All along the watchtower: Larval dragonflies are promising biological sentinels for monitoring methylmercury contamination

By Roger J. Haro

Abstract

Humans have used other organisms to detect environmental danger for centuries (e.g., the canary in the coal mine). The use of "biosentinels" has developed and expanded to become a mainstay for monitoring environmental contaminants like methylmercury, a pervasive and largely anthropogenic neurotoxin. Biosentinels provide insights on how and where contaminants are entering and moving through aquatic food webs. Many water bodies in the Great Lakes region, including those in national park units, have fish-consumption advisories because of the atmospheric deposition of mercury and its conversion into methylmercury, which can biomagnify. For many years young yellow perch served as the principal biosentinel for monitoring methylmercury. Resent research shows that the diverse assemblage of dragonflies in this region can provide an additional suite of biosentinels, complementing the use of perch among water bodies with fish and expanding the reach of methylmercury monitoring to include fishless ecosystems (e.g., small ponds and wetlands).

Key words

biosentinels, contaminant monitoring, dragonfly larvae, fish-consumption advisories, methylmercury

IN THE POPULAR FANTASY SERIES *Game of Thrones*, the Night's Watch portrays vigilant sentinels silently watching for trouble and sending word to the people behind the wall to prepare and react if danger approaches. Humans similarly rely on biological sentinels to detect dangerous substances in the environment and depend on them as early warning signals. Stories about the sensitive canary succumbing to low levels of toxic gases, alerting miners to take evasive action, illustrate the idea of a biological sentinel. Now, instead of bringing the canary to the site of a potential hazard, scientists and resource managers are recognizing the importance of the stories that resident organisms can convey about the environmental condition or health of their ecosystems. These organisms are called biological sentinels or, simply, *biosentinels*. The diversity of organisms in an ecosystem provides an array of candidate biosentinels, each one telling a slightly different story about the environmental health of the local environment.

Today the stories told by biosentinels can be vastly more informative than a simple signal that it is time to leave the mine. These stories can reveal the risk of exposure to contaminants such as methylmercury. The organisms are sampled after accumulating the contaminants from their environment, and their tissues are then analyzed to estimate the contaminant concentration. These analyses can provide clues to how and where a contaminant entered the biosentinel. The story can expand to identify other players, for example how contaminant levels in the biosentinel are transferred to predators, or how their own dietary preferences and feeding behaviors affect their exposure to bioaccumulative contaminants that are transferred in food webs. Thus the stories biosentinels tell can be extremely informative and useful.

Useful biosentinels are those organisms that consistently "integrate" uptake of contaminants over a range of concentration in both space and time. The bioavailability of a contaminant to an organism depends not only on the biogeochemical behavior of the contaminant but also on specific traits involving the life history, physiology, and trophic ecology of the organism. Any combination of conditions and traits that would prevent or limit the organism's exposure to a specific contaminant lowers its value as a potential biosentinel. Another practical consideration is the ease with which the organism can be collected, identified, and analyzed. If such conditions are satisfied, biologists and resource managers weigh the cost-effectiveness of using a specific biosentinel. This is especially important if the biosentinel is to become part of a sustained monitoring program. Such practical considerations have focused attention on larval dragonflies as potential new biosentinels for monitoring methylmercury contamination in freshwater systems, especially in our national parks.

Mercury in the environment

Mercury (Hg) is a naturally occurring element in the environment, but human sources now contribute about 70% of the mercury in the atmosphere. The atmospheric transport and deposition of mercury in both dry and wet forms pose a considerable threat to areas far from traditional point sources of mercury, such as mines and industrial sources. Lacking local, geologic mercury sources, organic methylmercury is formed from inorganic mercury that has been atmospherically deposited and transformed by mercury-methylating bacteria, which can occur naturally, for example, in the shallow sediments of lakes and wetlands. Take Ryan Lake in Voyageurs National Park as an example: a gorgeous, southern boreal lake surrounded by rugged rock outcroppings and white pines. Located in northern Minnesota near the Canadian border, the lake is accessible only by boat and a 1.5-mile (2.4 km) hike. Yet the predatory fish inhabiting its tea-stained waters have the highest known concentrations of methylmercury documented for any lake in Minnesota. Mercury in the form of methylmercury bioaccumulates and biomagnifies through the Ryan Lake food web so that a filet of a northern pike contains more than 1,000 parts per billion of Hg, a concentration exceeding the U.S. Environmental Protection Agency's fish-tissue criterion for methylmercury (300 parts per billion wet weight), which was established to protect the health of humans who eat noncommercial fish. The risk of neurological damage to humans from eating contaminated fish, like the northern pike from Ryan Lake, prompted the issuance of fish-consumption advisories for thousands of water bodies throughout the United States, including many in our national parks. This problem is exacerbated by the sensitivity of certain water bodies to mercury pollution, which is highly location-specific and depends on a number of physical, chemical, and landscape factors. For example, the mercury concentration in prey fish and predatory fish can vary almost 10-fold among inland lakes of Voyageurs National Park (Wiener et al. 2006).

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As states and nations strive to reduce anthropogenic emissions of mercury into the atmosphere, how will we know whether concentrations of methylmercury in food webs, fish, and wildlife respond and decline? Conversely, how will we know whether mercury emissions from distant but rapidly developing nations like China are impacting our aquatic ecosystems? How can we adequately expand our understanding of a contaminant that displays such high spatial and temporal variability? For freshwater ecosystems in the Great Lakes region, such challenges may require the monitoring of biosentinel organisms beyond those that have been used.

Use of small prey fish as biosentinels

As the scope of the mercury deposition problem became evident to scientists and resource managers in the 1980s, they soon realized that there were key contaminant transfer points in affected food webs. One was the pathway for human exposure from the consumption of contaminated sport fish. However, there were other vulnerable end points in the food web, such as the common loon, an iconic avian piscivore in Canada and the United States. This is where small yellow perch (*Perca flavescens*) come into the story. As young fish, they serve as an important trophic link to both game fish, such as northern pike and walleye, and breeding common loons that nest and raise their young in northern lakes. It is not surprising that the yellow perch became an important biosentinel for monitoring mercury in many lentic waters (e.g., lakes, ponds, or swamps) (Wiener et al. 2007). Yellow perch are ubiquitous and often very abundant in the northern temperate and boreal lakes of North America. They are found in a wide array of water quality conditions, from soft, poorly buffered, low-pH lakes to hard-water marl lakes. Numerous studies have shown that the concentration of mercury in one-year-old yellow perch is strongly correlated with the mercury concentration of coexisting game fish. Their distribution in lakes surrounding the industrial Rust Belt of North America and their intermediate position in the food webs of those lakes have made small yellow perch an effective biosentinel for monitoring methylmercury in much of the eastern United States and Canada.

There are limitations to the use of yellow perch and other small prey fishes as

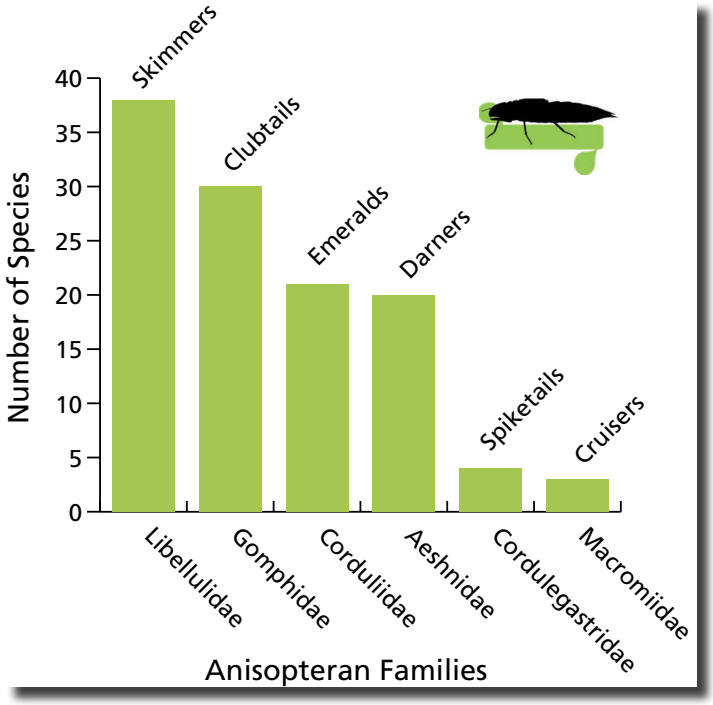

Figure 1. Number of dragonfly species by family recorded across counties containing six national park study units in the Great Lakes region. In total, 116 species of dragonflies (Anisoptera) were recorded. Common names for each dragonfly family appear above each bar. Species distribution data were derived from Abbott (2007).

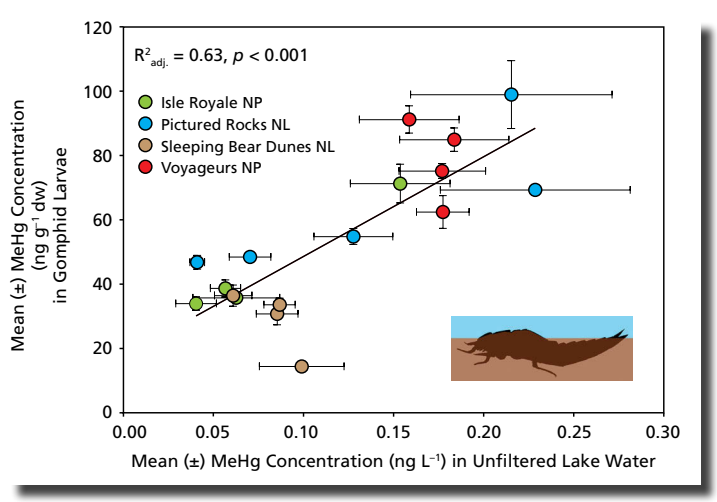

Figure 2. Relation between mean (±SE) concentrations of MeHg in burrowing gomphid larvae and unfiltered water from 17 lakes in the northwest Laurentian Great Lakes region. Data for coexisting species of burrowing gomphids were combined to estimate mean MeHg in larvae for each lake. Means for MeHg in water were calculated from samples collected in 2010, 2011, and 2012. Means for gomphids were calculated from samples collected in 2008, 2009, and 2010. The linear regression model is shown as a solid line.

biosentinel organisms. Although yellow perch are often abundant in lentic systems, they do not typically inhabit lotic habitats (i.e., those characterized by fast-moving water) and certain wetlands, such as bogs and ephemeral ponds. Moreover, recent research has shown that emergent aquatic insects from fishless water bodies can be important points of methylmercury transfer to terrestrial consumers, such as spiders, invertivorous birds, and bats (Blackwell and Drenner 2009).

Larval dragonflies as biosentinels for mercury

A diverse assemblage of dragonflies inhabits the aquatic environs surrounding the Great Lakes (fig. 1). Upon emergence as adults, they are conduits for the transfer of methylmercury from the aquatic to the terrestrial ecosystem. These insects are promising biosentinels of methylmercury in aquatic food webs, given that they inhabit a diverse array of aquatic and wetland habitats and their use as biosentinels can extend the assessment of food web contamination to fishless aquatic habitats. All dragonfly larvae are obligate predators, bioaccumulate methylmercury (fig. 2), and are restricted to the water body where they were hatched. Most are identifiable to species, and sufficient numbers and sample mass can be readily obtained with simple, inexpensive gear (e.g., a D-shaped net). Their ecology is well documented at the genus level, which greatly facilitates and enhances the interpretation of data from chemical analysis of larvae.

The utility of burrowing dragonfly larvae as biosentinels of methylmercury in aquatic food webs has been examined by Haro et al. (2013), who collected late-instar (i.e., individuals near maturity and adult emergence from the aquatic environment) dragonfly larvae in the genus *Gomphus* spp. (clubtails) from 17 inland lakes in four national parks in the western Great Lakes region (Isle Royale National Park, Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Voyageurs National Park). They conducted a statistical analysis to determine the number of dragonflies to collect in order to detect a 20% difference in mean total mercury concentration in their tissue from a lake. The same was calculated for young yellow perch sampled from the same group of lakes. The results indicated that only 10 dragonfly larvae needed to be sampled, whereas 40 yellow perch were required (fig. 3). In the Great Lakes region, the logistical advantages are clear for adding dragonfly larvae as biosentinels for mercury monitoring. The sampling gear required for collecting age-one yellow perch is more difficult to carry into hard-to-reach lakes like those in the rugged interior of Isle Royale. Nevertheless, if lakes of interest are close to one another, it is not unreasonable to expect that multiple lakes could be sampled in a single day us-

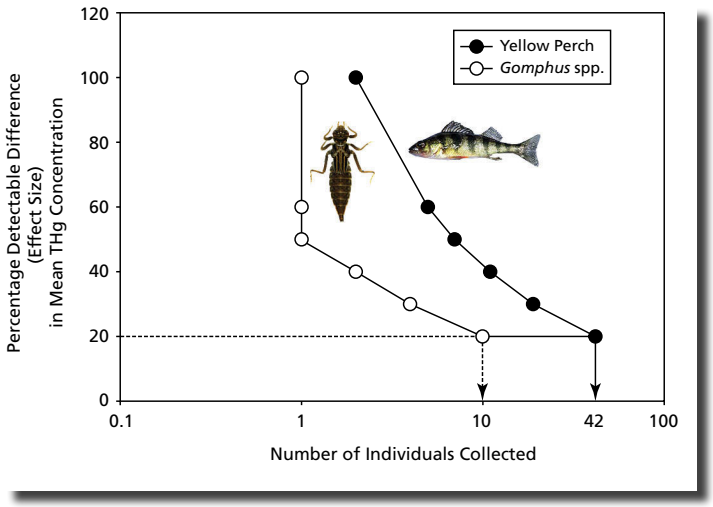

Figure 3. Estimated sample sizes (i.e., the numbers of individuals required) needed to detect differences in concentration of total mercury (THg) in small, whole yellow perch (total length ≤ 76 mm or 2.9 in) and larval *Gomphus* in lakes of the northwestern Great Lakes region with a Type I error (α) of 0.05 and a statistical power (1–β) of 0.80.

The risk of neurological damage to humans from eating contaminated fish, like the northern pike from Ryan Lake, prompted the issuance of fish-consumption advisories for thousands of water bodies throughout the United States, including many in our national parks.

ing dragonfly larvae as biosentinels. Their ease of collection is also a strong impetus for their use in a nationwide citizen science–based monitoring program (see the article by Flanagan Pritz et al. on page 74).

More research is needed on the mechanisms behind the uptake of methylmercury as well as on its trophic transfer from larval dragonflies. The larvae obtain their oxygen by actively drawing water into their rectum, where their gills reside. This rectal ventilation may be an additional pathway for the uptake of methylmercury. Furthermore, behavioral and physiological differences among the taxonomic families of dragonflies may also affect the uptake of methylmercury. These issues will provide important lines for additional research. These unanswered questions do not detract from the fact that larval dragonflies are a new and potentially powerful biosentinel for expanding our ability to assess mercury in the waters of our national parks and beyond.

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