout simply throttle down their metabolism and stop growing as they wait out the lean years. Were a trout to let its guard down in this fashion in the ocean, a bigger fish likely would swallow it whole. But adult lake trout in the Great Lakes food web only had to worry mostly about eating, not being eaten. This ability to pace its growth with available food sources made it the perfect fish to regulate—or, more accurately, harvest—the slow flow of energy through the Great Lakes that starts 93 million miles away.

"There is nothing like them," says Mark Holey, a Great Lakes trout specialist with the U.S. Fish and Wildlife Service. "Lake trout have the characteristics to most efficiently transfer the energy in that ecosystem from, basically, sunlight into fish flesh."

And just as humans bred canines for distinct characteristics—shepherds for herding, hounds for hunting, Dobermans for protection, etc.—a similar sort of specialization happened naturally with lake trout in the Great Lakes. Because of the relatively small number of predators that made their way into the lakes before the rivers connecting them to the outside world disappeared, lake trout evolved in the Great Lakes over thousands of years to fill multiple ecological niches that otherwise might have been occupied by other species. In Lake Michigan alone some biologists believe the fish were organized into at least 100 stocks, many of which became isolated populations that bred only among themselves. Across the Great Lakes, each stock became uniquely adapted to thrive in the areas it colonized. Some populations thrived amid mudflats or boulder-strewn open waters hundreds of feet deep by accruing loads of fat in their muscles and body cavities that gave them a buoyancy so they could swim easily throughout the varying lake depths, whether near the surface or in the high-pressure zones of the deep. Their eyes were larger and positioned closer to the top of their heads than some other forms of lake trout—perfect for a fish that, shark-like, attacked schooling whitefish and ciscoes from below.

Other breeds lived in shallow waters and competed with whitefish and ciscoes for crustaceans and insects. Some were better equipped to strip plankton from the water. Some spawned in cobble, others on rocky reefs and still others in areas where the lakebed was smothered in algae. There were also some stocks that spawned, salmon-like, in rivers and streams.

Depending on where it lived, a trout's mature size varied from barely 12 inches to nearly four feet. Its skin color could be green or brown with patches of yellow or orange. Or its skin could range from white to nearly black, and span all the grays and silvers in between. Depending on the stock, its flesh ranged from white to pink to deep red. Most lake trout stocks spawned in the fall but others spawned in summer and still others in spring.

The early fishermen who chased these fish gave the stocks different names. There were red fins and yellow fins. There were buckskins, grease balls and paper bellies. There were moss trout, shoal trout and fats. There were bay trout and there were black trout. And they were legion.

The recorded natural history of all these lake trout stocks is sketchy; overfishing beginning in the mid-1800s began to take its toll before a comprehensive stock survey was conducted. But an early attempt to explain the various populations in northern Lake Michigan was made by one James J. Strang, a fiery rival of Brigham Young for leadership of the Mormon Church after the religion's founder, Joseph Smith, was assassinated by a mob in Carthage, Illinois, in 1844. Brigham Young took his faithful to a relatively verdant valley in the Utah desert, which today is known as Salt Lake City—home to a worldwide church claiming more than 15 million members.

Strang, more latter-day pirate than saint, took his own flock in the opposite direction—eastward into the middle of northern Lake Michigan. There, on the 13-mile-long, 6-mile-wide Beaver Island, the 5′4″ Strang, with a beard as orange and long as a carrot, fashioned himself a crown, stuffed some cushions with island moss and called it a throne and proclaimed himself king.

"For any little disobedience of his harsh laws, he ordered floggings," recalled Stephen Smith in a 1940 newspaper story. Smith, 91 at the time, claimed to be the last person alive to have lived under Strang's brutal rule. "He killed any number of men and women, and had others tied up and flogged 'til they bled. He sent men to loot gentile (non-Mormon) stores and even had pirates sailing around the island to rob the fishing boats."

Like his rival Brigham Young, Strang took multiple wives, including one who dressed as a man in a black coat and stovepipe hat, called herself Charles Douglas and claimed to be Strang's "personal assistant." During his six-year reign Strang survived a naval battle with mainlanders as well as a trip to U.S. District Court in Detroit, where he was accused of counterfeiting, piracy, and interfering with the mail and murder, among other charges.

"He talked to that jury and his tongue was like silver. And that jury believed him and said, 'Not Guilty' to all charges against him," Smith recalled. "King James came back to Beaver Island more full of himself than ever, even the U.S. Government couldn't beat him."

But the man Smith called a "cocky little tyrant" was not all trouble. He had so many followers in his church—up to 12,000 at its peak—that he was able to get elected to the Michigan Assembly in Lansing, where by all accounts he acquitted himself well as a lawmaker. He established a newspaper. He was an abolitionist who granted blacks full membership to his sect more than a century before mainstream Mormons did.

And he became a self-styled naturalist who was among the earliest to attempt to classify the types of lake trout swimming in the waters off his island. In an 1853 report he sketched the life history of a plump trout known as a siscowet, which, because of its white flesh, he said some fishermen (incorrectly, it turned out) speculated may be a "mule"—a cross between lake trout and whitefish. He also made note of the skinnier but larger "Mackinacs" that lived in shallower waters, swam alone except when spawning, and gobbled up everything under the surf, regularly plundering the nets fishermen had set to catch schooling whitefish.

"They are a voracious fish of prey, seizing and devouring so far as we can learn, every other kind, even their own," Strang wrote. "Herring are their constant prey. Whitefish of two pounds weight have been found within the belly of the trout. Small trout are sometimes found in them." Strang explained that catching lake trout at that time, which he noted could grow to more than 50 pounds, was a ridiculously laborious process, especially in winter. "The moment the bite is felt the fisherman throws the line over his shoulder, and runs with all his might, in a direct line, till the fish is on the ice," he reported.

The trout weren't much easier to catch from a boat. Strang described how fishermen let the fish pull the boat, *Jaws*-style, until it exhausted itself. This was no easy way for a fisherman to make a living. He reported two fishermen working together full-time did well if they caught 800 pounds of trout in a week.

Strang was shot in the head in 1856, according to Smith, by two disgruntled followers who had left his church after they refused Strang's edict that their wives—along with all other women on the island—wear bloomers. The murderers were never charged, and Strang's tyrannical reign was largely lost to history.

Soon so too would be the era when a couple of fishermen's weekly 1,000 pound lake trout haul would be considered huge.

In the years following Strang's death, Great Lakes fishing evolved from a local industry that sustained lakeshore communities into a treasured national resource as the fishing fleets became motorized and the net hauling mechanized. The annual lake trout haul on Lake Michigan alone by the 1890s was topping more than 8 million pounds. Fishermen on Lake Superior and Lake Huron reported somewhat smaller but similar hauls, and harvests on Lake Ontario exceeded one million pounds. (Lake Erie, a much shallower and warmer body of water, had a much less significant lake trout fishery, though a stunning 44 million pounds of ciscoes were hoisted annually by 1890.)

No matter how hard the lake trout stocks were fished, the lakes continued to yield millions of pounds of lake trout annually, decade after decade all the way into the 1940s, when some 100 million pounds of all species of Great Lakes fish were being harvested each year. And then, in just a matter of several years, stocks of lake trout and several species of ciscoes suddenly vanished. Whitefish populations across the lakes were similarly decimated, if not completely destroyed.

Greedy fishermen alone could not have wrought such instant devastation. It turned out they had an accomplice in an environmental calamity that was unlike any in the history of freshwater fisheries—a stealthy, eel-like bloodsucker that wriggled up the shipping canals built in the 19th century that had destroyed the lakes' natural barrier to the East Coast. This ancient predator exposed the young lakes for what they were—ecological babies, really. And just as vulnerable.

The speed and extent of the fishery collapse that followed the sea lamprey's discovery in Lake Michigan in 1936, in Lake Huron in 1937 and in Lake Superior in 1938 left ecologists and fishermen baffled. By 1949 federal biologists were predicting the "complete" collapse of lake trout stocks on the three lakes, and whitefish and ciscoes were headed in the same direction. This is how one newspaper reporter in 1950 described an ecological meltdown of unprecedented scope:

> A few weeks ago Henry Smith, commercial fisherman of Waukegan, Ill, took his boat out into the trout beds of Lake Michigan. He set four miles of nets.
>
> Several days later he went out again and lifted them. He caught six trout. Five years ago the same operation might well have produced 6,000 pounds of fish.
>
> Now those great succulent trout are gone. The Great Lakes' fishing communities are crumbling. Millions of dollars' worth of nets and gear and boats lie useless. Young men seek other jobs, but the older ones hold on, desperately trying to eke out a living catching coarser fish.
>
> There is a murderer abroad in our Great Lakes that has all but destroyed one of America's greatest commercial and sporting fish.

> His name is the sea lamprey, an eel-like bloodsucker originally a native of the Atlantic ocean. Having begun on the lake trout because of its small, soft scales, this same killer is now preying on the whitefish, the herring, the chub . . . anything that moves.

Indeed. Speaking later that same year at a gathering of the American Association for the Advancement of Science, a Michigan professor revealed that the lampreys had begun attacking humans. "However," explained Wayne State University's Charles Creaser, "they do not try to feed as they do on fish. They release their hold when the swimmer leaves the water, leaving only a tooth pattern on the unbroken skin."

Creaser also noted the lampreys had begun attaching themselves to motorboats traveling as fast as 15 miles per hour, a phenomenon he speculated likely contributed to their fire-like spread across the Great Lakes throughout the late 1940s. In Lake Michigan alone the annual lake trout commercial harvest in 1944 was still nearly 6.5 million pounds. Five years later it had dropped to 342,000 pounds, and five years after that, it was zero. It was a similar story for whitefish, of which Lake Michigan commercial fishermen harvested nearly 6 million pounds in 1947. A decade later the annual catch had dropped to 25,000 pounds. Trout crashes also happened on Lakes Huron and, later, Superior and, to a lesser extent, Lake Erie, which not only had a smaller lake trout population but also lacks the cold, fast-flowing crystal clear spawning rivers required by what is, pound for pound, one of nature's most devastating—and durable—predators.

THE MOST GHASTLY THING ABOUT THE FOSSILIZED BEAST THAT the young paleontologist chiseled from a nearly 400-million-year-old rock in 2005 was its mouth. The ancient fish, discovered in a pile of shale near the southern tip of Africa, had a sleek body and a fat head, like a giant oversized tadpole. Atop that head yawned a single nostril. The little creature's two beady eyes were set back from the front of its face and pushed to the side in a manner that made it apparent that this was a killer that didn't take its prey head-on. And then the mouth. It really wasn't a mouth at all, in terms of what you think of when you think of lips and jaws and teeth. It was just a round hole in the bottom of its head rimmed with 14 fangs in a manner that created the most absurd, exaggerated overbite imaginable. If Bart Simpson had a pet water snake, it would look something like this. It was hard to imagine how this jawless creature could chew and devour its prey, and it couldn't.

The find of this ancient sea creature, which opened a window into life in the prehistoric oceans was, oddly, a byproduct of the civil unrest that plagued South Africa in the waning days of apartheid. A main road slicing through the slums of Grahamstown, a city with a population of about 70,000 in East Cape, was being rerouted in the mid-1980s in order to keep whites and blacks from having to cross paths. The construction project involved cutting through hillsides heavy with vegetation on the city outskirts, exposing a wall of rock cut through by black shale. Rob Gess, then a teenager in the area with a keen interest in geology, started picking through those flaky shale scraps with a pocket knife after he found he could separate the layers of shale as if he were turning the pages of a book. And, thick with the fossilized remains of plants and fish, those pages told the story of what life was like in one ocean lagoon 360 million years ago. The shale, it turned out, was once muck in a swampy lagoon that existed at a time when Africa, South America, Antarctica, India and Australia were fused into the super continent called Gondwana.

In the late 1990s when the freshly exposed shale faces along the new roadside started to slough, the government provided Gess, by then a graduate student in paleontology, a flatbed truck and six laborers to remove about 30 tons of the material. Gess eventually built a shed to keep all his free, fossil-rich rock from weathering. It was there in 2005 that he discovered the remains of the predator that evidently thrived by latching onto the bellies of its victims with its suction-cup mouth rimmed with teeth made from a protein similar to that found in human fingernails. A toxin in its saliva acted as an anti-coagulant to keep the host's blood flowing, and the creature hung on until its own belly was full—or until there was nothing left for its victim to give. It was a most primitive way to make a living—and a killing—but one that proved devastatingly effective.

Gess's specimen showed no evidence of a bony skeleton, only a head, gill basket and spine made of cartilage—squishy material that generally makes for a poor donor to the fossil record. This meant the fossil was actually only an impression unearthed between the flakes of rock, almost as flat as a picture. So how could the scientists determine from this sketchy image so much about how this creature lived and how it attacked its prey? It turned out this crude killer had left behind other hints of how it lived—its babies. And those babies' descendants left behind more offspring. And so on, through the Carboniferous, Permian, Triassic, Jurassic and Cretaceous periods and into the Cenozoic period that began nearly 66 million years ago, and through all its epochs—the Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, Holocene, and on and on and on. All the way up until the day the Erie Canal opened—in 1825.

Gess's fossil represents a direct ancestor of today's sea lamprey, which is native to the Atlantic Ocean's coastal waters and the rivers that feed them. Aside from some minor evolutionary tune-ups, including a few more rows of teeth and a little bit more length and girth, Gess's find showed the predator has not evolved significantly since the day its ancestor got stuck in the mud of that Gondwanan lagoon. Conventional wisdom is that animals with such a specialized design are likely to fade as their prey evolve or go extinct. But not lampreys, which

somehow managed to survive four of the earth's five mass extinctions. They outlasted placoderms, which could grow larger than the biggest sharks of today and were protected from razor-toothed predators with turtle-like shells on their backs and heads, as well as the shark-sized reptiles called ichthyosaurs that swam the ocean a quarter billion years ago. And they survived plesiosaurs, marine predators that could grow to a dinosaur-sized 50 feet in length.

"Essentially," Gess said, "this is such a successful morphology that as long as there are cool waters and aquatic vertebrates for it to feed on, the lamprey continues to be a success." And nowhere has that success been greater than in the Great Lakes. Sea lampreys today are but a bit player in the Atlantic Ocean's overall ecology. They have endured, but haven't decimated ocean stocks. They also give back to the food web; lampreys are a welcome meal for fish species like cod, swordfish and striped bass.

But the saltwater native proved to be an ecological menace when it finally made its way up the canal system from the ocean and into the Great Lakes, whose vastness above Niagara Falls belied the relatively simple food web that existed before construction of the Welland and Erie Canals. Four species of lampreys are native to the Great Lakes basin and have existed for thousands of years in harmony with the other Great Lakes fish. Two of the species never reach the fish-attack stage and instead spend their lives burrowed into streams that feed the lakes, like worms. They survive by poking their heads from the streambed and sucking plankton and other microscopic material from the water flowing past. The two other native Great Lakes lampreys do prey upon fish in open waters, but are only about a foot long and never posed a threat to the existence of other Great Lakes fish species.

And then, with the expansion of the Welland Canal toward the end of the 19th century, came the sea lamprey. Like salmon, sea lampreys are anadromous, which means they spend the first part of their lives in freshwater rivers and streams before descending to the ocean to live as predatory adults and then return to freshwater streams and rivers to spawn and die. But, also like salmon, sea lampreys don't necessarily need a saltwater component in their lifecycle—not if they can find a body of water big enough and filled with enough fish to serve as a surrogate sea.

THE FIRST GREAT LAKES SEA LAMPREY WAS DISCOVERED IN Lake Ontario in 1835. There is debate as to whether sea lampreys had always existed in Lake Ontario, but many researchers believe the lampreys only colonized the lake after the Erie Canal opened. The theory is that lampreys, which are native to East Coast rivers, including the Hudson River, could have ventured into the eastern portion of the Erie Canal and then invaded Lake Ontario by swimming up the Erie Canal's "feeder" canals. These manmade waterways descended from the Lake Ontario basin to keep water flowing in the eastern portion of the Erie Canal. Because adult lampreys are built to swim upstream, the water coursing down from Lake Ontario would have drawn them in that direction.

The sea lamprey, which devastated the lake trout population soon after it invaded the Great Lakes.

It might seem logical that at least some lampreys would have continued their westward migration toward Lake Erie as well, but today's lamprey experts find that unlikely. The water in the western portion of the Erie Canal was too warm, too slow moving and too polluted, especially compared to the alluring cold, clean waters pulsing into the Erie Canal from the Ontario basin. But this does not explain why lampreys did not immediately make the jump from Lake Ontario to Lake Erie by swimming up the Welland Canal when it opened in 1829—nearly a century before the first lamprey was found above Niagara Falls. One explanation is that Lake Ontario didn't have the appropriate spawning habitat for sea lampreys to thrive to the point that they began to crowd each other out and had to seek new waters to invade. Another possible explanation is the design of the early Welland Canals; lampreys seeking upstream waters to spawn would have been flummoxed once they hit the middle of the canal where the water did a most unnatural thing; it flowed in both directions—toward Lake Ontario and toward Lake Erie. Because of a rocky high point on the canal route that put the canal bed at an elevation higher than Lake Erie, water from a feeder canal had to be channeled into the Welland Canal near this crest so boats could float over it. When water from that feeder canal coursed into the Welland Canal at the crest, it then flowed in two directions in the Welland—south toward Erie and north toward Ontario. So a lamprey, nature-built to always swim upstream, would have sensed the downstream switch in current at the crest and headed into the feeder canal and, the theory goes, likely would have ended up in a tangle of upland streams and soggy ditches draining agriculture lands—a biological dead end and, if the story ended there, a life saver for fish in the upper Great Lakes.

This underwater hump in the Welland Canal—perhaps the last line of defense preventing a sea lamprey invasion of the upper Great Lakes—was obliterated when the canal's third expansion was completed in the 1880s and with upgrades in the following decades. The deepened channel finally allowed Lake Erie water to flow continuously down the Welland Canal, through the locks, and into Lake Ontario. This gave the lampreys a continuous upstream migration into Lake Erie.

It is also possible that lampreys had been trickling into Lake Erie ever since the first Welland Canal opened—and perhaps hitchhiking their way through its waters by latching onto boat hulls—and that it just took years, decades even, for a breeding population to become established in Lake Erie and then grow large enough for humans to take notice.

Whatever the reason, the first sea lamprey was not found above Niagara Falls until 1921, a 21-inch adult taken in open lake waters about 200 miles beyond Buffalo on the western end of Lake Erie. It would be another 15 years until a lamprey was discovered in the next Great Lake, when Lake Michigan commercial fisherman Frank C. Paczocha found a 15-inch specimen latched just beneath the eye of a four-pound lake trout caught in the waters off Milwaukee. I can only imagine what went through his mind as he stared for the first time at a creature that looks as if it is not of this world and, given its primordial lineage, it isn't.

In spring of 2015 my daughter's sixth grade science class carved into a batch of lamprey carcasses, probably because the dissection specimen company was selling them cheaper than standard-issue frogs. It's one thing to see a picture of the prehistoric parasite, and quite another to run a finger over its dark gray, scaleless skin and, lightly, across its pin-sharp teeth. The foot-long specimens that arrived vacuum packed had a pencil-lead sized nostril on the top of their heads and black, bulbous eyes, behind each of which trailed seven eye-like slits—the lampreys' gills. Unlike most fish that take water—and the dissolved oxygen it contains—in through their mouths, lampreys pull their oxygen through these oval openings because their suction-cup mouths are built to be latched onto prey around the clock.

I was invited by the middle school science teacher to attend one of these squeal sessions, which peak when the 12-year-olds use scissors to cut through their specimens' skin to expose a pale orange paste that is tens of thousands of orange poppy seed-sized eggs. "These are its babies?" howled one girl. "Oh, that is nasty."

Those eggs, had they been allowed to hatch in the wild, would have grown into adults up to two feet in length and peaked in weight at about a pound. It is an ecologically pricey pound—each lamprey can kill 40 pounds of fish during the year or so it spends chasing its prey.

The problem in the early days of the invasion was that the young Great Lakes had no natural predator equipped to control a killer so stealthy and so fiendishly efficient that the press had taken to calling it a vampire. But then a University of Michigan graduate student and World War II veteran named Vernon Applegate showed up and did what no creature in the past 360 million years had apparently been able to do. He got under the lamprey's skin. He figured out how it migrates and how it hides. How it feeds, how it breeds, and how it dies.

And then he put a stake in it.

BY 1950 THE GREAT LAKES SEA LAMPREY INFESTATION WAS AT ITS peak, its commercial fishing industry at its low point, and the lakes' intricately stitched together ecosystem, thousands of years in the making, was in shambles. It was also the year Applegate, after three years of field research in some of the most lamprey-infested waters of the Great Lakes, produced his dissertation, *The Natural History of the Sea Lamprey,* Petromyzon marinus, *in Michigan*. The 334-page document was fat with charts, pictures, sketches and graphs, and it evidently left at least one of his University of Michigan professors rapt. The chief of the university's Institute for Fisheries Research made a point of adding a page inside Applegate's dissertation cover noting it was a document for the ages, that it should be sent straight to the Library of Congress for microfilming and to be catalogued. "Unusually and exhaustively detailed" is how the fisheries chief termed the work that included exquisitely detailed information about the lampreys' physiology as well as a litany of statistical breakdowns on everything from the time of day lampreys choose to swim upstream to reproduce to the types of rocks they use to build their spawning beds to whether the female or male does more work in that pre-mating enterprise. (It's the male.) But the reviewer also called the document "clear and pleasing." Pleasing, because Applegate was clearly on his way to figuring out how to get under the species' ancient, slimy and theretofore impenetrable skin.

Applegate, a wiry ex-infantryman from Yonkers, lived for three years along two lamprey-infested rivers in northern Michigan in search of a weakness in the lifecycle of one of evolution's most durable models. He did it with an intensity that, more than a half century later, still leaves those who worked with him—or who had brief encounters with him—bemused. Applegate toiled around the clock, chasing the slithering gray or black parasites up rivers through the night and into dawn with flashlights and a notebook. He set traps to catch adults swimming upstream to spawn, and traps to catch young lamprey riding downstream on springtime floods toward the lakes. He built outdoor pens to watch them breed. He peeped into their evolutionary secrets through the glass of the aquariums at his lab on the shore of Lake Huron, whose ecological health evidently became more important to him than what was going on under his own pale skin.

"I've heard him described as living on cigarettes and aspirin," said Howard Tanner, a renowned Great Lakes fisheries biologist, who met Applegate while Tanner was studying at Michigan State University, and who would one day, if unintentionally, undermine Applegate's goal of restoring the lakes' native lake trout. "He was very intense. A small man. Red haired."

A perception by many early on in the Great Lakes invasion was that the lampreys devastating the fish populations were primarily a big-water inhabitant. But it turned out their killer stage comprised

only a snippet of their life. The majority of a sea lamprey's existence—more than five years of its roughly seven years—is spent as a blind, worm-sized vermin burrowed into the beds of rivers and streams feeding the Great Lakes. Only their mouths are exposed for them to suck from the water algae and any other nutritious material drifting on the stream currents. That meant that for every crop of lampreys swimming in the lakes' open waters—and there were hundreds of thousands of them by the time Applegate began his studies—there were maybe six times that number burrowed into streambeds, growing ever so slowly, invisibly and inexorably, until it was their turn to attack.

"Aquarium observations make it easily understandable why lamprey larvae are seldom observed in their 'beds' in a stream. The vibrations set up by footsteps across the floor of a wooden building caused all aquarium-held specimens to retreat from the surface into the depths of their burrows," Applegate wrote in his dissertation. "After several minutes, if all remained quiet, they returned to the surface again and resumed feeding."

Applegate noted that footsteps along stream banks triggered a similar response and "for this reason, individuals of this life history state are seldom seen, even by careful observers, in their natural surroundings."

Adult lampreys returning to the rivers and streams to spawn were similarly cryptic. Applegate noted that when researchers stepped into a stream where pre-spawning adults were lurking under rocks, logs, overhanging banks and in the depths of dark pools, their escape instinct was extreme. "When prodded from these hiding places they dash blindly away with little regard for the direction taken," he wrote. "In several instances, disturbed specimens darted at right angles to the current with so much force that they slithered several feet up onto a low, grass bank or mud flat."

Biologist Vernon Applegate holding a lake trout under attack by a sea lamprey.

Applegate learned that spawning lamprey preferred streams with bottoms peppered with gravel that had a diameter no smaller than three-eighths of an inch and no bigger than two inches, and that they typically did not migrate up those streams until early spring, when the water temperature rose above 40 degrees. He found in one creek that he studied for three years the upstream migration took place under the cover of darkness up to 99 percent of the time. Thousands of lampreys could infest a single stream like a virus, invisible to everyone—except Applegate. He watched how individual male and female lampreys work together to build spawning beds by excavating stones and moving them about with their suction-cup mouths (hence their Latin name, loosely translated as "stone sucker"), stacking them just so to give the fertilized eggs drifting downstream on the current a protected place to

settle. He found the nests by learning precisely what type of material they needed to successfully reproduce. Gravel with a little sand was ideal. Boulders, bedrock and rubble were deal killers. So were streams that were entirely soft-bottomed. Applegate also learned that lamprey needed a specific type of stream current, one strong enough to keep the eggs floating downstream but not one so swift it would sweep the eggs beyond the newly built nests.

Like a private detective trying to find out a subject's sexual habits, he staked out the stream banks on one stretch of river in 1948 and found it had 954 nests. He then observed actual sex on 338 of those spawning beds. He found 71 percent of those beds were home to monogamous couples; 13 percent were nests with one male spawning with two females, and he found nine nests that had one male and five females. He described the actual spawning act with a crisp clinical detail that echoed that of the work being done at the same time by Alfred Kinsey at the Institute for Sex Research across the state line at Indiana University.

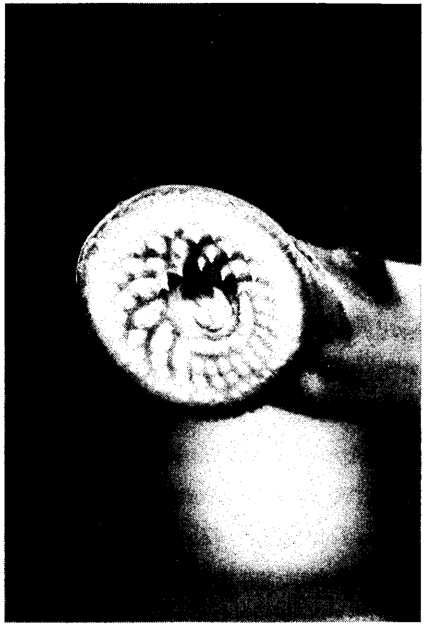
"The male approaches the female generally along the long axis of her body which is parallel to the current. In doing so, he frequently runs his mouth lightly over the anterior half of her body until the branchial zone is reached," Applegate wrote. "At this point the male fastens himself firmly to the female with his mouth. Almost immediately he wraps the posterior third of his body in an abrupt half-spiral about that of the female so that their vents are approximated. The extrusion of the eggs and milt is preceded and accompanied by a very rapid vibration of the bodies of both individuals for a two- to five-second period. Following that, the male releases the female immediately." Applegate also kept a keen eye on the thermometer and noted none of this occurred until a stream warmed to 50 degrees.

Now he knew where, how and when his subjects spawned. He had cages built in streams so he could contain a lamprey couple through the whole reproduction session. He watched the freshly fertilized eggs coast downstream until they were caught in the lower wall of the spawning bed. Then he watched the parents anchor themselves on rocks with their mouths, upstream from the spawning bed, and violently shake their bodies to kick up sand that floated downstream to give their young a protective cover in the stone wall.

The parents would then take a breather for a few minutes and repeat the breeding process. Over and over until both were, in the most literal sense, spent—both inevitably died soon thereafter. The mating period typically lasted about 16 hours, though one couple he watched in early 1947 mated for three and a half days. Spawning females release as many as 100,000 eggs, but Applegate noted that usually fewer than 1,000 of those eggs hatch. That normally didn't happen for 10 or 12 days after the spawn. Around the 20th day after fertilization, the squiggly lampreys, smaller than a sliver of finely shredded cheese, emerged from the pebbly home their parents had built for them and drifted down stream until they hit calm waters—eddies, side channels and wide spots in the streambed—where soft sediments are found. There, they plunged to the bottom, where they would make their home for the next five or six years.

If the current failed to steer the juvenile lampreys to welcoming, soft-bottomed streambeds, Applegate's lab experiments revealed just how determined larval lampreys could be. He noted in his aquarium experiments that if a tiny burrowing lamprey hit a rock while diving for a soft place to hide, it often knocked itself out. But when it regained consciousness, it almost invariably slithered off in search of softer material into which it could find a home.

After lurking and feeding in the streams for a half-decade or more, growing on average only about an inch per year, the blind, burrowed lampreys would begin their transformation into bloodsuckers. Eyes emerged on the side of their heads. So did the creatures' horrifying circular mouths with spiky rows of teeth and piston-like tongues, rough as an emery board to rasp away their victims' skin and scales. Once the metamorphosis was complete, the new crop of lampreys erupted almost all at once from the streambed and headed for open waters. Applegate noted most of the migration came in late March and early April, as water temperatures rose, but before the thermometer hit 41 degrees.



The sea lamprey uses its suction-cup mouth to latch onto its victims' bellies.

"One of the most striking characteristics of the downstream movement of newly-transformed sea lampreys is the abruptness with which large numbers of individuals suddenly leave the mud banks and move downstream," he wrote. "Under the impetus of rising waters, a virtual emergence takes place and hordes of the new adults travel downstream on the rise and crest of floodwaters. This surge of movement downstream frequently ends as suddenly as it begins."

The lampreys' open water fish-feasting period lasts 12 to 18 months during which they range as far as 200 miles from their spawning streams. Unlike a species like salmon, lampreys don't have a homing sense for their birth waters; they'll swim up any stream their keen noses tell them has a larval lamprey population.

Applegate's research suggested that the slithering killers marauding across tens of thousands of square miles of open Great Lakes water weren't indestructible after all. They were sitting targets, if you knew when and where to shoot. "Plainly," Applegate concluded, "the most vulnerable times in the lamprey's life are its periods in the stream—as a larva or young migrant and later when it goes back to spawn."

The initial control strategy, which was already in use before Applegate presented his dissertation, was to attack the lampreys on the Great Lakes' most heavily infested streams and rivers by building weirs, which are mesh barriers that allow water to flow downstream but block the upstream passage of spawning adults. The concept worked. Three months after Applegate defended his dissertation, the U.S. Fish and Wildlife Service reported that experimental traps in 12 northern Michigan streams had caught 29,425 adult lampreys set to spawn. This was a remarkable early success; if one lamprey could kill 40 pounds of fish, those dead lampreys alone could have been responsible for killing some 1.2 million pounds of native fish. And since each female lamprey could produce several hundred offspring, the biologists were getting confident they were on their way to throttling the explosion.

Researchers had also begun to explore electric barriers, a strategy that would prove effective in deterring upstream migration of adults but ineffective on downstream-migrating juveniles that, even if incapacitated by electricity, could still drift through the barrier zone on

swollen spring currents. The electric barriers were also costly to operate and prone to failing. The biggest problem with both weirs and electric barriers was that they could be breached with floodwaters. Also, because a creek could have six year classes of lampreys burrowed into its streambed at any given time, the barriers would have to be successfully operated for the better part of a decade. If one failed just one time, in just one year, it would unleash a fresh crop of parasites to colonize the lakes anew.

Applegate knew that something more effective than these physical barriers was needed. And he knew he was in a race against time—against a creature for which time didn't seem to pass. He was determined to control the lamprey infestation in time to save the remnant stocks of Lake Superior lake trout that had up to that point managed to survive the infestation. He hoped eventually to use them in a breeding program to restore lake trout populations to Lakes Michigan and Huron. But he worried that it might well be too late. Even if government crews were able to install weirs on all the spawning tributaries to Lake Superior immediately, there would still be several years in which larval lampreys would continue descending into the lakes, and that might be all it would take to doom the Lake Superior population of lake trout as well.

He decided that he needed a poison that would destroy the lampreys without wiping out all the other species in the streams or the lakes they fed. His goal was ambitious—"Complete eradication of sea lampreys above Niagara Falls."

The problem was, such a poison did not yet exist.

IN A CONVERTED COAST GUARD LIFESAVING STATION AT THE northern tip of Michigan's lower peninsula in the early 1950s, the freshly graduated Applegate, who had taken a job with the U.S. Fish and Wildlife Service, began a secretive program to develop the perfect poison for juvenile lampreys. One of his colleagues was Louis King, who still remembers the despair he felt the day he arrived on the shore of Lake Huron, fresh out of graduate school in Missouri and with a wife and children in tow. He said the lake looked dead.

"What I saw when I got here," the 84-year-old said in the living room of his home in far northern Michigan near the shore of Lake Huron, "was virtually a desert. A big desert. Nothing was there. No commercial fishing. No recreational fishing." King said he was "overwhelmed" by the scale of the waters, which seemed to him to be more ocean than lake. "I thought: How in the world could they ever, ever control lamprey in this vast body of water—and there were five lakes!"

Miles from any town in their lab on the shore of Lake Huron, Applegate and his crew began testing industrial poisons that arrived daily from factories across the globe. They came labeled with numbers but often with no names; some of the chemical companies submitting their products jealously guarded the formulas in case one turned out to be the lucrative potion that would save the Great Lakes. The program is considered by today's scientists to have been the biological equivalent of a moon shot. But the poison screening system the crew used at the time was anything but rocket science. Workers filled 10-liter jars with water and dropped two juvenile lampreys into each one, along with one rainbow trout and one bluegill. Then they dropped in the poison. The idea was to find a concoction that would destroy the lampreys while leaving the rainbows and bluegills—a suitable proxy for the lakes' native fish species—unharmed.

Cliff Kortman's job was to weigh and mix the powders that arrived from chemical companies around the world.

"All I got was little bottles with a skull and crossbones on it," Kortman told me. He had no college education and was hired initially as a janitor. He said he and the other chemical testers worked with little protection beyond white lab coats and, sometimes, safety goggles or a mask. Kortman remembered how one day he stirred a white powder into a beaker and, as he was walking across the room to put it in the lamprey jar, the solution went poof, literally evaporating into the laboratory air. So he tried it again, and it happened again. Other chemicals were so pungent the room would have to be evacuated. This routine went on for more than two years.

"Imagine testing 40 to 50 unknown chemicals daily," King said. "You just have to keep at it."

Kortman recalled the day he said he opened bottle number 5,209. It was dumped into the jars with the lampreys and the two other fish species, and it didn't take long before the lampreys went limp. The trout and bluegill kept flitting about. "That one was pretty something," Kortman recalled more than a half century later. That one put the scientists on the path to save the Great Lakes.

On July 26, 1957, the *Milwaukee Journal* broke news that the "blind and desperate hunt" for the perfect lamprey poison had succeeded. The first application of it in the wild happened later that year under the cover of darkness, on a tiny creek near Cheboygan, Michigan, with "almost the secrecy of a nuclear project," according to a local newspaper article at the time. Precise dosages of the chemical were pumped into the creek and in the following hours, just as Applegate's crew of "lamprey chokers" had hoped, thousands of the night crawler–sized lamprey surfaced lifeless from the streambed, with no ill effects to any other fish in the area. Applegate described the scene that night as a "real purty sight."

"By midnight, the weary crews returned to Cheboygan for hot lunches. The lid of secrecy was lifted a bit—there were hints, knowing glances," the newspaper reported. "The lamprey had had it."

Further experiments would reveal an even more effective chemical, and by 1961 so much of this "lampricide" was flowing into streams feeding Lake Superior that the lamprey population had been declared under control. Similar poisonings would have a similar impact on the other Great Lakes and by 1967 researchers figured they were well on their way to pushing the Great Lakes' lamprey population down to about 10 percent of its peak, where it remains today due to a nonstop poisoning program that costs about $20 million annually.

But the lamprey solution came too late to save the lake trout in Lakes Michigan and Huron. This was trouble for more than the lake trout and the commercial fishermen who depended on them; at the very moment Lake Michigan's lake trout population was crashing, barely 100 miles to the west, 20th-century naturalist Aldo Leopold was laboring on his seminal work, *A Sand County Almanac*, in which he uncannily captured the critical role an apex predator plays in its ecosystem. Writing about mountains that had been stripped of their wolf packs so hunters could enjoy thicker deer herds, Leopold observed:

"I have watched the face of many a newly wolfless mountain, and seen the south-facing slopes wrinkle with a maze of new deer trails. I have seen every edible bush and seedling browsed, first to anaemic desuetude, and then to death. I have seen every edible tree defoliated to the height of a saddlehorn. Such a mountain looks as if someone had given God a new pruning shears, and forbidden Him all other exercise. In the end the starved bones of the hoped-for deer herd, dead of its own too-much, bleach with the bones of the dead sage, or molder under the high-lined junipers," he wrote. "I now suspect that just as a deer herd lives in mortal fear of its wolves, so does a mountain live in mortal fear of its deer."

Had Leopold, who died in 1948, lived long enough to take a day's drive over to the shore of Lake Michigan to witness the bizarre, utterly unpredictable aftermath of the lamprey invasion beginning in the 1950s, he might have found an equally apt way to convey the notion

that sometimes a native predator's job isn't merely an essential matter for a functioning ecosystem. It is an existential one.

THE SEA LAMPREY INVASION THAT DECIMATED THE UPPER GREAT Lakes' population of native predators turned out to be just the first wave of ecological trouble unleashed by the 19th-century canal building that opened the Great Lakes to the ocean. After the lampreys slithered their way up the shipping channels came a much more harmless-looking intruder—a type of river herring cherished on the East Coast. Once in the Great Lakes, this fish acquired a new reputation.

Like lampreys, salmon and striped bass, the foot-long river herring normally spend their adult lives in the ocean but spawn in freshwater. Individual female river herring can lay tens of thousands of eggs each spring. Those eggs hatch in a matter of days into wiggly, transparent babies about the size of a grain of rice that feast on flea-sized river plankton with such ferocity that they can grow to three inches in less than two months, and in late summer the now four- or five-inch-long juveniles make their run to the ocean. The fish spend three or four years in the Atlantic before they make the return trip to spawn. It's impossible to peg just how many of these fish swarmed the waters of the East Coast hundreds of years ago, but their range stretched from South Carolina to Newfoundland—and one stream in Maine alone is believed to have carried as many as 100 million juveniles each spring. Only a small percentage of the migrating juveniles survived to return to spawn, but the arrival of these half-pound fish with rich, oily flesh was a time-honored seasonal event. Ancient fire pits littered with fish bones reveal Native Americans have been feasting on river herring for at least 4,000 years and used the fish to fertilize their crops of corn.

The river herring brought out the best of Colonial Americans—they provided a pioneering form of welfare in the 1700s, so plentiful and easily preserved by salting or smoking that they were given away to the elderly and the needy in coastal New England communities. And they also brought out the worst in early Americans—they were shipped to the West Indies for $1 per barrel and fed to slaves.

The fish were important to more than humans. Historical reports show black bears used to scrounge for herring along stream banks. Later, as agriculture progressed in the colonies, pigs snorted their way down to those same creeks to gobble their fill. River herring are also a food source for such bird species as eagles, osprey, great blue herons and loons. In the ocean, they are a source of protein for striped bass, cod, haddock, halibut, blue fish, tuna and even seals, porpoises, dolphins and whales. They eventually became a prime bait fish for the East Coast lobster, crab, cod and haddock commercial fishing industries. But overexploitation and two centuries' worth of migration-blocking dam construction took their toll, and today the river herring run at only a sliver of precolonial levels. In 2011 the Natural Resources Defense Council petitioned to have them listed as a threatened species under the Endangered Species Act, to no avail. Perhaps it is because river herring aren't struggling everywhere.

No one knows how these ocean fish made their way from the Eastern Seaboard into Lake Ontario, where they were first found at the end of the 19th century. Maybe the river herring were actually natives, having made the trip on their own by fighting their way up the St. Lawrence River and into the only Great Lake below Niagara Falls. Some have accused the U.S. Fishery Commission (a predecessor of the U.S. Fish and Wildlife Service) of accidentally planting the species when its biologists dropped a load of similar looking shad into the lake to boost the population of this forage fish to feed its native Atlantic salmon (exterminated by the end of the 19th century) and trout. Or, perhaps, the river herring migrated up the Hudson River, then up the

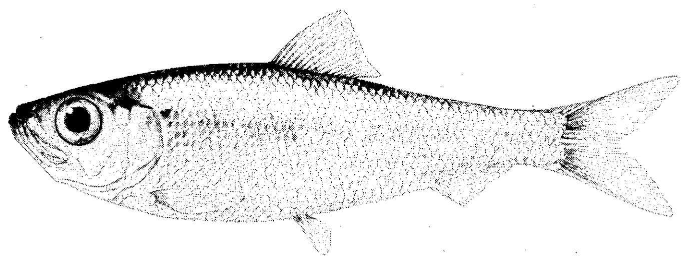
Erie Canal and then into one of the canal's feeder waterways connected to Lake Ontario.

However the herring got to Lake Ontario, there was little fanfare when the first one was identified in 1873. As was the case for lampreys, the big water of a Great Lake proved to be a suitable replacement for the ocean portion of the herring's lifecycle, and in Lake Ontario the East Coast fish lived for a few years in harmony, if not obscurity, with the native fish. A likely reason is the big lake's predators—Atlantic salmon and lake trout—would have been able to keep them in check. But when commercial overharvests destroyed the populations of those big fish, the now-landlocked river herring began to appear in the 20th century in "almost incredible" numbers, in the not-so-scientific words of Robert Rush Miller, a biologist at the University of Michigan.

It was just a matter of time before they sought new waters to colonize. As with the lamprey, there was a significant lag between the discovery of river herring in Lake Ontario and its migration up the Niagara Falls—bypassing Welland Canal and into the upper Great Lakes. The first river herring found above the falls was in Lake Erie in 1931. They then quickly spread westward, turning up in Lake Huron in 1933, in Lake Michigan in 1949 and in Lake Superior in 1954. Their numbers at first were minuscule; in the early 1950s river herring in the upper Great Lakes were still so rare that specimens were sent to regional museums as a novelty. *Imagine that, an East Coast river herring swimming in our own Great Lakes!*

Had the river herring made their way into the lakes before the lake trout were knocked out, they might have slipped into the food web with scarcely a ripple. But with no predators to keep their numbers in check, they turned viral. Too small to fall prey to the lampreys, the tiny toothless Great Lakes river herring, which are only about half the size of their East Coast cousins, dominated the remaining native fish species by outcompeting them for food and by feasting on their young. If the Great Lakes had been a forest, the lamprey invasion was a fire that burned them down. And the first river herring were the seeds of the weed infestation that blew in afterward.

The result can only be described as an ecological meltdown—particularly on Lake Michigan—previously unmatched in scope or speed. By 1962, biologists estimated the river herring accounted for 17 percent of the fish mass in Lake Michigan. Three years later that number was pegged at 90 percent. The exotic herring had similar success in Lakes Huron and Ontario, and took hold to a lesser degree in the colder and more sterile Lake Superior, and the warmer and more predator-filled Lake Erie.



The alewife, also known as a river herring.

Biologists knew by the mid-1960s the pocket comb–sized fish were swarming in Lake Michigan at extremely high numbers—engine propellers cruising the lake churned the fish up to the surface as if they were bubbles—but nothing prepared them for the size of the dead schools that mysteriously appeared in the summer of 1967, and nobody in the Great Lakes by that point was calling them river herring. They had another word for the hundreds of billions of silvery intruders, and it might as well have been Cockroach-of-the-Inland-Seas, or Locusts of the Lakes. They called them alewives.

THE PILOT FLYING THE NAVY SEAPLANE ACROSS THE DEEP BLUE waters of Lake Michigan must have thought he was hallucinating when he passed over what appeared to be a series of white-as-ice streaks stretching for miles upon miles on the mid-summer lake surface. Or maybe he figured the muggy 90-degree blast of High Plains air pressing down on the lake on this mid-June day in 1967 was kicking back some sort of optical illusion, something known to happen in the Great Lakes. From time to time, residents of Muskegon, Michigan, for example, report seeing the nighttime skyline of Milwaukee, some 80 miles of open water to the west. This, given the earth's curvature, is an optical impossibility. What these people actually glimpse is both real and an illusion. A pocket of hot air sitting above a cool layer can bend the lights of Milwaukee shooting into the night sky eastward, toward the Michigan coast. So the flashing red light of a Milwaukee TV tower that a Muskegonite might see is real, but if he were to set out in a boat to reach it, the baffling light would eventually fade into the black sky.

But the pilot and his passenger from the Federal Water Pollution Control Administration weren't gazing *across* the lake on that breezy day back in 1967. They were looking straight down, surveying the lake's southern end for telltale signs of pollution plumes when they saw a series of white swaths stretching almost the whole distance between the coastal cities of Muskegon and South Haven. The pilot didn't have to guess how large the splotches were; he could calculate them based on the geography of the shoreline. The two cities lie some 50 miles apart. He tipped his wing and dove close enough to the lake surface to know that he wasn't looking at some sort of froth churned up by one of the industrial chemicals so wantonly dumped in southern Lake Michigan during those pre–Clean Water Act days. He had found a mass of belly-up dead and dying fish that numbered in the millions, if not the hundreds of millions, if not the billions. It would have been impossible for him to even hazard a guess, because he had found Mother Nature whacked out in a manner that no freshwater biologist had previously encountered.

The fetid slick of alewives was, mercifully, drifting east, bobbing on the waves toward the relatively unpopulated shoreline of eastern Lake Michigan, where they were destined to rot and eventually wash back out into the open water. But then the winds shifted and pushed the mess back across the lake, toward the 3.5 million residents of Chicago. The first fish carcasses started floating in that weekend. A few days later, 30 miles of Chicago shoreline had been smothered—some places shin-deep—in a mound of rotting fish goo. There had been similar but smaller die-offs across the Great Lakes earlier in the decade, including one the year before that plugged the screens on the cooling water intakes at a Lake Michigan steel plant south of Chicago, causing a loss of a half million dollars a day during a 10-day period.

Yet nothing was like what washed ashore that July, and Chicagoans would never look at their lake the same way. The inland sea that had sustained them for more than 100 years with a marvelous array of native freshwater fillets suddenly started retching millions of pounds of inedible flesh that smelled like human waste. The saltwater native alewives were fantastically good at breeding in the Great Lakes. It just happened that they weren't so good at living in them. In the next several weeks an army of hundreds of workers across the southern end of Lake Michigan used shovels and bulldozers to remove the flesh. Chicago workers reported within the month that they alone had disposed of enough alewives to cover two football fields—500 feet high. But even the city with big shoulders couldn't shovel fast enough. This is how one UPI news report characterized the losing battle: "Chicago was running out of places to bury dead fish, out of money for their removal, and out of people to do that work. A dozen park district employees

quit their jobs in olfactory disgust. Morale among those remaining was described as 'low.'"

Those who did stay on the job started cutting corners. "In some cases, the fish are buried to a depth of four or five feet on the beach. Equipment includes sand sifters to separate fish from sand," stated a July 25, 1967, report by the Federal Water Pollution Control Administration. "Although disposal might include burning of dead alewives, such action would result in air pollution. Deodorants have been applied to dead fish and beaches to reduce the stench of decomposition. In some cases, chemicals are used on beaches to control fly maggots in the dead fish."

By the middle of the summer newspapers were estimating that the total cleanup cost on Lake Michigan would reach $50 million—$350 million in today's dollars. The impact spread beyond Chicago. Fish piled up on beaches all across southern Lake Michigan that summer, costing the tourism industry an additional $55 million—again, in 1967 dollars, making this all the better part of what would be a billion dollar problem today.

Not all the dead fish made it ashore; divers scouring the lake bottom reported seeing six-foot-high mounds of carcasses. Yet the lake continued to have an apparently unlimited supply of living alewives. Sonar readings taken around that time showed that a single swimming mass of the fish measured 10 miles long and up to 60 feet wide. The number of fish in that cluster is mind boggling. At the time, a biologist calculated that a mere 15-foot-wide sphere-shaped school of alewives contained as many as 6,000 fish. Some commercial fishermen of the era survived the infestation by figuring out where the shrinking pockets of native whitefish, perch and chubs could be found, but it was almost impossible to avoid running into alewives. Ken Koyen, one of the few remaining commercial fisherman on northern Lake Michigan, can still feel the jolts he and his father suffered when they hit midwater piles of dead alewives while motoring out to their fishing grounds near Washington Island off the tip of Wisconsin's Door Peninsula. "In places they were so thick," he said, "it was like hitting a snowbank."

Some commercial fishermen tried to make a dollar off the alewives by catching them for two pennies per pound, hauling ashore some 40 million pounds of them on Lake Michigan alone that summer of 1967. Food scientists of the era were scrambling to figure out how to turn that flesh into a digestible—if not marketable—form of human food. They explored alewife fish sticks, alewife breakfast sausages and even mixing the alewife flesh into bread dough, molding it into loaves and baking it in industrial ovens. None of that panned out. The only market for the fish was to churn them into cat food, turn them into liquid fertilizer or convert them into fur coats—much of the haul was sold as feed to Midwest mink farms.

By the time the summer die-off ended, estimates of the dead ranged from 6 billion to 20 billion carcasses, each fish dying almost exactly the same way, as described by a biologist with the Great Lakes Fishery Commission: "The stricken fish swam weakly on their sides in vertical spirals that brought them to the surface. Some exerted sudden bursts of swimming effort and were propelled sideways or downward. Their attempts to regain equilibrium lasted several seconds before they again rose to the surface where they quivered and died." But why?

EVEN AS THE 1967 DIE-OFF WAS RAGING, BIOLOGISTS LAUNCHED an exhaustive survey along the "U" that is the southern end of Lake Michigan (from Milwaukee to Chicago to Gary, Indiana to Grand Haven, Michigan) to test the lake for chemical and bacterial trouble. They tested along hundreds of miles of shoreline and waters further offshore for sulfates, nitrogen, chloride, phenol and cyanide. They sniffed for pesticides. None of the chemicals they found were at levels

markedly different from where they were before the die-off. Some surmised that the kill was tied to an outbreak of deadly blue-green algae fertilized by sewage spills, a theory later dismissed because similar levels of the algae had been present prior to and after the die-off. Another theory, subsequently debunked, was that alewives were so abundant they had literally suffocated by sucking the oxygen out of the water.

Other researchers cut into the stomachs of alewife carcasses to see what they were eating. The fish kill peaked in late spring and early summer, spawning time and a period when fish typically don't feed, so it would not be surprising to find empty stomachs. Even so, more than half of the fish sampled contained a type of zooplankton that is digested so fast it was clear the fish were finding food—and eating it—right up until the time they died. Others, probably tired of thinking about it, speculated it was just a case of the fish reaching old age. Everyone was left stumped. "The findings did not indicate any extreme or bizarre pollution conditions in the waters that could have caused the massive die-off," concluded the federal report released in the weeks after the first dead fish showed up in Chicago.

The real problem, it turned out, was the alewives themselves. The Great Lakes version of the fish grows only about six skinny inches in length, compared to a fat foot or longer for their ocean cousins. Great Lakes alewives' kidneys are under immense stress because, not being a true freshwater species, the fish are forced to constantly urinate to expel the freshwater persistently seeping into their cells. At the same time, their bodies are working overtime to retain what precious salts they can pull out of the freshwater. Great Lakes alewives also have a stunted thyroid, likely due to a deficit of iodine in freshwater. This may further prime them for death when the real trouble hits: water temperature swings unlike anything the species had to deal with in the ocean. Winds churning deep cold water from the bottom can drop Great Lakes temperatures by as much as 20 degrees in just a matter of minutes.

So by 1967 three of the five Great Lakes—Michigan, Huron and Ontario—were overrun with a rapidly reproducing species ill-suited for living in them. Biologists of the time expected the alewives to rebound at some point due to a lack of bigger fish to eat them, and they expected further die-offs. The lakes were broken, and there was no reason to believe they could right themselves on their own. What had just happened on Lake Michigan proved that.

"To summarize, Lake Michigan was left with a fish population consisting largely of one species, the alewives," stated the federal report in late July 1967. "The natural enemies of the alewives, the predatory fish species, could no longer assert a controlling effect in maintaining a balanced fish population."

Applegate had a plan to solve this problem by restoring the all-but-extinct lake trout populations with a massive hatchery program using eggs and sperm from remnant trout stocks that continued to hang on in Lake Superior. But another biologist had another plan. He didn't want to just resuscitate Mother Nature. He wanted to give her an upgrade by stocking the lakes with an exotic predator that he thought would be a sexier catch than native lake trout.

If Vernon Applegate was the Great Lakes' oncologist who saved them by developing a precision chemotherapy that could be dispensed on an ecosystem scale, Howard Tanner was their plastic surgeon.

Chapter 3

THE WORLD'S GREAT FISHING HOLE

THE INTRODUCTION OF COHO AND CHINOOK SALMON

In early summer 1968, two businessmen from Waukegan, Illinois, slinked away from work, stopped at a local delicatessen to grab some takeout sandwiches and beers, drove down to the city marina, hopped on a little boat and puttered out into Lake Michigan to go fishing.

It was less than a year since southern Lake Michigan's shoreline had been smothered under millions of rotting alewives. Individual specimens of the invasive fish weigh only about four ounces but, collectively, the little herring had so overwhelmed what was left of the lake's native fish populations that biologists of the time estimated that for every 10 pounds of fish swimming in the lake, 9 pounds were alewives. The businessmen, hopeful they might catch that elusive 10th pound and in a rush because they were on the clock, didn't bother to take off their ties as they dropped their lines in the water about a half mile from shore.

"With sandwiches in one hand, rods in the other, they soon caught several silvery fish that ranged from 3 to 5½ pounds apiece," wrote the *Chicago Tribune's* Tom McNally. "In 45 minutes they caught seven, then they quit and hurried back to work."