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A Decapod Crustacean "Who-Dun-it?"

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by Peg Van Patten

Long Island Sound lobstermen in 1999 must have had feelings something akin to the shock expressed by the characters on a television crime show, who are going about their daily business when they suddenly discover corpses in their midst. But these dead bodies, found from Norwalk to the Westernmost Sound, were crustacean, not human. There were, by some estimates, a million dead. Like the pathologists on the TV crime shows, the questions asked by investigators into the lobster mortalities over the intervening years up to present include whether the deaths were due to natural causes or something more ominous.

And so, "the suspects" were rounded up, and a huge investigation, by expert scientists, began. The lobster industry, environmental groups, the public, and yes, lawyers, demanded a definitive answer. Even you, *WL* readers are suspect: could, as the old Pogo cartoon suggested, the enemy be the collective "us"? Like the popular crime shows, the conclusions will not be revealed until the end of this article, because the pursuit of the investigation is the interesting part.

TV analogy aside, there is nothing frivolous or fictional about this situation. It is dramatic. The mortalities have had a devastating economic impact on a group of hardy individuals who enjoy setting and hauling traps, on the water in all sorts of weather, making a living by harvesting the sea. In some cases, 70% of the fishermen in affected areas lost 100% of their income, according to statistics collected by the Connecticut Department of Environmental Protection in 2000. Some lobstermen found other work, some are still fishing, some lost homes, some sold their boats and traps and moved on.

> "The animals just aren't out there"
> *–Penny Howell, CT DEP*

"We're seeing all-time lows for lobster harvests in 2003 and 2004" said Penny Howell, senior fisheries biologist for Connecticut Department of Environmental Protection. The dockside harvest was estimated as being worth $35 million in 1998. "In 2003, we landed about 671,000 pounds compared to 1,700,000 pounds in 1984." The situation is comparable in New York. "Once the catch dipped below 800,000 it was an all-time low." It's not because fishers have ceased fishing, she said, "Our trawl surveys show that the animals just aren't out there."

In 1999 and afterward, a segment of the Long Island Sound lobstermen and some nonprofit organizations, immediately and vocally blamed pesticides. Three pesticides were used along the shores of Connecticut, New York City, and Long Island, to control mosquitoes that might spread the deadly West Nile virus. Pesticides were applied aerially and in briquets in storm drains, mostly in late summer and early fall; there were reports of unprecedented numbers of dead lobsters in the fall. But proximity of timing does not prove cause and effect, as any crime show buff knows.

Past Long Island Sound lobster mortalities had occurred, due to

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During trawl surveys by the Connecticut Department of Environmental Protection, characteristics and measurements of lobsters caught are recorded in order to assess the population dynamics.

some anomalous environmental factor or disease, but not on such a huge scale. The average temperature of the Sound has been rising in recent years, and in 1999 it stayed warm for a long time. Low dissolved oxygen in the Western Sound in late summer, made worse by warm waters and lack of mixing, has been a chronic problem since the 1980's. Changes in sediments, potential toxic substances, and disease pathogens also warranted careful examination.

Indeed, early on, a killer was found. University of Connecticut pathologist Richard French found the culprit, a paramoeba (a microscopic parasitic organism) during autopsies of dead lobsters. Like any grotesque movie alien, the paramoeba somehow gained internal entree to the lobsters' bodies, then "ate" through their nervous systems, making them limp, then blind, then finally engulfing their brains for the final blow. All lobsters autopsied by UConn scientists in 1999 had paramoeba; all sick, lethargic lobsters died within 24 hours and were subsequently found to have paramoeba.

All this was determined early on. But too many vexing questions remained. Was this paramoeba new to the Sound? Had it been there all along, and if so, what had changed? Or was the tiny beast a secondary cause of the mortality? In other words, did something else weaken the lobsters so that the paramoeba was able to infect and kill them, like the way pneumonia or AIDS can ravage a human's immune system to the point were something else brings about the final blow?

As if all that wasn't bad enough, other nasty, odd things were happening. Lobsters in the eastern Sound, and further north in New England, increasingly afflicted with "shell disease". Lobstermen also reported a new phenomenon: "eggers", or female, egg-bearing lobsters, prematurely shedding their shells. Ordinarily the molt would not occur until the eggs had been released for hatching. It was decided that while the research initiative was formed to look into the Western Long Island Sound mass mortality, these aspects should be included too. (see article, p.5)

Once the fishery was declared a disaster by then Secretary of Commerce William M. Daley, at the behest of the Governors of Connecticut and New York, $13.9 million in federal funds was allocated for research into the mortalities, and for lobster industry relief. The State of Connecticut added another million to the "lobster pot". The Atlantic States Marine Fisheries Commission established a Lobster Steering Committee, and under its auspices a Lobster Management Board was formed. Members included representatives from ASMFC, the two state environmental agencies, the Sea Grant programs of the two states, N.O.A.A. fisheries, U.S.E.P.A., the National Sea Grant Program, and two representatives for the lobster industry.

Scientists nationwide competed for grants to participate in the effort, culminating in the formation of several research teams, each investigating a different piece of the puzzle. The resulting team of scientists, involving at least 17 projects in 30 institutions, knew that things were happening in the Long Island Sound environment that might have caused, or contributed to, the lobster deaths.

"We asked the scientists to look into how some recent extremes in certain environmental parameters might have impacted the lobsters and made them more susceptible to disease," said Edward C. Monahan, Connecticut Sea Grant Director.

The teams looked at pesticides, toxic substances, pathogens and disease, the movements of substances in the water column, and a suite of environmental parameters such as temperature, salinity, oxygen, storm events, and sediments. Regular meetings were held each year; first, a meeting for the scientists to pool their observations and collectively discuss what they were seeing and swap ideas, followed by a second, public symposium to report progress.

At every step, lobstermen were included and contributed both observations and valuable suggestions. This went on for four years, with the last formal symposium held on October 4, 2004.

Simultaneously, litigation was ongoing. Lobstermen of the two states sued several pesticide

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Sylvain DeGuise, a UConn pathologist and veterinary scientist, prepares to draw blood from a healthy lobster to test the effects of malathion.

manufacturers, alleging that their products had harmed the lobster industry.

When preliminary results were presented, it was clear that lobsters were more sensitive to all three of the pesticides—malathion, pyrethrins, and methoprene—than other organisms previously evaluated. Tiny amounts, much less than the proverbial drop in the bucket, were lethal in the laboratory. That made perfect sense because, after all, crustaceans and insects are closely biologically related; "cousins" on the evolutionary family tree.

In fact, Sea Grant research by Hans Laufer's University of Connecticut laboratory back in the 1980's warned that the molecules of some insecticides were chemically similar to growth hormones found in both insects and crustaceans. Something that interfered with insect metabolism or reproduction, then, might logically interfere with the same processes in crustaceans, such as lobsters, crabs, and shrimp. Levels of those same hormones also trigger or inhibit molting, egg development, and behavior.

This finding was seized upon by some as positive evidence that pesticides had killed the lobsters. However, just as crime show aficionados know that a suspect has to be physically placed at the scene of the crime to be convicted, to say that pesticides had harmed Long Island Sound lobsters would require demonstrating that pesticides had indeed been present where lobsters live. No one could say for sure whether or not pesticides had, in fact, ever reached the lobsters, which live in burrows or cobbles of rock on the bottom of the Sound. Efforts ensued to find out how much and which pesticide was used where, how fast pesticides decayed in air and water, and how much if any might have actually reached the bottom waters. It was a task tougher than anyone imagined. Record-keeping methods of pesticide applications were different–kept by the State in New York; kept by towns and cities, and the DEP after 1999 in Connecticut. Adding to the complexity, trade brands and concentrations used varied from site to site.

Labels on the pesticides warned that they were not to be applied in or near water bodies, so manufacturers claimed that their instructions for use were not followed. A skeptic might argue that it's hard to find mosquitoes away from water bodies. To add fuel to the fire, endocrine disrupting chemicals, which include some pesticides, were being blamed for deformities in frogs and reproductive anomalies in fish. Those who applied pesticides considered it essential, given the human health threat of the West Nile and Eastern Equine Encephalitis viruses carried by mosquitoes.

Meanwhile, other investigators were putting together a huge patchwork of data on water temperatures, chemical reactions in sediments, oxygen measurements, rainfall, and so on to get the big environmental picture. The extended warm temperatures, that research team concluded, was probably enough to weaken and maybe kill the lobsters alone. But it also made just about everything else worse. Shell disease was exacerbated at higher temperatures; oxygen depleted more; even the potential effects of pesticides were heightened by warming. Some investigators found that the very bottom sediments, where lobsters live, were exuding higher levels of sulfides and ammonia.

"In the absence of bacterial infections, temperature of 24°C alone will not kill lobsters as long as oxygen levels are high," Richard Robohm, a researcher at the NOAA National Marine Fisheries Service, Milford Laboratory, reported for the lobster physiology team. "Adding hypoxia at this temperature, however, kills 90% of disease-free lobsters in 8 days. Add sulfides and ammonia and mortality was 100% within 4 days."--so it would seem the prime mover was nature, as well as any human influence on eutrophication as well as local and/or global warming. Now add the paramoeba.

What about the original suspect? A "John Doe" of parasites for a while, the paramoeba, like some crime suspects, proved elusive to name. It was, to date, also impossible to culture. It was finally painstakingly identified through its DNA as a species of *Neoparamoeba*, a one-celled protozoan, and then further narrowed to a strain of *N. pemaquidensis*, the same culprit fingered as the cause of gray crab disease.

While some scientists insist that this beast alone could have killed the lobsters, most agree that it was the whole soup of factors, a "Perfect Storm" of conditions coming together, to form a worst-case scenario for the lobsters.

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"Perfect Storm, I'd call it 'Perfect *Warm*'" said Carmela Cuomo, a researcher affiliated with Yale University and the University of New Haven. Cuomo's team identified the unusually high levels of sulfides and ammonia in that bottom inch or so water-sediment interface, a micro-habitat seldom examined by sampling equipment.

The warmer waters, Cuomo's group believes, caused the unusually high emissions, which also contributed to weakening the lobsters' immune functions. Bottom temperatures between August and October went from about 19.2°C average in 1998 to 20.3 in 1999, a warming of about 2.2°F.

Is this warming of Long Island Sound a one-time phenomenon? No one can say for sure but it's not out of line with what's happening nationally. Despite our clinging to gloves and hats into March with this abundant snowfall in the Northeast, this winter (2004-2005) was nonetheless the tenth warmest on record for the United States, according to scientists at the NOAA National Climatic Data Center in North Carolina.

Nationwide, temperatures between December and February were much above normal, bringing dry conditions in the Northwest and abnormally heavy rains and mudslides to the Southwest. NOAA reports that the average temperature for the contiguous United States this winter was 35.9 (2.2 degrees C), which was 2.8 degrees F (1.6 degrees C) above the 1895-2004 mean. The mean temperature in 39 states was above average. Thus the average rise in temperature nationally is very similar to the extent of warming in Long Island Sound. This does not bode well for cold-water species.

"'Perfect *Storm*'–I'd call it 'Perfect *Warm*'!"
–Carmela Cuomo, UNH

Despite the clear evidence implicating temperature as the overriding factor in the lobster deaths, even today some resolutely insist the pesticides had to have killed the lobsters in 1999. A cliff-hanger for what was billed as the finale of the four-year research effort, the Lobster Health Symposium organized by Sea Grant and held at the State University of New York in October 2004, was the results of the pesticide modeling group. Hydroqual, Inc., an engineering firm, was contracted to pool and bin all of the pesticide group's data, and incorporate it into a complex computer model that would take into account many parameters, to show how much pesticide, or other materials, actually ended up at the bottom of Long Island Sound, in what concentration, and where.

Cliff-hanger, because by the time the modelers got all of the information they needed, they had to work non-stop up till the last minute to compile and enter it all, and run the model. Such models make predictions of what most likely happened, given the most complete information they can get from a variety of sources. The model suggested that pesticides were, at most, a minor player in the lobster mortalities.

Of the pesticides examined, only one, sumethrin, was shown to be even a small localized factor. Sumethrin and resmethrin are pyrethroids, thought by some to be an "environmentally-friendly" choice because they are synthethic versions of natural pesticides found in chrysanthemums. The commercial version, however, is highly concentrated and much more potent.

The pesticides applied break down very rapidly, and so decayed as they sank before reaching the bottom. The pesticides were not applied directly to the Sound, either, but models conservatively assumed that all the pesticides applied actually reached the Sound, an unrealistic scenario. Whether pesticides sprayed aerially in marsh areas had any effect on any marsh-dwelling crustaceans was not investigated in this effort.

"Other than the 'answer' to the problem, the most valuable thing to come out of the lobster research initiative is the tremendous collaboration of all these researchers from around the country, sharing information that strengthened the projects and will probably lead to future collaborations" said Nancy Balcom.

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"Culls," lobsters missing a claw, could be released and regenerate a new claw. Sea Grant research shows that such lobsters are at a disadvantage in that they may not be able to fend off their aggressive male competitors until the new claw grows.

Michael Horst, Mercer University School of Medicine, is one of a huge team of scientists at more than 30 institutions funded via Sea Grant who contributed to the Long Island Sound lobster research effort

Working with lobstermen is nothing new to Balcom, who has been a Sea Grant Extension educator for 16 years, and is now Connecticut's outreach liaison between the industry and academia.

"I have a huge amount of respect for those guys," Balcom said. "They have such broad experience on the water, and are in an industry that they love. They have a tough job, and many have hung in there, raising issues and suggesting ideas to restore lobsters to Long Island Sound." For example, one lobsterman came up with the idea of throwing back "culls" –less desirable animals for market because of flaws such as a missing claw–so that they can continue to reproduce. This measure is one of a range of management options now being considered to help restore the population.

"This initiative worked better than anyone expected because all of the people involved were so responsive," Balcom said. Because periodic reporting on progress was part of the requirements for the funding, the research was an unusually public effort, in which the scientists themselves were in a sense put under the microscope. They were asked to produce quickly, and to share their preliminary results before publication, and were frequently called by reporters to provide off-the-cuff statements.

"The tight follow-up and required reporting structure forced integration between laboratories," agreed Sylvain DeGuise, a University of Connecticut pathologist, "and the discussion at ongoing assessment meetings allowed researchers to fill in the gaps and synthesize our findings."

Lobstermen Mike Theiler and Bart Mansi believe that more specifically localized management could help prevent die-offs like the Long Island Sound disaster. They suggest that when LIS lobster populations reached an all-time maximum, in the year or two before the die-off, allowing larger sizes to be harvested would have alleviated problems of overcrowding, which probably contributed to the stress and spread of disease.

"Predator-prey relationships are a very delicate balance in an ecosystem," Theiler says, "and when they get out of whack it's very bad." He believes that increased harvesting of lobsters when they were in their heyday would probably have increased the fish populations too. But management decisions are presently made on a broad regional basis, not specific to any one body of water, even one as large and as unique as Long Island Sound.

Long Island Sound lobsters are distinctive in that they tend to remain in the Sound, without much migration happening. Their life cycle is quite different than that of the offshore lobsters beyond the Sound; they are smaller, don't live as long (about 5-7 years, compared to 35-50), and reproduce less frequently. Larval lobster production counts, also at a peak just before the 1999 event, have been extremely low since the die-off, although some lobstermen report finding large masses of larvae in the stomachs of the now-increasing predator fish. Population rebuilding will be hindered by the lack of immigration of lobsters into the Sound.

Lobster restoration and stock enhancement efforts using juveniles raised in hatcheries have been tried before in many locations, but generally have failed. Incomplete understanding of all life stages has been one factor, and the "free lunch" principle another. Any organisms grown in relative isolation and then dumped into "the drink" without having learned escape behavior skills, quickly become munchies for eager predators.

There are still many things we don't know about lobsters, considering their value as a resource. However, while the results of the investigation into the Long Island Sound lobster mortality might not please everyone, it's clear that we now know much more about them. We know a lot more about lobster physiology and pesticide tolerances and effects. We know how LIS lobsters differ from others. We know more about the characteristics of the bottom of Long Island Sound, particularly where the sediment meets water. We know more about the causes of shell disease and how it progresses. Scientists have new tools in their technology toolboxes, to measure various parameters, identify diseases, and to detect substances flowing in water.

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A new disease of the lobster immune system, calcinosis, was discovered and described by scientist Alistair Dove, and a new Marine Sciences pathobiology facility was established at Stonybrook University on Long Island.

New insights were gained into the life cycle of Long Island Sound lobsters and how it differs from their offshore relatives. Much of the new knowledge may be used by decision-makers as well as biologists in the future.

We know now that manganese can be used as a proxy to measure the extent of hypoxia experienced by lobsters, because it accumulates in their gills over time during periods of oxygen deprivation. Scientists say that a level of 100 parts per million (ppm) of manganese in lobster tissues would indicate a potential for catastrophe. Lobsters tested from pristine waters in the Faeroe Islands and southwest Sweden had only 8 to 80 ppm, whereas Western Long Island Sound lobsters had about 300 ppm in their gills, the scientists say. Lobster blood, which is blue, changes chemically in the late summer. Higher temperatures, at least in the lab, stress lobsters by reducing the blood cells' ability to attack disease-causing organisms.

Left, ripe lobster eggs released by a "berried" female; right, a young lobster in one of the larval stages. Reprinted from "Lobster Health News", ASMFC, CT/NY Sea Grant.

This wealth of new discoveries will prove valuable if and when the lobster population of Long Island Sound begins to come back, as well as to the lobster industry in other locales.

Surely, the lobster saga serves as a clear example that temperature warming is having very specific effects on cold-water metabolic organisms in our region. If continued prolonged summer warming doesn't allow the Long Island Sound lobsters to rebound, then at least we can understand that the ranges of these animals really are moving north, as predicted by climate scientists.

–PVP

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