

Mercury in snow at Acadia National Park reveals watershed dynamics

By Sarah J. Nelson

Mercury at Acadia

AS A CLASS I AREA, ACADIA NATIONAL PARK (Maine) is afforded the highest level of air quality protection under the federal Clean Air Act Amendments (1990). Acadia hosts the highest peaks along the East Coast (~1,530 feet [466 m]), and its steep slopes and proximity to coastal fog create an environment conducive to intercepting polluted air masses (Weathers et al. 1986). Investigators have documented elevated deposition of contaminants, including mercury (Hg), at Acadia (Norton et al. 1997; Bank et al. 2007; Johnson et al. 2007; Kahl et al. 2007), which in certain areas of the park causes at least as much Hg contamination in tree swallow chicks and eggs as in birds living at a mercury-contaminated Superfund site in Massachusetts (Longcore et al. 2007).

PRIMENet, a long-term watershed research program at Acadia (Tonnessen and Manski 2007), has shown that the legacy of wildfire affects Hg in watersheds and biota for decades or longer (Bank et al. 2005; Johnson et al. 2007; Kahl et al. 2007). Because their needles have more surface area than deciduous leaves and they keep their foliage year-round, coniferous forests, like the spruce-fir forests of an unburned Acadia watershed, are more effective than postfire deciduous forests at canopy scavenging of atmospheric Hg (Grigal 2002; Johnson et al. 2007). That is, conifer forests collect more dust and dry particles on their foliage than deciduous trees. Dry-deposited Hg is washed to the forest floor in subsequent rain, fog, and snow events and collected as “throughfall” (Grigal 2002; Miller et al. 2005; Weathers et al. 2006; Johnson et al. 2007). Throughfall allows investigators to assess deposition across heterogeneous, forested areas by deploying a large number of samplers and comparing chemistry data with patterns in landscape features (Weathers et al. 2006).

Reports in the scientific literature suggested that Hg concentrations in snow throughfall might be low, though data were sparse (Nelson 2007). Therefore, the goal of this research was to collect winter throughfall Hg data and assess Hg mobility in forested research watersheds in Acadia to establish the importance of this Hg load to the terrestrial ecosystem (Nelson 2007).



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Figure 1. Investigators used three methods to collect precipitation in the mercury deposition study at Acadia National Park. Here they deploy Teflon and plastic bags in snow tubes. Throughout the season they compared paired Teflon-lined tubes, collecting one bag and replacing it after each snow event while leaving the other bag deployed all winter. The third, plastic-lined tube (photo foreground) was used to collect other chemical data about snow at Acadia.

Methods

I measured snow throughfall deposition in Acadia at several sites in winter 2004–2005. Because few published papers described methodology for snow collection, I used three methods in this research: event sampling, cumulative sampling, and snowpack sampling. During event sampling, I deployed “snow bags” (i.e., Teflon liners in plastic tubes) to collect throughfall of large snowfall events (fig. 1). I deployed snow bags all winter for cumulative sampling and collected cores of intact snow on the ground for snowpack sampling. Detailed field methods and sample type descriptions are provided in Nelson (2007) and Nelson et al. (2008).

Key findings

This study generated three major findings. First, the concentration of Hg under conifer forests after snowfall events in winter was similar to that found during the growing season in rain (fig. 2). As with rain throughfall, conifer forested sites had the greatest Hg concentration and deposition, followed by mixed sites, then deciduous sites, and finally nonvegetated sites. This finding differed from results of the few published studies from other sites, which suggested little Hg in snow (e.g., Mason et al. 2000).

Second, estimates of Hg in snow throughfall deposition varied by a factor of as much as three, depending on the collection method (fig. 3). When snow bags remained open to the atmosphere all winter, Hg could be emitted from the deposited snow back to the atmosphere. This method provided a low estimate of Hg deposition to watersheds. The closed snow bags collected after each event provided the greatest estimates of Hg flux to watersheds. Previous research at other sites (e.g., Mason et al. 2000) reported relatively low Hg burdens in snow, but their samples were left uncovered, allowing Hg to escape. This research demonstrates that closing collection devices after snowfall events effectively traps Hg.

Third, I documented that soils and leaf litter could contribute Hg to the overlying snowpack (fig. 3). I applied a labeled Hg tracer to

soils and litter in late autumn. I then sampled the snowpack near the end of winter to determine whether any of the tracer moved vertically up into the snowpack. I recovered the labeled tracer in all the snowpack samples from sites that had been treated, and found greater amounts and percentages of total Hg of the tracer in the bottom portion of snowpack than in the top portion.

Acadia in context

Having identified snow throughfall deposition of Hg as a potentially important flux to forested watersheds, I synthesized published and unpublished snow Hg concentration and deposition data from temperate to subboreal North America to provide a broader context for the findings from Acadia, and to assess whether the controls on winter deposition at Acadia apply elsewhere. Studies that provided information on vegetation at collection sites reported Hg ratios in throughfall (wet + dry, under forests) to open (wet + dry, nonforested) deposition in snowpack as 2.1:1, and 3.8:1 for throughfall (wet + dry, forested) to wet-only (nonforested, no dry) deposition in snow events. These ratios are greater than the overall average growing season throughfall to wet deposition (1.8:1) (Grigal 2002). Across the broad geographic region and in discontinuous studies spanning 14 years, snow Hg concentration and deposition were consistently greatest in bulk

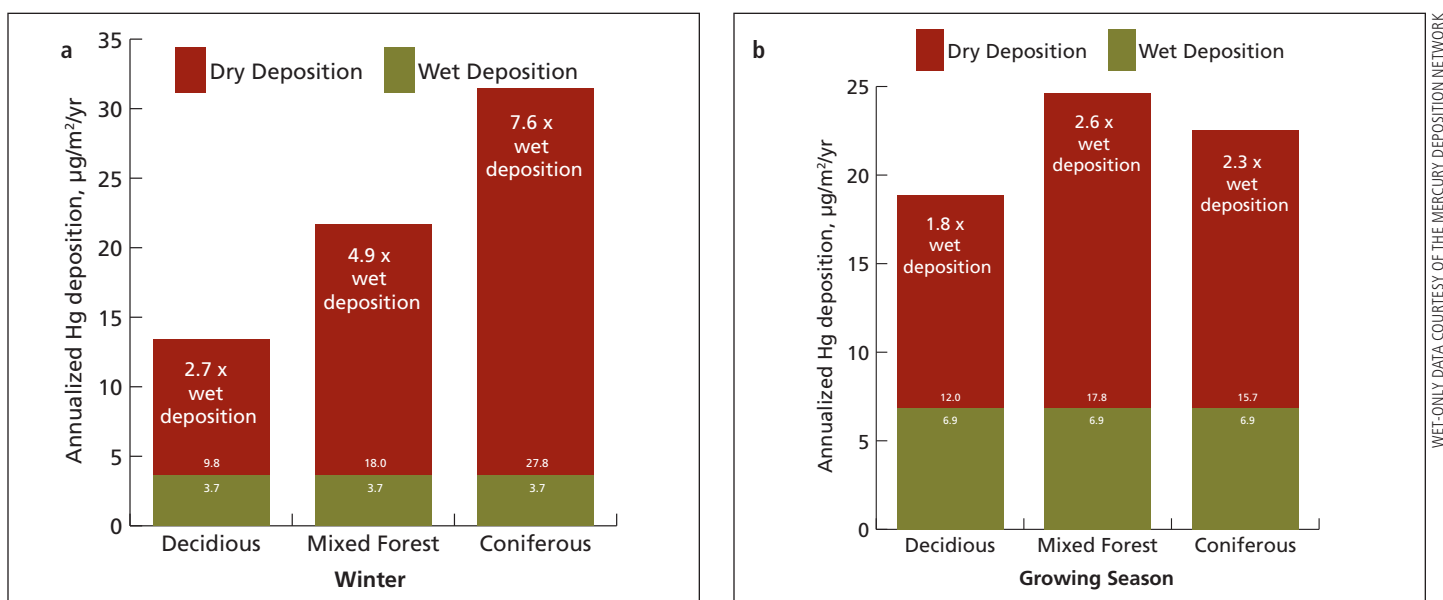
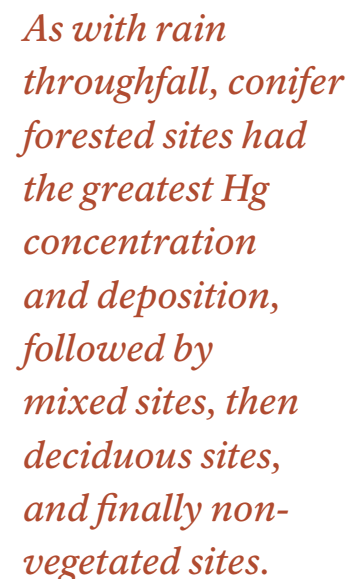


Figure 2. This study measured throughfall of mercury (Hg) during winter (a) and the growing season (b) in Acadia National Park, Maine. Bars show the contribution of wet-only deposition, plus the amount of dry deposition inferred from throughfall measurements. The sampling period for winter throughfall was from 15 December 2004 to 16 March 2005 and from 28 May to 17 November 2004 for growing-season throughfall. The graph shows estimates from these measurements annualized to per-year rates for comparison. The overall average ratio reported for growing season throughfall (wet + dry) to wet deposition is 1.8:1 (Grigal 2002), whereas the ratio of throughfall to wet deposition averaged 3.1:1 during the growing season at forested sites at Acadia.



throughfall at conifer sites and lowest at open bulk sites without vegetation cover. This relationship held despite different field and laboratory methods. As with rain throughfall, this could be because of the greater scavenging efficiency of the coniferous canopy as compared to the deciduous canopy (largely bare twigs in winter). Another (yet unstudied and unpublished) mechanism for enhanced deposition in snow under coniferous canopies could be that dry particles could settle onto intercepted snow that sits on top of branches between storms.

This research provides new information regarding Hg inputs in winter. Although researchers have already identified winter processes such as snowmelt as important components of winter watershed chemical mass balances (Shanley et al. 2002), few published results document total atmospheric deposition in winter. The results of this study suggest that researchers can characterize the range of total deposition of Hg by focusing on two types of sites—those with year-round canopy and those without cover

In this study, three methods for measuring Hg in snow provided widely varying estimates of Hg inputs in winter (fig. 3). Collections after each major snowfall, particularly at conifer sites, contained the highest estimates of deposition (fig. 2); snow that was open to the atmosphere throughout the entire winter, allowing for volatilization and emission of deposited Hg, provided the lowest estimates of deposition. Snowpack sampling (of intact ground snow) provided an intermediate estimate of Hg. However, findings of this study indicate that soils and leaf litter could contribute Hg to the overlying snowpack; further research is necessary to determine the mechanisms that led to translocation of Hg. These findings can inform models that assess effects of changing Hg emissions. Furthermore, long-term monitoring to assess such changes would benefit from periodic snow-event throughfall sampling. At Acadia National Park, complementary research (Kahl et al. 2007) and ongoing monitoring continue to quantify the amount of mercury that falls onto the landscape and discrete studies track mercury as it moves through ecosystems and into living things.

Acknowledgments

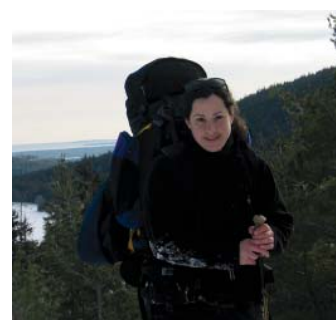
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About the author

Sarah J. Nelson was a 2003 Canon Scholar from the University of Maine, Orono. She completed her dissertation, “Winter contribution to annual throughfall inputs of mercury and tracer ions at Acadia National Park, Maine,” in 2007. Dr. Nelson is an assistant research professor at the Senator George J. Mitchell Center for Environmental and Watershed Research, University of Maine, Orono, and can be reached at sarah.nelson@umit.maine.edu.



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Sarah Nelson and her team hiked more than 200 miles (322 km) (50 [80] of them on snowshoes) with packs full of rain, snow, and ice in carrying out her research on airborne mercury deposition at Acadia National Park.