Validating landscape models for mercury in northeast lakes using dragonfly nymphs as mercury bio-sentinels

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Collaborators and Affiliations: Bill Zoellick, Schoodic Institute

Completion date: October 31, 2014

Brief: Dragonfly larvae mercury was mostly in the methyl form (88%) supporting their use as bio-sentinels but there was not a strong link between dragonfly mercury and water mercury. Dragonfly data should be evaluated statistically against fish mercury concentrations to evaluate their use as a less destructive bio-sentinel suited for refining fish advisories.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service. http://www.nsrcforest.org

Project Summary

Mercury (Hg) is a toxic pollutant that is widespread in northeastern US ecosystems. Resource managers' efforts to develop fish consumption advisories for humans and to focus conservation efforts for fish-eating wildlife are hampered by significant variability in fish Hg concentrations from site to site – often in neighboring lakes. Watershed characteristics that vary across the Northeast such as forest type and wetlands are important predictors of methylation. Although data syntheses leading to hotspot maps (e.g., Evers et al. 2007) and sensitivity modeling have been conducted (Krabbenhoft et al. 2011), we still lack studies that use sentinel biota and have statistically rigorous sampling designs across the broad region. Fish Hg concentrations are most often used as biological indicators of Hg sensitivity in lakes; however, fish may move between waterbodies and interpretation can be confounded by size, species, diet, gender, and age. This project sampled lake water and a bio-sentinel, dragonfly larvae, in a statistical sample of 74 lakes that are part of US EPA long-term monitoring across the region to (1) test models for prediction of Hg and MeHg in water, and (2) determine the efficacy of this bio-sentinel in predicting sensitivity to Hg across the region. In the Upper Midwest, MeHg in dragonfly larvae was significantly, positively correlated with THg in perch (Knights et al. 2005) and researchers concluded that dragonfly larvae were promising bio-sentinels in that region (Haro et al. 2013). We hypothesized that dragonfly larvae are good indicators of Hg spatial patterns because they are widespread in freshwaters across this region, long-lived (1–5 years or more), exhibit site fidelity, are carnivorous, contain almost all of their Hg as MeHg, and have relatively high Hg concentrations. The project leveraged ongoing research at a statistical sample of 74 lakes across New England states and New York, sampled annually by cooperators in the US Environmental Protection Agency (EPA) Long-Term Monitoring (LTM) Network.

East Branch Lake. Maine

Why mercury?

- Mercury (Hg) is delivered to Northern Forest ecosystems via deposition from both short and long range atmospheric emission sources, and ultimately bioaccumulates in aquatic and terrestrial foodwebs.
- All New England states have statewide fish consumption advisories, and New York has advisories on specific waterbodies and regions (US EPA 2010).
  - Recent sensitivity modeling in progress by the US Geological Survey indicates that portions of the northern forest region are among the most sensitive to Hg in the US (Krabbenhoft et al. 2011).
  - Mercury deposition from the atmosphere is somewhat elevated in the Northeast as compared to western US states, but chemical variables such as dissolved organic carbon, pH, and sulfate (SO_4) plus wetland extent are the most important determinants of sensitivity to Hg methylation, the process by which Hg becomes toxic and can be bioaccumulated by biota (Wiener et al. 2006).
- This project determined how Hg and methylmercury (MeHg) vary in lakes across the Northeast landscape, and provides predictions for Hg and MeHg in lakes and biota because of the statistical sampling design.

Why bio-sentinels?

- Mercury fish consumption advisories in most northeastern states are statewide, rather than specific to certain water bodies, because of the difficulty in distinguishing which systems are most affected – in other words, there is great spatial variability in mercury concentrations in water and fish.
- Although data syntheses leading to hotspot maps and sensitivity modeling have been conducted, we still lack studies that use sentinel biota and have statistically rigorous sampling designs across the broad region during a single late-summer index period.

  For example, fish were sampled nationwide in 500 lakes during 2000-2003 by US EPA (US EPA 2009); however, fish may move between waterbodies and confounding factors such as size, species, diet, gender, and age can be controlled for but require several assumptions.

Somerset Reservoir, VT; Photo A. Baumann

Why dragonflies?

We proposed that dragonfly larvae are useful Hg bio-sentinels because they:

1. are **widespread** and found in most surface waters in the region,
2. are **long-lived** and **predacious** in aquatic systems (1-5 years as nymphs),
3. exhibit **site fidelity**,
4. are important **prey species** for fish (e.g., Haines *et al.* 2002),
5. contain virtually all Hg in the **MeHg form** (Mason *et al.* 2000, Haines *et al.* 2002, Gorski *et al.* 2003; and this study)
6. and are **simple** to capture, process, and analyze at **meaningful** Hg concentrations.

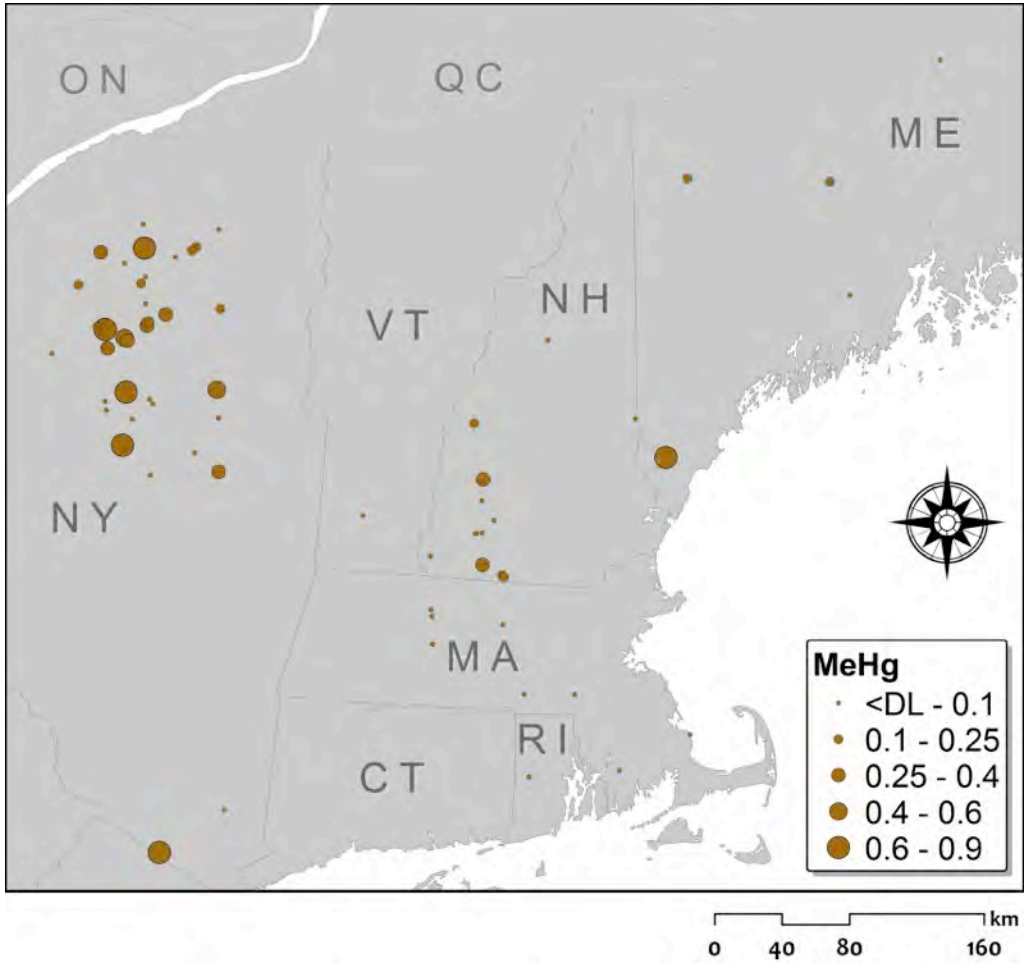
To date, there is no single biosentinel of Hg and MeHg exposure across aquatic ecosystems that can be linked to actual concentrations of THg or MeHg in surface waters. This project makes those connections in an efficient and cost-effective way, by leveraging existing sampling effort (US EPA long-term monitoring network) that took place in a statistical population of northeast lakes in the Northern Forest region.

Sampling sites

- 74 US EPA LTM Network (long-term monitoring) lakes across New England and New York (Fig. 2).
- This lake set (called "TIME") is a statistical population of acid-sensitive lakes, a subset of EMAP lakes (Young and Stoddard 1996).

http://www.epa.gov/airmarkets/assessments/TIMELTM.html

Map: Locations of 74 LTM Network TIME lakes. Dots show concentrations of MeHg in lake water, in ng/L.



Sampling: lake water & dragonfly larvae

Sampled during late summer index period, July–September 2012

- Full water chemistry (major ions, DOC, pH, ANC) in water
- THg and MeHg in water
- Dragonfly larvae netted and individually bagged on site using clean techniques for Hg

Laboratory analyses

At Dartmouth:

- Dragonfly individuals identified to family and measured (length, wet weight, dry weight)
  - To reduce the potentially confounding influence of dragonfly family, we selected individuals (n=10 per lake) from families Corduliidae and Libellulidae, which were found in all but one sampled lake
- Larvae analyzed for THg using a Milestone DMA80 or GC-ICPMS (small samples; cross-comparison with overlap samples)
- Water and a subset of larvae speciated (inorganic and MeHg) using GC-ICPMS

At the University of New Hampshire:

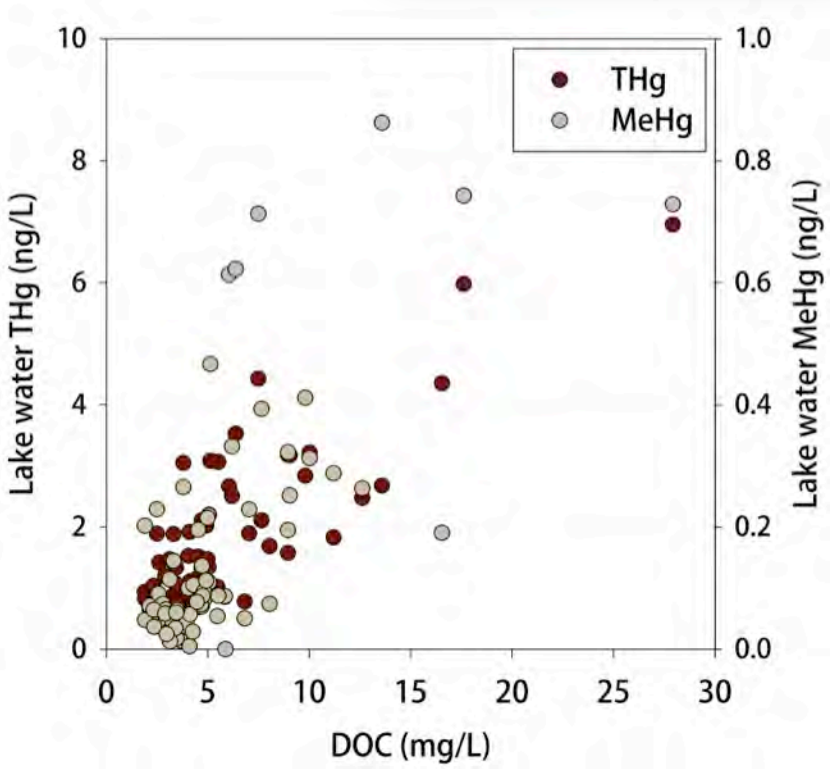
- Lake water analyzed for major ion and acid-base chemistry as part of ongoing US EPA LTM Network research

Photos: Examples of Libellulidae (top two photos) and Corduliidae (bottom photo) dragonfly larvae, target families in this research. These are exuviae (shed exoskeletons). *Photos: A. Anderson, Kingfisher Photography, Old Town, ME*

Water chemistry

- Inorganic and MeHg were strongly positively correlated across the set of all lakes (Pearson's R=0.78)*
- The strongest correlations were between THg and DOC in lake water (Pearson's R=0.81)*
- By region:

  THg in water was more strongly correlated with DOC in the New England set of lakes (R=0.85, n=31) as compared to the Adirondack set of lakes (R=0.72, n=42)*



** Correlations computed on log-transformed variables.*

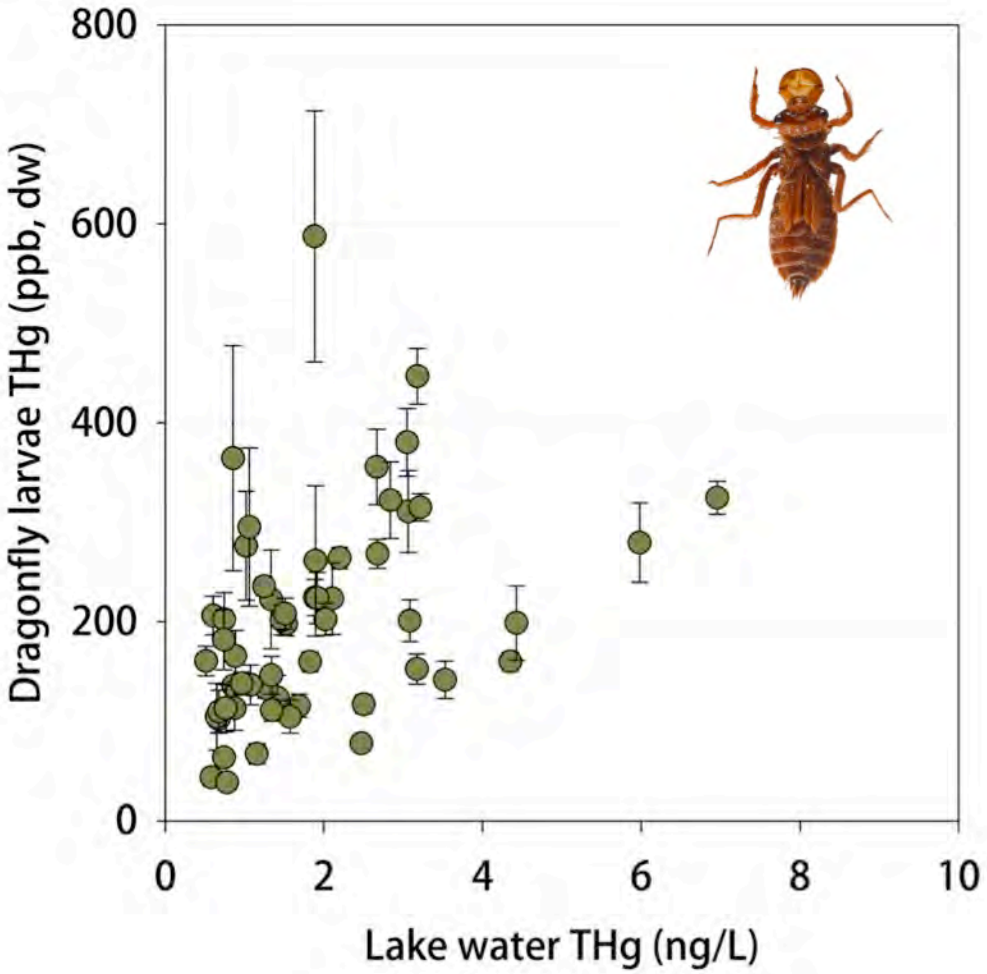
Mercury in dragonfly larvae

- THg: Mean=188±118 ppb, dw (n=427, *representing 640 individuals, some pooled*)

- We analyzed a subset of three larvae from each lake for both MeHg and THg.
  - MeHg: Mean=189±137 ppb, dw (n=172)
  - MeHg was 88±12% of total Hg (n=122)

Thus, THg is a good proxy for MeHg in dragonfly larvae in these northeastern lakes

Mercury in dragonfly larvae



Does THg in lakewater influence Hg in dragonfly larvae? The strongest correlation of the suite of chemical variables was between lakewater THg and dragonfly larvae Hg (R=0.48). The lack of strong relationships with water chemistry suggests de-coupling of water chemistry from biotic concentrations.

Feature story & video, UMaine Today:
Hewitt, R., Spring 2013. Sentinel Species. UMaine Today cover article plus related video. Available: https://umainetoday.umaine.edu/past-issues/spring-2013/sentinel-species/

Sentinel species

Dragonflies aiding mercury monitoring research in freshwater ecosystems

By Rich Hewitt

Microscope lunar images by Ed Lindley

IN THE PASTORAL settings of freshwater ecosystems, dragonflies buzz and flit through the grasses and floating plants of ponds and lakes. But an up-close look at the larvae of these wetland predators brings images from *Alien* and other sci-fi horror films to mind.

Large, bulbous eyes. Six spindly legs on a somewhat short, slightly stubby body. Gills in their abdomens to breathe. A lower jaw-like feature that's more like an extendible weapon, shooting out in an instant to grab something edible as it passes by.

And they eat just about anything that moves — from mosquito larvae and tadpoles to small fish. Even other dragonfly larvae.

Indeed, dragonflies spend most of their lives as larvae — up to five years. The larvae hatch from eggs in the water, grasses or mud, grow up to 2 inches long and molt repeatedly before developing wings and taking flight.

That aquatic existence is what endears dragonflies to biogeochemist Sarah Nelson, who studies the insects as bio-sentinels of mercury in freshwater ecosystems.

Nelson, a scientist at the Senator George J. Mitchell Center and the School of Forest Resources at the University of Maine, has been researching mercury in the environment since she first walked onto the Orono campus as a graduate student. Building on a long history of mercury research at UMaine, she is now the primary investigator for several studies regarding mercury, including research involving dragonfly larvae.

At the same time, she has worked with other agencies and organizations to develop educational programs that put teachers, students and citizen scientists into the field as frontline researchers.

Armed only with hip waders and dip nets, students from schools throughout New England regularly go searching for dragonfly larvae under Nelson's guidance. They are not only discovering science, she says, but also are participating in meaningful research that has bolstered the work being done by professional scientists. Dragonfly larvae are easy to identify and it doesn't take the students long, as one of their teachers put it, to "get their dragonfly eyes on."

"They know what they're looking for," Nelson says. "It's hard to get them out of the stream. They go out and bring back what they find on the stream bottom, and they're just amazed at the critters they see. That's a great place-based learning outcome in its own right."

IT WAS DURING a student program, in fact, that Nelson first had an inkling that dragonfly larvae might be a good indicator species for high mercury levels. She had worked with Bill Zoellick at the Schoodic Education and Research Center (SERC) Institute at Acadia National Park, Maine Sea Grant and Dartmouth College to develop a program now called Acadia Learning. It put students through what Nelson characterizes as a "mini-masters" research project in which they develop hypotheses, collect data, interpret results, and present their findings. They were working to identify mercury concentrations in invertebrates when students at one school noticed that mercury levels in their specimens were always higher than in those collected by students at another school.

Nelson says she also noticed that students at all of the schools in the

Results/Outreach

THE PATS' CHALLENGE
MIKE LOWE BREAKS IT DOWN, C1

MAINE/NEW ENGLAND
He's got plenty to fight for / B1

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WEATHER: Showers early, then cloudy and windy
High 69
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State struggles to reduce threat of home heating oil spills

Despite stricter rules and better technology, factors hinder progress in Maine, which sees hundreds of leaks every year.

By TUX TURKEL
Staff Writer

The cold night air that swept into Maine late last week was a reminder that another heating season is bearing down, and for a few unlucky homeowners, filling up the oil tank this fall will have disastrous results: a costly and damaging leak or spill.

Every year, between 450 and 500 home heating oil spills are recorded in Maine, a number that has not declined since 1998, when the state launched a program to replace leaking or unsafe tanks.

More than 7,000 tanks have been replaced under the program, which is expected to cost $800,000 this year, with the funds coming from a surcharge on oil deliveries.

Over the years, more than a quarter million gallons of heating oil and kerosene have leaked or been spilled, according to state data compiled for the Maine Sunday Telegram, despite the fact that heating system installation rules have become stricter and tank technology has improved.

INSIDE
IS YOUR TANK SAFE? CHECK OUT OUR GRAPHICS, A8-9

New tanks and new technologies offer a way to reduce spills and leaks, but state officials have been reluctant to impose new requirements because of concerns about the costs. That has left improvements in the hands of the private sector,

Please see TANKS, Page A8

Gordon Chibroski/Staff Photographer

SIDEBAR INSIDE
A property in West Bath, left, where a kerosene spill required extensive cleanup and aging oil tanks needed to be replaced, exemplifies how quickly costs can mount. Read more, Page A8

What are these animals telling us?

Because they are sensitive to change, so-called **'sentinel species'** can reveal a lot about the ripple effects of pollutants in our environment. And that, scientists say, serves as a warning about our own fragile future.

By NORTH CAIRN
Staff Writer

INTERACTIVE GRAPHIC
Check it out at pressherald.com

Working in Acadia National Park one recent morning, Sarah Nelson, a biological geochemist at the University of Maine, stood with her five assistants in boots and waders and jabbed at the sediment on the bottom of Hodgdon and Seal Cove ponds with long-handled nets.

Their target was dragonfly larvae, and the samples they took to a lab on campus would be identified, analyzed and finally incinerated.

In the ash they would measure concentrations of mercury, a toxic heavy metal that can wreak havoc on the environment and human health.

For researchers like Nelson, the dragonfly is not just an elegant insect with a voracious appetite for mosquito larvae. It's also a "sentinel" species, a stand-in for humans that provides clues to potentially harmful environmental conditions we otherwise might not notice.

Fifty years have passed since Rachel Carson first coined the term, but as human impacts on the planet multiply, scientists say it's still a critical concept for understanding changes in the environment.

"Long-term ecological research (on sentinel species) is absolutely required," said H. Bruce Rinker, director of scientific advancement at the Biodiversity Research Institute in Gorham. "In order for us to understand us, we need to look at other species."

The study of sentinel species goes back a long time, arguably to ancient times when the art of augury was practiced. By examining the entrails of certain animals, it was thought, the fate of emperors or the outcomes of battles could be predicted.

The classic sentinel species – at least in America – harks back to the mines of the 19th century. The expression "canary in the coal mine" – once employed to describe the process of releasing a small yellow bird into mine shafts to gauge air quality and the safety of miners – has become a linguistic fixture to illustrate how the fate of one species may portend the circumstances faced by others.

A miner who watched a canary flutter off and fall or head into a tunnel without returning knew not to enter the darkness himself. If the level of toxic gases – usually, carbon monoxide – could kill a bird, the theory held, they could hurt a man, too, or even kill.

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Photo credits: All images from Maine Sunday Telegram files except copepod, courtesy Gulf of Maine Research Institute; falcon, Reuters; and mantis, GNU free documentation license

In Congress, Syria looms over already busy agenda

Lawmakers return Monday, the president addresses the nation Tuesday, and an initial Senate vote is likely Wednesday – Sept. 11.

By ANDREW TAYLOR and DONNA CASSATA
The Associated Press

WASHINGTON — Congress returns to work facing a momentous vote on whether the United States should attack Syria, a question that overshadows an overcrowded and contentious agenda of budget fights, health care, farm policy and possible limits on the government's surveillance of millions of Americans.

Back Monday after a five-week break, many lawmakers found as a major obstacle to President Obama's promised strikes against Syria amid fears of U.S. involvement in an extended Mideast war and public fatigue after more than a decade of conflicts in Iraq and Afghanistan.

Obama insists the world must act. He blames Syrian President Bashar Assad for gassing his own people, killing 1,429 civilians, including 426 children. The Syrian government has denied responsibility for the Aug. 21 chemical weapons attack outside Damascus, and blames rebels.

On Wednesday, the 12th anniversary of the Sept. 11 terrorist attacks, the first showdown Senate vote is likely over a resolution authorizing the "limited and specified use" of U.S. armed forces against Syria for no more than 90 days and barring American ground troops from combat. A final vote in the chamber is expected at week's end.

"I think we're going to get 60 votes. It's a work in progress," Senate Majority Leader Harry Reid, D-Nev., said Friday.

Support for the president is stronger

Please see SYRIA, Page A12

INSIDE
In U.S. cities, protesters oppose strike on Syria, A12
Vote carries political risks for Maine's delegates, B1

THE FISHERMAN'S TALE

A life lived large ends in a sea of questions

A friend who was with him on his last night talks about Billy McIntire's ill-fated swim, and the 'toughest decision of my life.'

By MATT BYRNE
Staff Writer

OGUNQUIT— In the life and times of Billy McIntire, it was hardly an unusual sight.

Before midnight under a nearly full moon, McIntire – a consummate hard worker with a jovial reputation and a penchant for having a good time – was heading for his boat, three women and a friend in tow.

In the days since his death that night, the few witnesses who know firsthand how McIntire was lost have largely remained silent or have all but left town, only fueling rumors and speculation about his final moments.

VIDEO
pressherald.com

"None of this should have happened," said Tim Levesque, who set off with McIntire that night, along with the three women, whom they had met at a bar. After a night of drinks and dancing, they headed to the first boat McIntire had ever owned, the Clover.

The night ended with McIntire lost at sea. He remains missing and presumably drowned.

McIntire, 51, partied harder, fished longer and landed more monsters, often in second-rate boats, than almost anyone else he knew. And he knew everyone worth knowing in this seaside town, and was a boisterous, gleeful presence in the lives of nearly all of them.

After a lifetime spent at sea, McIntire was comfortable operating in the harshest of conditions, often fishing more than 100 miles from shore for as long as a week in search of a prize-winning tuna. But on the night he disappeared, the waves were calm, the skies were clear.

Please see McINTIRE, Page A10

Contributed photo

Fisherman Billy McIntire, shown at work in 2008, is presumed drowned after diving off his lobster boat late in the evening of Aug. 22, investigators say. His body has yet to be recovered.

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Maine Sunday Telegram cover story:

Cairn, N., Sept. 8, 2013. What are these animals telling us? Available: http://www.pressherald.com/news/what-are-these-animals-telling-us_2013-09-08.html?searchterm=north+cairn; Plus interactive feature: http://www.pressherald.com/news/projects/interactive-sentinel-species_2013-09-08.html

Results/Outreach

Scientists Study Mercury Pollution With Dragonfly Larvae

The Adirondack Lakes Survey Corporation (ALSC) recently completed collections of dragonfly larvae in acid rain sensitive Adirondack surface waters in a new study of mercury pollution.

ALSC staff assisted Dr. Sarah Nelson of the University of Maine Mitchell Center and School of Forest Resources, and collaborators at the SERC Institute, Maine Sea Grant , the USGS Mercury Research Lab, and Dartmouth College, who have been developing the concept of using dragonfly larvae as bio-sentinels for mercury concentrations in northeast lakes and streams. Dragonfly larvae or immature dragonflies live in the water for the first year or years of their lives.
"This project easily fit our mission as an organization," says James Dukett, Program Manager for the ALSC. "We were happy to participate, and look forward to Dr. Nelson's mercury analysis of dragonfly larvae."

The project will study dragonfly larvae mercury and lake water mercury in a statistical set of lakes across the Northeast (New England states plus New York).

"Our work has been using dragonfly larvae as bio-sentinels – to help us understand which types of watersheds and waterbodies seem to have greater mercury," Nelson said. "The work will help us understand if we can model mercury sensitivity in lakes and their food webs, and if dragonfly larvae are good indicators of that sensitivity."

Mercury is a natural element but is found in elevated levels locally, largely due to fossil fuel emissions in the mid-west. Mercury travels far in the atmosphere and often lands in remote locations worldwide far fro m it's source.

The lakes that were sampled are part of the ALSC's Adirondack Long-Term Monitoring program, which receives support from the New York State Energy Research Development Authority, New York State Department of Environmental Conservation, and the United States Environmental Protection Agency.

The ALSC is a 501c3 nonprofit organization with headquarters in Ray Brook, New York. The ALSC

ALSC involvement in Adirondacks:

Warren, J. Oct. 17, 2012. Scientists Study Mercury Pollution With Dragonfly Larvae. Adirondack Almanac, available: http://www.adirondackalmanack.com/2012/10/adirondack-lakes-survey-conducting-murcury-study.html

--, Oct. 16, 2012. ALSC Participates in Study on Mercury Deposition. Adirondack Base Camp, Available: http://www.adirondackbasecamp.com/2012/10/alsc-mercury-deposition/

Lynch, M., Oct. 10, 2012. Dragonfly larvae part of mercury study. Adironadack Daily Enterprise, available: http://www.adirondackdailyenterprise.com/page/content.detail/id/533545/Dragonfly-larvae-part-of-mercury-study.html?nav=5046

--, Oct. 10, 2012. Adirondack dragonflies tested for mercury contamination in mountain waters. North Country Now, available: http://northcountrynow.com/news/adirondack-dragonflies-tested-mercury-contamination-mountain-waters-069142

Linkage to earlier NSRC research

Earlier NSRC-funded research compiled a database of Hg in biota across the Northeast, and identified biological Hg ‘hotspots’ (Evers et al. 2007).

This research project is based on statistical sampling of a population of northeast lakes that are regularly sampled as part of US Environmental Protection Agency (EPA) monitoring, and a single bio-sentinel species.

Thus, the work complements and expands the previous NSRC-funded research.

Mountain Pond, Maine

Dragonfly larvae as bio-sentinels

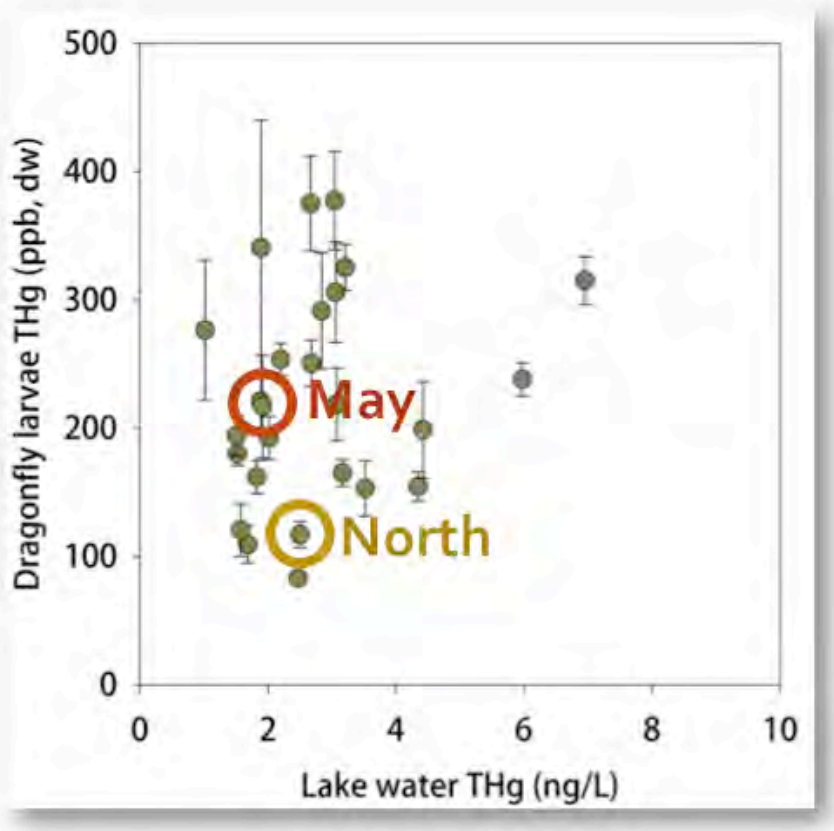
- Dragonfly larvae Hg was mostly MeHg (88%), supporting their use as bio-sentinels.
- Dragonfly larvae were found in almost all lakes, and during a short timeframe (30-45 minute sampling period per lake).
- Few published studies have reported concentrations of Hg in dragonfly nymphs, but some recent studies report correlation of Hg and methylmercury (MeHg) concentrations in prey - including dragonfly nymphs - with fish concentrations (Haines *et al.* 2002; Knights *et al.* 2005; Ward *et al.* 2009, 2010; Haro et al. 2013).

Implications & Application

Water chemistry and mercury

- DOC, THg, and MeHg in surface waters were correlated, supporting current hypotheses about controls on transport and methylation (e.g. Krabbenhoft *et al.* 2011, Driscoll *et al.* 2007).
- Water Hg does not predict biota Hg. Multivariate analyses are being used to evaluate confidence in high and low Hg in water and in dragonfly sentinels.
- Dragonfly larval Hg highlights lakes with known fish Hg issues, whereas water Hg concentrations do not.

For example, May Pond (which has a specific waterbody advisory for Hg) had moderate water THg and MeHg, but higher dragonfly THg (~200 ppb); neighboring—and eutrophic—North Pond (in the same NH State Park) had higher water THg, but ~100 ppb THg in dragonflies.



Future directions

- The project provides baseline data for Hg in water and dragonfly larvae in lakes across the region. Following implementation of emissions reductions regulations, these lakes can be re-sampled to determine how changes in emissions affect mercury in water and foodwebs.

- The project contributed approaches and ideas to newly-funded research that expands the geographic scope of this line of inquiry nationwide, through sampling 50 national parks. See: http://www.nature.nps.gov/air/studies/air_toxics/dragonfly/index.cfm

Products

Peer-reviewed publications

S.J. Nelson, C.Y. Chen, D.P. Krabbenhoft, et al. Beyond "hotspots" – dragonfly bio-sentinels describe vulnerability (or not) of northeastern lakes and their foodwebs to mercury accumulation. In prep. for submission December 2014.

Other publications

Nelson, S.J., A.J. Baumann, A. Coffin, K. Johnson, C. Schmitt. 2013. Lake Site Assessments: US EPA TIME-New England Lakes. Report to US EPA-CAMD, May 24, 2013.

Seminars

Nelson, S.J., E. Lindsey, A. Baron, C. Flanagan. Dragonfly larvae as sentinels of mercury contamination in Maine and beyond. Merryspring Nature Center lecture series, May 6, 2014.

Nelson, S.J., E. Lindsey, A. Baron, C. Flanagan. Dragonfly larvae as sentinels of mercury contamination in Maine and beyond. Edith Patch seminar series, Old Town, ME, October 26, 2013.

Nelson, S.J. Are you where you live or what you eat? Developing dragonfly larvae as bio-sentinels for mercury. Keynote lecture; Twin States Mercury Project, Dartmouth College, Hanover, NH, February 15, 2012.

Products

Conference presentations

- Nelson, S.J., C. Chen, D.P. Krabbenhoft, J.S. Kahl, B. Zoellick, 2013. Validating landscape models for mercury in northeastern US lakes using dragonfly larvae as mercury bio-sentinels. ICMGP - International Conference on Mercury as a Global Pollutant, July 28- Aug. 3, 2013, Edinbugh, Scotland. (poster)
- Nelson, S.J., B. McDowell, S. Kahl, J. Saros, A. Baumann, K. Strock, I. Fernandez, 2013. Northern New England update. US EPA 2013 Cooperators' Meeting. Troy, NY, June 4-6, 2013.
- Nelson, S.J., C. Chen, D.P. Krabbenhoft, J.S. Kahl, 2013. Dragonfly larvae as mercury bio-sentinels: a statistical survey of northeast lakes reveals landscape-driven patterns in water and biota mercury concentrations. NERC (Northeastern Ecosystems Research Cooperative) meeting, March 19 – 20, 2013, Saratoga Springs, NY.
- Nelson, S.J., C. Chen, H. Roebuck, B. Zoellick. Sensible sentinels: Preliminary mercury data for dragonfly nymphs (*Odonata: anisoptera*) across northern New England corroborate expected spatial pattern. Acadia Science Symposium, October 26, 2011. (poster)
- Nelson, S.J., C. Chen, H. Roebuck, B. Zoellick. Sensible sentinels: Preliminary mercury data for dragonfly nymphs (*Odonata: anisoptera*) across northern New England corroborate expected spatial pattern. The 10th International Conference on Mercury as a Global Pollutant (ICMGP), Halifax, NS, July 24-29, 2011. (poster)

Products

Other tangible products

The following protocol was based, in part, on sampling protocols developed for this project:

Nelson, S.J., C. Flanagan. 2012. Sampling protocol for the collection of dragonfly larvae and water samples from National Parks for mercury analysis. March 2012.

Teachers involved in the Acadia Learning program helped develop pilot projects that contributed to this effort; they followed this research in teacher workshops and in classroom efforts: http://participatoryscience.org/project/mercury-watersheds

Popular press

See “Outreach Products”, above.

Products

Leveraged/follow-on grants

- USGS-NPS Water Quality Partnership ($300,000), Linking freshwater mercury concentrations in parks to risk factors and bio-sentinels: a national-scale research and citizen science partnership (C. Eagles-Smith, S.J. Nelson, D. Krabbenhoft, C. Chen. R. Haro). Funded August 2013.
- US National Park Service, Director's Office, ($72,000), Citizen Scientists Study Mercury in Dragonfly Larvae (Flanagan, C. and S.J. Nelson). Funded March 2013.
- UMaine Multiuser Equipment Initiative ($41,555), *Proposal to purchase a methyl mercury analyzer* (Aria Amirbahman, Rodney Bushway, Aram Calhoun, Cynthia Loftin, Sarah Nelson). Funded Spring 2012.
- University of Maine High End Instrumentation Research ($4,680) (S. Nelson, C. Devoy). Funded December 2011.
- University of Maine, Regular Faculty Research Funds. ($10,000), *Developing a citizen science program for mercury in National Parks: can dragonfly larvae both inform science and engage Park audiences?* (S. Nelson). Funded December 2011.

The **Adirondack Lakes Survey Corporation** sampled many Adirondack Lakes for water Hg and dragonfly larvae. They also provided logistical support for Maine-based crews sampling in the Adirondack region. Staff from **state and tribal resource management agencies** assisted with permitting and local contacts.

Acknowledgements

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