

A Framework for Monitoring the Response to Changing Mercury Releases: Wildlife indicators

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Abstract

A principle concern with elevated mercury in the environment is the potential for adverse effects in organisms. Methylmercury is of particular concern due to its greater ability to bioaccumulate in food webs than inorganic mercury. Both humans and certain wildlife species are at greater risk of effects from methylmercury due to exposures at higher trophic levels on food webs. To characterize these exposures in wildlife and be able to monitor changes with time thus requires a comprehensive approach that considers mercury releases, atmospheric transport and deposition and watershed transport, cycling and transformations within water bodies, and bioaccumulation up the food web.

A bioindicator can be defined as an organism that responds predictably to contamination in ways that are readily observable and quantifiable. This response could be at any level of physiological or ecosystem organization from molecular or cellular at one end of the spectrum to population or community at the other end. Wildlife species are good indicators of the status of contaminants in the environment because they reflect not just the presence but the bioavailability of the contaminant of interest, integrate over time and space and among local, regional and global sources, and respond to toxic insult in ways that are relevant to human health at both the whole organism and sub-organismal level.

Issues of importance in designing a strategy to address changes in wildlife exposures to mercury (which also must be considered in design of a broader mercury monitoring network) include geographic and broad habitat considerations (e.g. lake vs. riverine vs. coastal, and hydrological factors such as extent of wetlands, drying/wetting cycles and any potential gradient in mercury loadings), other watershed and within water body characteristics (such as size of water body, soil and water chemistry, sediment biogeochemistry), and food web characteristics (such as number of trophic levels and changes through eutrophication or introduction of exotic species). In addition, recent studies indicating relatively high mercury exposures in some terrestrial wildlife species indicate the value of including such species in a biomonitoring network, even though mechanisms of mercury cycling and uptake are not clearly understood.

Introduction

In designing a mercury monitoring network that includes a wildlife component, a principal objective is to document changes in mercury exposure (and potentially effects) relative to changes in mercury loadings to an ecosystem. More specific objectives might include the ability to:

1. Discern spatial differences and temporal changes in mercury exposures (and potentially effects) in wide-ranging individual species;
2. Discern temporal changes in exposures (and potentially effects) in more limited range species in specific locations of interest;
3. Identify the role of loadings vs. other factors (e.g. food web changes) in mercury exposure changes;
4. Identify the impact of changes in mercury releases from specific sectors and/or geographic areas on exposures in specific locations.

The development of such a network must take into account the numerous variables and factors affecting mercury exposure and effects in wildlife species, including geographic and habitat differences (both the broader differences between four major habitat types considered – terrestrial, freshwater, coastal/estuarine, and marine – and differences (including trophic changes) within each habitat type, and host factors (including species migratory status, home range size, functional niche, diet, sex, and age.) A mercury monitoring network for wildlife must be integrated into the broader mercury monitoring context, taking into account sources and atmospheric transport, deposition and watershed transport, cycling within a water body, and uptake within the aquatic food web. Because wildlife (in particular top-level predators) are the integrators of a mercury signal that has already been integrated across several media (air, water, sediments, and fish), the inclusion of wildlife is therefore challenging, and will require careful attention in overall network development.

Methods

Wildlife indicators can establish baseline conditions, act as early warning signals of environmental problems, identify the extent of contamination, define critical pathways and responses at multiple trophic levels, as well as integrate biological exposure with the physical and chemical environment. Indicator selection was based on a combination of criteria or characteristics that included:

1. Well-characterized life history;
2. Capable of concentrating and accumulating contaminant(s) of concern;
3. Common in the environment;
4. Geographically widespread;
5. Sensitive and hence indicative of change;
6. Easily collected and measured;
7. Adequate size to permit resampling of tissue;
8. Occurrence in both polluted and unpolluted areas;
9. Display correlation with environmental levels of contaminants;
10. Has background data on the natural condition.

Issues of Concern

Geographical and Habitat Differences: Geography and habitat variability affect MeHg production, bioaccessibility and uptake into wildlife. Interpretation of mercury in wildlife also requires a working knowledge of sex, age and tissue differences. Biogeochemical differences in aquatic and terrestrial systems are particularly important determinants of Hg methylation. For example, in the Northeast, there is likely enough atmospherically deposited Hg to create ecological risk anywhere in that region. However, adjacent lakes can have drastically different levels of MeHg and this variation is related to nonlinear biogeochemical and hydrological processes. Similarly, among 15 Wisconsin lakes within the same airshed, concentrations of MeHg in water and fish varied by an order of magnitude. The strongest environmental correlate of MeHg in water was DOC which accounted for >80% of the variability between lakes; pH was the strongest correlate of fish MeHg ($r^2 > 0.70$).

Methodological issues: Both the development and application of bioindicators present a number of methodological considerations. One key requirement is to relate dose/effects studies in the laboratory, and residue levels/effects studies in the field. For many years these studies were conducted by different groups of scientists, and the connections were not made. Bioindicator species where there were clear links between exposure levels, tissue levels and effects were the most useful.

Host factors: The ecological constraints of any species must be well characterized. Diet, functional niche, migratory status, and home range size influence a species' suitability as an indicator. Seasonal changes in these parameters also reflect contaminant concentrations. An animal's age and sex, overall body condition, and health status also influence its suitability as an indicator. All of these factors can also alter the bioavailability, toxicokinetics and toxicodynamics of a contaminant, thereby altering uptake, distribution, and effects.

Types of Indicators: Mercury exposure may be measured in many compartments in an organism. Objectives and logistical considerations dictate compartment choice. Non-lethal choices include abandoned eggs, blood, feathers, fur, scales, and tails for lizards and snakes. With some additional effort muscle and even organ biopsies may be included in this category. These compartments provide avenues for sampling individuals over time and can provide short-term and long-term insights on mercury bioaccumulation. Availability of fresh carcasses can also provide information on mercury exposure; emphasis is typically on the liver, kidney, spleen, muscle, and brain.



Results

Based on criteria identified for a national Hg monitoring network, candidate wildlife species for

exposure, by habitat type, include Bicknell's thrush and raccoon (terrestrial), common loon (lake), tree swallow (freshwater wetland), herring gull, bald eagle and common tern (lake/coastal), mink (riverine), saltmarsh sharp-tailed and seaside sparrows (estuarine), harbor porpoise (or other smaller marine mammals) (nearshore marine), Leach's storm petrel (offshore marine) and belted kingfisher (comparisons across aquatic habitats). All of these species meet a large number of criteria for bioindicators identified, although in some cases, other species in the same taxa rank relatively high as well, and ongoing research may identify additional reasons for their inclusion as suitable mercury bioindicators. For species included in the network, it is recommended that each species be monitored annually (generally at a fixed time after arrival at breeding sites, for migratory species).

Wildlife indicator species chosen for the National Mercury Monitoring Network

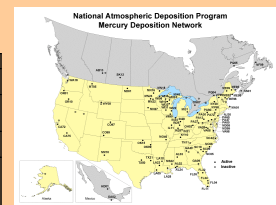
Habitat Type	Species	Age	Tissue	Rationale
Terrestrial	Bicknell's thrush	Adult	Blood	Ability for significant uptake of Hg in montane habitats; high priority for conservation; blood levels related to atmospheric deposition models
	Raccoon	Adult	Hair	Widespread distribution and easily studied; prey for endangered species (Florida panther)
Lake	Common loon	Adult	Blood, egg	Widespread distribution and easily studied; large existing database; sensitivity to Hg; existing database for continental Hg exposure and lab and field effects
Lake/coastal	Herring gull	Adult	Egg	Widespread distribution and easily studied; large existing database documenting trends in Great Lakes
	Bald Eagle	Juvenile, Adult	Blood, Feather	Widespread distribution, large existing database, apparent reproductive effects
	Common tern	Adult	Feather, egg	Widespread distribution and easily studied; large existing database; sensitivity to Hg
Estuarine	Saltmarsh Sharp-tailed and Seaside Sparrows	Adult, juvenile	Blood	Obligate estuarine species, high conservation concern, existing database on exposure, small home range
Riverine	Mink	Adult	Fur ^a	Widespread distribution and easily studied; existing database on exposure and effects; sensitivity to Hg
Marine nearshore	Harbor porpoise ^b	Adult	Muscle ^c	Widespread distribution; some existing data; concern about immunological effects
Marine Offshore	Leach's Storm-Petrel	Adult, juvenile	Blood	Widespread distribution, common, easily sampled at nest site, potential connection with global Hg signal
Comparison across aquatic habitats	Belted kingfisher	Adult, fledged young	Blood, egg	Widespread distribution across habitat types; large and consistent clutch size; ease of capture; relatively high mercury exposures

Notes:

- a. May require better understanding of relationship with internal tissue mercury concentrations (see discussion in Section 5.6).
 b. Harbor seal or grey seal would also be candidates for similar reasons, and ringed seal would be appropriate marine mammal target for Arctic biomonitoring, due to wide distribution, significant uptake rates for Hg importance in diet of polar bears.
 c. Liver and kidney are more typically analyzed in marine mammal species, but due to both accumulation and detoxification as discussed previously, muscle tissue may be more appropriate indicator, in particular for shorter-term exposures, assuming methodological issues are resolved (see Becker, 1991).

The National Mercury Monitoring Network

- Envision sampling within each of approximately 10 core regions in U.S. (or North America)
- Sampling scheme involves **cluster** and **intensive** sites
- Sites would be preferentially linked with MDN sites



	Cluster	Intensive
# Sites/ecoregion	Approx. 15-20	Approx. 1
Selection basis	Similar broad ecological characteristics but different site conditions	Include sites where changing loads are expected
Parameters measured	Primary Hg indicators	Generally primary Hg indicators + additional parameters
Purpose	Identify general trends	Address mechanistic questions (e.g. extent of biota MeHg change associated with changes in Hg deposition)

- Outline of indicators by major compartment for monitoring intensity

Compartment	Indicator	Sites	Compartment	Indicator	Sites
Air and watersheds	Total weekly wet Hg deposition	Cluster	Aquatic biota*	Yearling Forage fish	Cluster/intensive
	Speciated atmospheric measurements	Intensive		Piscivorous fish	Cluster/intensive
	Stackpack sampling	Cluster		Estuarine benthic invertebrates	Cluster
	Wet-deposited yield	Intensive		Raccoon	Cluster
Water and sediments (Hg characterization)	Evaporation flux (aquatic and terrestrial)	Intensive	Wildlife**	Mink	Intensive
	Total Hg and MeHg in surface water	Cluster/intensive		Common loon	Cluster/intensive
	Total Hg, MeHg, and % MeHg in surface sediments	Cluster/intensive		Herring gull	Cluster
	Total Hg accumulation in sediments	Cluster/intensive		Harbor porpoise & Leach's storm petrel	Cluster
Instantaneous methylated/dehydrohalogenation rates		Intensive	Bicknell's thrush	Cluster	
			Belted kingfisher	Cluster/intensive	

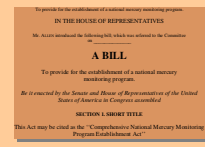
* Could analyze plankton to assist with mechanistic interpretations.
 ** Sampling tissues – generally blood, egg, fur or feathers, as appropriate; annual schedule (with sensitivity to seasonal variability).

- Release of the national Hg monitoring plan



- Overview paper in *Environmental Science and Technology* (Mason et al., 2005, 39(1):14A-22A)
- Book to be published by SETAC/Taylor & Francis (Fall 2006)

- National Hg monitoring plan legislation



- Legislative bill soon to be introduced in the Natural Resources Committee of the House of Representatives
- Bill sponsored by Congressman Allen