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Mercury Science and the Benefits of Mercury Regulation

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Executive Summary

Mercury (Hg) is a naturally occurring, but highly toxic, element. The amount of mercury in ecosystems has been greatly increased by human releases associated with mining, fossil-fuel combustion, and other activities. Since the 1970s, coal-fired electricity generating units (power plants) have been one of the largest sources of U.S. mercury emissions. Although Congress created a mechanism for regulating mercury emissions from electric utilities through the 1990 Amendments to the Clean Air Act, their regulatory status has been challenged since that time. The Mercury and Air Toxics Standards (MATS), promulgated in 2011, have led to marked decreases in mercury emissions and environmental mercury concentrations, but the benefits and costs of this regulation have been poorly characterized and quantified in prior analyses by the U.S. Environmental Protection Agency (EPA).

In the first section of this white paper, we provide background on the environmental sources of mercury, the cycling of mercury in the environment, and risks to human and ecological health associated with mercury exposure. We summarize the history of federal regulation; observed environmental and human health responses to regulation; and recent advances in scientific research that have informed quantitative understanding of the benefits of reduced mercury loading to the environment. We use this analysis to highlight some key gaps in the Regulatory Impact Analysis (RIA) performed by the U.S. EPA for the MATS rule.

In second section of the white paper, we make detailed recommendations for conducting a state-of-the-science analysis of the benefits from regulating mercury emissions from U.S. coal-fired utilities. Such an analysis should be consistent with current understanding of mercury emissions, deposition, exposure to humans and wildlife, and all health and environmental effects of mercury exposure.

These recommendations include the following elements:

1. **Emissions**: An updated analysis of the benefits of emissions controls for coal-fired power plants should use the best-available data on U.S. mercury emissions sources and speciation that are incorporated in the National Emissions Inventory (NEI).

2. **Deposition**: This analysis should include an updated assessment of electric utility-attributable mercury deposition; the fraction of total U.S. mercury deposition attributable to utilities; and the proportion of mercury deposition from global sources. It should use atmospheric models that reflect best-available understanding of atmospheric mercury emissions, chemistry, and transport. We recommend updating atmospheric mercury chemistry algorithms within the Community Multiscale Air Quality (CMAQ) model originally used by EPA for the 2011 MATS RIA.

3. **Marine Fish and Population-wide Exposure**: A revised analysis should quantify the methylmercury (MeHg) exposure pathways not only for recreational anglers, but also for the U.S. population that consumes fish from the commercial market, particularly US

coastal fisheries that are affected by U.S. utility-derived mercury. This approach would more accurately assess the U.S. population that is affected by methylmercury exposure and support estimates of changes in methylmercury exposure among different demographic groups.

4. **Cumulative Exposures**: To quantify the full health benefits of regulating mercury emissions, exposure assessments should consider both utility-derived mercury and how utility-derived mercury affects cumulative exposures.

5. **Neurocognitive Health Impacts**: In addition to characterizing the impacts of methylmercury exposure on IQ in children, the benefits analysis should quantify other sensitive neurocognitive outcomes such as memory, delayed learning, and behavioral impacts. Impacts on cognitive aging in adults could also be considered. The effects on these endpoints below the RfD should be analyzed and included in the benefits estimate. The dose-response relationship between IQ and methylmercury used in the 2011 MATS RIA should be updated to reflect the latest scientific understanding. Specifically, a steeper dose-response relationship is expected following correction for the confounding impacts of omega-3 fatty acids.

6. **Cardiovascular Impacts**: Improved cardiovascular health following reduced mercury exposure, such as avoided cardiovascular disease (CVD) mortality and ischemic heart disease (IHD) should be included in the benefits analysis, given the evidence for impacts of methylmercury exposure on cardiovascular health. Blood mercury data from the Centers for Disease Control and Prevention (CDC) data suggest there are tens of millions of adults in the U.S. population at risk for IHD and almost five million at risk for CVD mortality based on thresholds for methylmercury exposures.

7. **Environmental Justice**: We recommend that EPA more fully consider the environmental justice implications of mercury emissions and exposures. First, the communities that are disproportionately impacted by utility emissions of HAP must be identified. In addition, communities that are vulnerable to high methylmercury exposures due to cultural seafood consumption practices must be considered. New data on high-end fish consumers and socioeconomic attributes of consumers should be considered in a revised analysis. Further, disproportionate exposures of indigenous people, Pacific Islanders, and others, indicated by CDC blood mercury monitoring data, should be addressed.

8. **Ecological Benefits**: We recommend that methods for quantifying local impacts of mercury exposure on wildlife developed by the Natural Resource Damages Assessment and Restoration (NRDAR) program be applied to quantify the benefits associated with reduced utility mercury emissions on a national scale.

Introduction

Mercury (Hg) is a naturally occurring neurotoxic trace metal. The cycling of mercury through the global environment has been greatly altered by human releases associated with mining, fossil-fuel combustion, and other activities. Since 1970, coal-fired electricity generating units (power plants) have been one of the largest sources of mercury emissions in the U.S. Even though Congress created a pathway toward the regulation of power plant mercury emissions in 1990, their regulatory status has remained contested for the last 30 years. The Mercury and Air Toxics Standards (MATS) promulgated in 2011 have led to large reductions in mercury emissions, environmental Hg concentrations, and human exposures, but the benefits of this regulation have not been adequately captured by previous EPA analysis.

The first section of this white paper provides background on the sources of mercury emissions, cycling in the environment, and risks to human and ecological health associated with exposure. We provide a brief history of federal regulation, some of the observed environmental and human health responses to regulation, and an overview of recent advances in scientific research that have contributed to state-of-the science understanding of the benefits associated with reduced loading to the environment. We use this analysis to highlight some key gaps in the 2011 Regulatory Impact Analysis (RIA) performed by the U.S. Environmental Protection Agency for the MATS.

The second section of this white paper <u>recommends an approach and methods for conducting a state-of-the-science benefits analysis</u> for the regulation of mercury emissions from U.S. coal-fired utilities. This includes a roadmap for assessing any residual risks associated with ongoing mercury emissions.

Part I: Background on Mercury Science and Limitations of the Regulatory Impact Analysis (RIA) for the 2011 Mercury and Air Toxics Standards (MATS)

Background - Mercury Sources and Cycling

Mercury has been studied intensively since the 1950s. As a result, its health and environmental impacts are well understood. There are three broad categories of mercury emissions: geogenic (natural) emissions, primary anthropogenic emissions, and re-emissions of previously deposited natural and anthropogenic mercury back to the atmosphere. Prior studies have estimated that cumulative primary anthropogenic emissions to the atmosphere since 1850 have exceeded natural emissions by a factor of 78 (Streets et al. 2017). While human activities have increased concentrations of mercury in the atmosphere by 300%-500% since 1850, recent emissions reductions in the U.S. and Europe over the past two decades have led to a 30% decline in atmospheric Hg concentrations (Zhang et al., 2016).

The largest sources of anthropogenic mercury emissions in the U.S. since the 1990s have been coal-fired power plants, waste combustion (associated with diverse products that contained mercury from past use) and industrial sources. Many products containing mercury have been phased out and stringent emissions controls have been implemented on waste incinerators and coal-fired power plants. Here we focus on the environmental and health benefits that can be attributed to regulating coal-fired utilities.

Coal has a higher mercury content than other fossil fuels, leading to higher releases of mercury following combustion compared to other energy sources. However, when control devices are in place and operating, they can capture more than 90% of mercury released from combustion sources (Srivastava et al., 2006). Atmospheric emissions from power plants includes two forms of mercury: 1) ionic mercury (Hg(II)) that is redeposited close to where the mercury was emitted, and 2) elemental mercury (Hg(0)) that is stable in the atmosphere and may be transported long-distances before being deposited to the land or ocean (Figure 1).

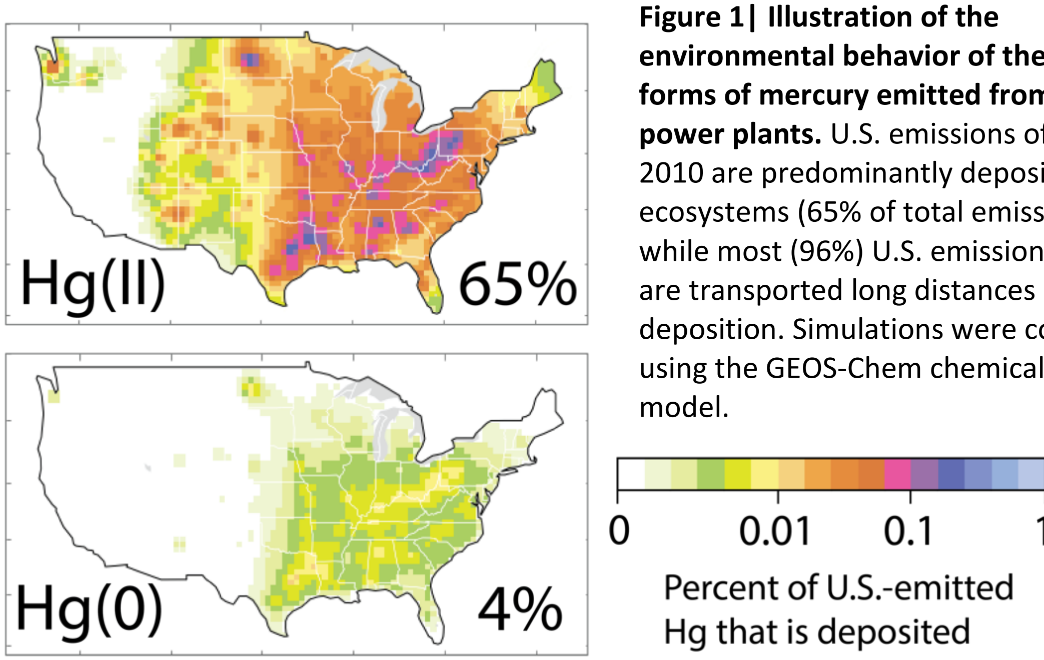

Figure 1| Illustration of the environmental behavior of the two major forms of mercury emitted from coal-fired power plants. U.S. emissions of Hg(II) in 2010 are predominantly deposited in U.S. ecosystems (65% of total emissions), while most (96%) U.S. emissions of Hg(0) are transported long distances prior to deposition. Simulations were conducted using the GEOS-Chem chemical transport model.

Mercury Exposure Sources and Health Effects

In ecosystems (mostly aquatic; wetlands, sediments, the water column of the ocean), some mercury is converted by microbes into an organic form, methylmercury (MeHg), which is the form of mercury that bioaccumulates in food webs. Methylmercury concentrations in predatory fish and marine mammals are typically 10 million to 100 million times greater than concentrations in water (Chan et al. 2003; Chen et al. 2012; Eagles-Smith et al., 2018). Methylmercury typically accounts for >90% of the mercury in the fish that people eat (Bloom et al., 1992). Fish consumption is the primary source of human exposure to mercury in the U.S. (Mahaffey et al., 2008, Sunderland, 2018).

Fish and shellfish harvested from both freshwater and marine ecosystems provide a healthy, low-cost source of protein and micronutrients. The presence of methylmercury offsets some of the benefits of this otherwise healthy food source and poses net risks to consumers if tissues are highly contaminated (Mahaffey et al., 2011). Frequent fish consumers, such as recreational and subsistence fishers, experience among the greatest exposures of individuals to methylmercury (von Stackelberg et al., 2017). For the general U.S. population, more than 80% of methylmercury intake is from consuming marine fish and shellfish sold in the commercial market and purchased at grocery stores and in restaurants. The remaining intake is derived mainly from farmed and freshwater fish and shellfish sold in the commercial market. A substantial portion of the marine fish are harvested from coastal ecosystems bordering the North Atlantic and North Pacific Oceans (Sunderland et al., 2018).

Older predatory fish species such as swordfish, shark, and orange roughy from the Gulf of Mexico often contain tissue burdens of methylmercury that exceed consumption guidelines intended to protect public health. High levels of methylmercury in many freshwater game fish have led to fish consumption advisories for many U.S. rivers and lakes. In 2010, the most recent year for which summary data exist, consumption advisories for mercury were in effect in all 50 states, one U.S. territory, and three tribal territories, accounting for 81% of all U.S. consumption advisories (US EPA, 2011). Consumption advisories for mercury exceeded advisories for all other contaminants combined at this time.

Once ingested, methylmercury can cross the blood-brain and placental barriers, after which it acts as a potent neurotoxicant. Children exposed to methylmercury during a mother's pregnancy experience persistent and life-long losses in IQ and motor function (Grandjean and Bellanger, 2017). Neurodevelopmental impacts can be detected even at low levels of methylmercury exposure, suggesting there is no threshold below which effects do not occur (Rice et al., 2010; Grandjean and Bellanger, 2017). In adults, methylmercury exposure has been associated with adverse effects on cardiovascular health, including increased risk of fatal heart attacks (Genchi et al., 2017).

Methylmercury exposure also has adverse impacts on wildlife. The health of songbird and bat species has been threatened by methylmercury exposure, particularly in wetland habitats (Evers et al., 2020). Wildlife that consume fish, especially obligate piscivores such as common loons, bald eagles, otters, mink, and marine mammals, are also adversely affected by methylmercury exposure (Eagles-Smith et al., 2017; Chan et al., 2003). The productivity of economically valuable game fish stocks can be compromised by high levels of mercury exposure (Sandheinrich and Wiener, 2011).

Regulatory History for Coal-Fired Power Plants

The 1990 Amendments to the Clean Air Act (CAA) established a framework for regulating hazardous air pollutants (HAP) under section 112 of the Act, 42 U.S.C. § 7412. Congress designated 189 pollutants as HAPs and ordered EPA to identify and list all categories of sources of these pollutants. After that, the EPA was to set standards for listed categories of major sources that would decrease HAP emissions by maximum achievable levels (including potentially eliminating emissions), taking into consideration costs, with a minimum stringency based on the actual emissions of the best performing sources in each category. Electric power plants were not initially a listed source category. Rather, Congress instructed EPA to evaluate whether it was "appropriate and necessary" to regulate HAP emissions from these plants based in part on two studies that Congress directed the agency to carry out. The first was to examine the impacts on public health from HAP emissions from these facilities. The resulting Utility Study Report to Congress (1998) found that mercury was the HAP of greatest concern from this source category. The second, known as the Mercury Study Report to Congress (US EPA, 1997) provided an assessment of the magnitude of mercury emissions in the U.S. by source, the health and environmental implications of those emissions, and the availability and cost of control technologies. As mercury science was rapidly developing and evolving at the time, the Mercury Study provided an early perspective on mercury contamination and its potential management.

Largely based on information from these studies, in 2000 the EPA determined it was "appropriate and necessary" to regulate HAP emissions from coal- and oil-fired electric utilities. It therefore listed those power plants as a source category under section 112. However, in 2005, the EPA changed course. It reversed its earlier appropriate and necessary finding and removed coal- and oil-fired power plants as a source category under section 112. Instead, EPA issued a regulation under a different section of the Clean Air Act (section 111). This regulation, the Clean Air Mercury Rule (CAMR), established a national market-based cap and trade system to limit mercury emissions from coal-fired electric power plants. Under CAMR, a 10-ton reduction in mercury emissions from electric utilities was projected to occur by 2010, followed by a 33 ton, or 70%, reduction by 2018. In 2008, the United States Court of Appeals for the District of Columbia Circuit held that EPA had acted contrary to the statute in attempting to remove mercury from the list of hazardous air pollutants, and vacated CAMR (*New Jersey v. EPA*, 517 F.3d 574; D.C. Cir. 2008).

In 2011, EPA confirmed its earlier finding that it was appropriate and necessary to regulate HAP emissions from power plants and promulgated the Mercury and Air Toxics Standards (MATS). EPA concluded that it was "appropriate" to regulate these emissions because they posed hazards to public health and the environment, and that it was "necessary" to regulate them because other provisions of the Clean Air Act did not adequately address the hazards. MATS established national emissions standards for coal- and oil-fired power plants. Even though EPA did not consider the costs of the rule when making the "appropriate and necessary" finding, it prepared a Regulatory Impact Analysis (RIA) for MATS that examined the costs and benefits of the regulation, because Executive Order 12,866 required such an analysis for all "significant regulatory actions."

There were numerous limitations to this analysis. As a result of these limiting assumptions, direct benefits from MATS were under-estimated as being between $4-6 M. Large co-benefits (mostly from reductions in particulate matter emissions that would occur as a result of installing pollution-control equipment to limit mercury emissions) were associated with the MATS rule ($37-90 B), which far exceeded the cost of regulation. EPA acknowledged at the time that there was severe undercounting of direct benefits from mercury reductions, as well as the absence of any quantification of the health and environmental benefits from reductions in emissions of other HAPs. EPA determined as part of the MATS rule that the Clean Air Act rendered costs irrelevant to the decision whether regulation is "appropriate and necessary." Thus, EPA considered its evaluation of health benefits and regulatory costs in the 2011 rulemaking to be legally irrelevant to the "appropriateness" of regulation, and that the monetized health benefits from associated reductions in particulate matter were so large as to clearly preponderate over the estimated costs.

In 2015, the Supreme Court ruled that the EPA had committed legal error when it determined cost was irrelevant in finding it was appropriate to regulate HAP from coal and oil-fired electricity generating units (U.S. Supreme Court, *Michigan v. EPA*, 576 U.S. 743 (2015)). In 2016, in response to the Supreme Court decision, the EPA issued a supplemental finding that, after considering cost, regulating hazardous air pollutants from power plants is appropriate and necessary.

MATS has produced significant benefits. Since it was promulgated in 2011 and fully implemented by 2015, mercury emissions from coal-fired power plants have declined by 84 percent from 26.8 tons in 2011 to 4.4 tons in 2017 (US EPA 2020). Prior to 2011, after signaling from EPA that regulations would be promulgated, 11 states had implemented mercury emissions standards for power plants—thus even some of the pre-2011 reductions in mercury emissions are indirectly attributable to EPA's decision to regulate. In addition, MATS is central to the U.S. commitments for control of mercury releases under the 2017 Minamata Convention on Mercury. Coal-fired electric utilities are currently the second largest source of mercury emissions in the U.S.

On April 16, 2020, the EPA once again attempted to overturn the Agency's prior determination and found that it is not "appropriate and necessary" to regulate mercury and other HAP from power plants. The EPA left MATS in place but, by purportedly reversing the finding, removed the legal underpinning of MATS, thereby inviting challenges to the emissions standards. The EPA also issued a "Residual Risk and Technology Review" at that time, which concluded that no further emissions reductions were warranted from affected power plants to protect human health. The decision to reverse the appropriate and necessary finding was based in large part on the limited and flawed cost-benefit analysis that was conducted for the 2011 RIA and never updated. Scientists have repeatedly pointed out that the methods and findings in this earlier assessment are inconsistent with current science on mercury exposure, the societal impacts of mercury pollution in the U.S., and the full benefits of emissions controls (Sunderland et al., 2016; Giang et al., 2016). EPA's Science Advisory Board also issued a report urging the Agency to develop a new mercury exposure estimate that would consider cardiovascular effects before finalizing the residual risk assessment (Science Advisory Board, 2020).

The anticipated EPA action is once again expected confirm the appropriate and necessary finding. The proposal may again estimate the costs and some of the benefits of regulating HAP from power plants. The proposal from EPA presents an opportunity to ensure that the Agency uses the best available science in its "appropriate and necessary" reaffirmation and to inform future residual risk and technology reviews to ensure that the progress that has been made in protecting human and environmental health is accurately characterized and sustained.

The Direct Benefits of Reducing Mercury Emissions Are Much Larger Than EPA Previously Estimated

Pollution controls on power plants have resulted in large reductions in atmospheric mercury concentrations and deposition (Zhang et al., 2016; Olson et al., 2020). Concentrations of mercury in the air and the amount of mercury deposited to U.S. ecosystems have both declined substantially after domestic reductions in mercury emissions (Castro and Sherwell, 2015; Zhou et al., 2016). Mercury concentrations in precipitation in the eastern U.S. proximate to major mercury emission sources that have implemented emission controls, closed, or shifted fuel sources show some of the greatest declines (Olson et al., 2020). Decreases in domestic mercury emissions from U.S. coal-fired utilities have been directly linked to declines in mercury concentrations in water, fish and sediment in the Great Lakes based on measurements of mercury stable isotopes (Lepak et al., 2015; 2019). Other studies have noted decreases in mercury concentrations in soils and sediments coincident with declines in emissions from U.S. sources (Drevnick et al., 2012). Declining trends in fish mercury have been observed in Massachusetts (Hutcheson et al., 2014), New York (Evers et al., 2020), and coastal fisheries (Cross et al., 2015). The estimated number of children born in the U.S. each year with prenatal exposure to methylmercury levels that exceed the EPA reference dose has decreased by half from 200,000- 465,000 in 1999/2000 to 105,000-263,000 in 2017/2018, depending on the measure used (EPA 2013, CDC 2021).

The 2011 RIA for the MATS rule only quantified benefits associated with a limited set of methylmercury exposures, specifically those of the children of freshwater recreational anglers who are exposed in utero. In contrast, the 2011-2012 National Health and Nutrition Examination Survey (NHANES) data published by the Centers for Disease Control and Prevention (CDC) data showed that 93% of U.S. individuals had detectable levels of mercury in their blood (Mortensen et al., 2014). This means that EPA's analysis did not consider risks attributable to EGU exposures for most of the U.S. population. Further, the main source of methylmercury exposure in the U.S. population is seafood sold in the commercial market. Of these fish, 82% are marine species, with more than 30% from domestic coastal ecosystems. Mahaffey et al. (2009) noted that the highest blood mercury levels in the U.S. population were found in people living in coastal areas.

Even among the small subset of exposures it addressed, EPA's quantified benefits analysis for mercury in the 2011 MATS rule also only considered one kind of effect: IQ reductions. The diverse health outcomes that have been associated with methylmercury exposures in the scientific literature are acknowledged, but not quantified, in the MATS RIA. These unquantified health impacts of methylmercury exposure include developmental delays, impacts on memory and behavior, cardiovascular effects for adults (i.e., risks of fatal heart attack), genotoxicity, and immunotoxicity.

In contrast to the extremely narrow set of quantified benefits in the 2011 RIA, some researchers have attempted to quantify the effects of methylmercury exposure more comprehensively. For example, the societal costs of neurocognitive deficits associated with all sources of methylmercury exposure in the U.S. have been estimated at approximately $4.8 billion (Grandjean and Bellanger, 2017). Studies that monetize additional health endpoints associated with methylmercury exposure, such as cardiovascular effects, and more comprehensively account for the exposed population within the U.S., suggest that the monetized benefits of reducing power plant mercury emissions in the U.S. are in the range of several billion dollars per year (Rice et al., 2010; Giang and Selin, 2016; Sunderland et al., 2016). These and other studies support the conclusion that mercury-related benefits from MATS are more than one hundred times greater than EPA estimated in the 2011 RIA. Even with these more comprehensive estimates, substantial benefits of controlling mercury and other air toxics remain unquantified due to data limitations (Sunderland et al., 2016). For example, benefits associated with reducing environmental mercury exposures for wildlife species such as songbirds, otters and loons have not been quantified and are likely substantial. Other unquantified human health benefits associated with reductions in methylmercury exposure that have not been monetized include endocrine effects (Tan et al., 2009), reduced risk of diabetes (He et al., 2013) and improved immune function (Nyland et al., 2011). Further, current benefits analyses do not address environmental justice concerns or directly account for the variation in mercury exposures by geography, income, race, and ethnicity or assess the distribution of benefits across these population subgroups.

Costs of Mercury Emissions Reductions Were Much Lower than EPA Previously Estimated

In 2011, EPA estimated the costs of complying with MATS at $9.6B/yr. This value was much higher than the actual cost (EPA, 2016). This situation—in which the projected compliance costs greatly exceed the actual costs—is common with environmental regulations. When a new or more stringent emissions limit is introduced, demand for control technology increases and companies are incentivized to innovate. These changes, combined with more widespread use of and experience with the technology and the regulatory process, result in technological advancements and cost reductions.

A 2015 analysis by James Staudt of Andover Technology Partners[1*] showed that the actual annual cost of compliance in the initial years of MATS implementation was approximately $2 billion—more than $7 billion lower than EPA had estimated in 2011. The Staudt/Andover study determined that this decrease was attributed to improvements in dry sorbent injection and activated carbon injection technologies that significantly lowered the costs of those

[1*] Declaration of James E. Staudt, Ph.D., CFA, at 3, *White Stallion Energy Center v. EPA*, No. 12-1100 (D.C. Cir. Dec. 24, 2015). James E. Staudt, Ph.D., Update of the Cost of Compliance with MATS—Ongoing Costs of Control (May 25, 2017) (Exhibit 1 to Letter from Brian Leen, President and Chief Executive Officer, ADA Carbon Solutions, LLC, to Peter Tsirigotis, Director, Office of Air Quality Planning and Standards, EPA (June 29, 2018) , *available at* https://www.sierraclub.org/sites/www.sierraclub.org/files/blog/ADA%20Carbon%20Solutions%20Letter.pdf.

pollution control systems; significantly lower natural gas prices than those used by EPA in the 2011 RIA estimates; and overestimates in the generation capacity that would require installation of fabric filters (also known as baghouses), dry flue gas desulfurization ("FGD") systems and wet FGD upgrades.

The entire industry has now come into compliance with the MATS rule. It is therefore not necessary for the EPA to rely on *ex ante* predictions of compliance costs. The EPA should use actual compliance costs as the basis for an updated cost-benefit analysis.

The Bottom Line

The science is clear: mercury emissions from U.S. power plants cause a variety of serious health harms, and the value of reducing emissions is orders of magnitude higher than EPA's initial effort at monetization for the 2011 rulemaking. We also know that the costs of complying with the rule were much lower than the 2011 estimates. Together, the larger benefits and lower costs lead to much higher net benefits from reducing mercury than EPA previously estimated. The health impacts of mercury emissions in the U.S. are large and disproportionately affect children and other vulnerable populations. Domestic mercury emission standards have markedly reduced mercury in the environment and improved human and wildlife health. The mercury-related benefits alone of the MATS rule greatly exceed values the EPA has estimated, the actual costs appear to be substantially lower than EPA has projected, and the total monetized benefits across all pollutants mitigated far outweigh the cost of the standards.

We strongly urge the EPA to analyze closely, and wherever possible, quantify and monetize the full range of benefits associated with reducing mercury emissions from electric utilities and to revise its Risk and Technology Review (RTR). An updated and retrospective analysis of the benefits of controlling mercury emissions from U.S. coal-fired utilities provides an opportunity to correct the public record and more comprehensively characterize and quantify the costs and benefits of MATS. In Part II of this white paper, we outline a roadmap for such an analysis that would reflect the state-of-the-science understanding of mercury cycling and accumulation in the environment and effects on the health of humans and wildlife.

Part II: Roadmap for a Retrospective Analysis of Benefits of Mercury Emissions Controls on U.S. Coal-Fired Utilities and Improving Future Residual Risk Analyses

1. Temporal Changes in Mercury Emissions from Coal-Fired Power Plants

State-of-the-Science: Coal-fired power generation peaked in 1998 (Figure 2), when EPA submitted the Utility Study Report to Congress. A preliminary risk-screening in this report identified "a plausible risk" to human and ecological health associated with mercury emissions and deposition from U.S. coal-fired power plants. Total U.S. electric power generation increased from 1949 - 2005, and then plateaued from 2005 - 2020. By contrast, electricity generation from coal increased between 1949 and 2008 and decreased thereafter (Figure 2).

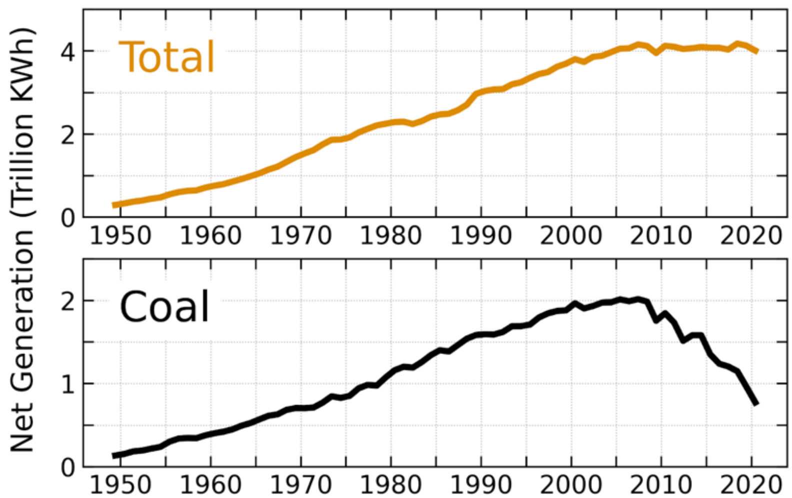

Figure 2 | Temporal trends in net electric power generation in the United States (1949 - 2020). Total generation (top, yellow). Electricity generation from coal (black, bottom). Data are from the US EIA *Monthly Energy Review.*

Large changes in the energy sector and declines in mercury emissions have been observed since 2011 due to declining utilization of coal, application of emission controls and retirements of coal-fired units (Figure 3). Between 2010 and 2017, annual mercury emissions from electric generating units (EGUs) decreased 84%. Throughout this period, coal-fired power plants had been the dominant mercury source among EGUs, responsible for greater than 99% of mercury emissions in the 2010 MATS information collection request (ICR).

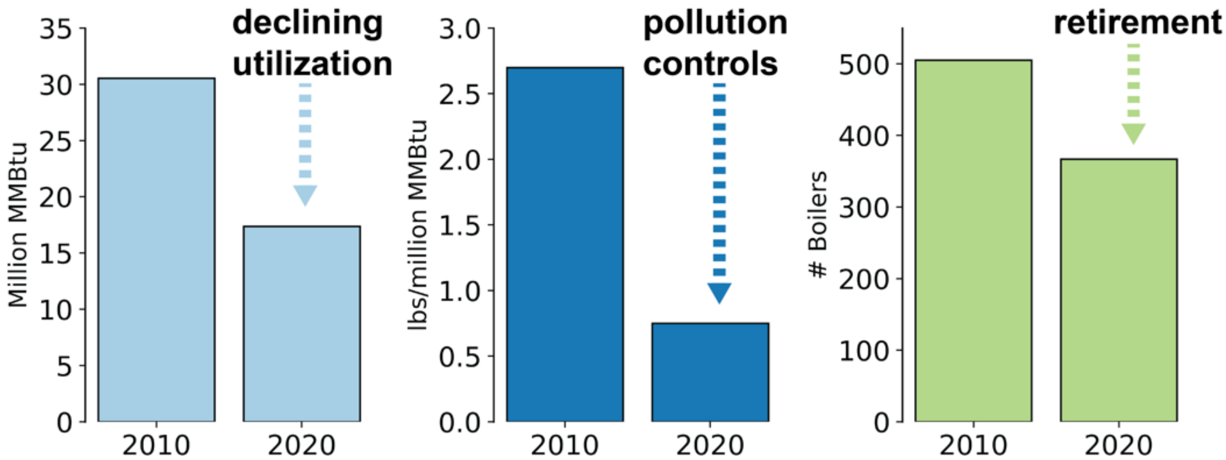

Figure 3| Change in coal-fired EGU characteristics between the MATS ICR (2010) and MATS reporting (2017 - 2020). Coal-fired EGUs have shown declining heat input (*left*), emission factors (*center*), and count (*right*). Annotations represent factors contributing to these changes. For consistency, we show trends for only the EGUs represented in both the ICR and MATS reporting.

Prior to the MATS rule, coal-fired power plants were the largest source of mercury emissions in the U.S. (Figure 4). As a result of the large temporal changes in mercury emissions, the benefits associated with emissions controls for coal-fired utilities are strongly affected by the baseline year chosen to index changes. Some states began to develop their own emissions control strategies prior to the MATS rule and industry trade journals indicate the utility sector began to plan for regulation in the late-1990s. Maximum benefits associated with reducing mercury emissions from coal-fired power plants would be estimated by comparing peak-emissions years (i.e., sometime between 1990 and 2005) to the most recent values. Regulatory benefits for the MATS rule would need to be related specifically to those actions taken under Section 112 of the *Clean Air Act*.

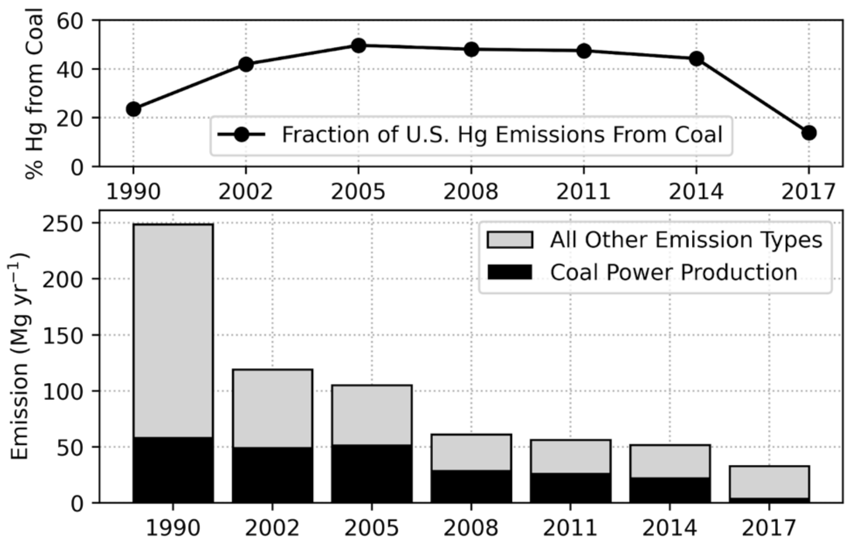

Figure 4 | United States mercury emissions (1990 - 2017). Bottom: Annual mercury emissions from coal-fired power plants (*black*) and total U.S. emissions (*black + gray*). Top: the fraction of total domestic emissions from coal combustion. Data are from the US EPA *National Emissions Inventory* (NEI).

The US EPA National Emissions Inventory (NEI) provides a useful assessment of total domestic mercury emissions, including emissions attributable to coal-fired utilities. The 2011 MATS proposal used 2005 as the baseline year for the analysis (Figure 5). Emissions projected for 2016 in the MATS proposal overestimated actual emissions compiled by NEI. Further, Zhang et al. (2016) corrected an error in reporting by EPA of the speciation of mercury released by utilities that resulted in an underestimate of declines in deposition of Hg(II) following addition of pollution controls. These discrepancies emphasize the need for a retrospective benefits analysis based on confirmed NEI data.

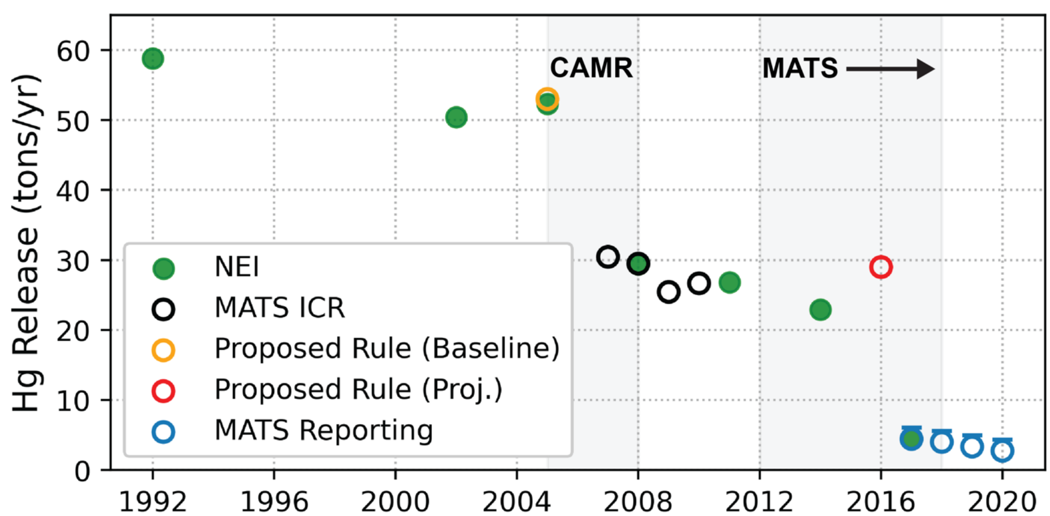

Figure 5 |Comparison of different data sources on mercury releases from coal-fired power plants. Data are from the US EPA *National Emissions Inventory* (NEI) (green), the MATS ICR (black), the MATS Regulatory Impact Assessment baseline (gold) and projection (red), and MATS hourly reporting data (blue). Blue dashes on the upper part of blue circles represent upper-bound emissions from low-emitting coal EGUs exempted from hourly reporting requirements. Shaded regions represent active years for the Clean Air Mercury Rule (CAMR) and MATS. We exclude the 2002 – 2006 estimates from the MATS ICR due to the lack of available emission factors in the data prior to 2010.

Recommendation: An updated analysis of the benefits of emissions controls for coal-fired power plants should be conducted. We recommend best-available data on U.S. mercury emissions sources and speciation that are incorporated in the NEI be used for such an analysis.

2. Total and Utility-Attributable Mercury Deposition in U.S. Ecosystems

State-of-the-Science: Mercury deposition in U.S. ecosystems is derived from domestic and global anthropogenic sources, and natural and reemitted historical mercury. Information on changes in global and domestic emissions over time is needed, in combination with information on atmospheric chemistry and transport, to understand and attribute changes in mercury inputs to U.S. ecosystems. Typically, such an analysis is conducted by running a 3-D atmospheric chemical transport model (CTM) and calculating wet and dry deposition of mercury to U.S. ecosystems with and without emissions from U.S. coal-fired power plants. Temporal changes in mercury deposition are computed by forcing the model analysis with emissions values for different years. Differences among model simulations result from variability in emissions information used as an input for the analysis and the simulated atmospheric chemistry of mercury. Importantly, mercury undergoes reactions (oxidation-reduction (redox) chemistry) in the atmosphere that convert mercury from the stable, long-lived form (Hg(0)) to the rapidly deposited form (Hg(II)) (Figure 1).

Extensive research on mercury emissions and atmospheric mercury chemistry has occurred since the MATS RIA was developed. Several emissions inventories have been produced that are useful for analyzing changes in U.S. mercury deposition. Streets et al. (2019) developed the most temporally and spatially consistent estimate of global mercury emissions that we recommend for specifying global boundary conditions for this analysis. The GEOS-Chem model was used in the original MATS RIA to simulate the boundary conditions for a regional atmospheric chemical transport model (Community Multiscale Air Quality; CMAQ). Updated versions of these models could be used in the proposed analysis (Ye et al., 2018; Shah et al., 2021).

Shah et al. (2021) developed a state-of-the-science simulation of atmospheric mercury redox chemistry within the GEOS-Chem model (Figure 6). The new simulation framework considers chemical reactions discovered after the MATS RIA based on measured photolysis rates and quantum chemistry calculations. The chemical reaction scheme used in this model should be incorporated into an updated version of the CMAQ model used in the original MATS analysis. The version of the CMAQ regional atmospheric model used in the 2011 MATS RIA no longer reflects best-available understanding of atmospheric mercury chemistry and deposition and therefore such analyses need to be updated. This approach is important because the locally deposited fraction of mercury releases was underestimated in the modeling conducted for the 2011 MATS RIA.

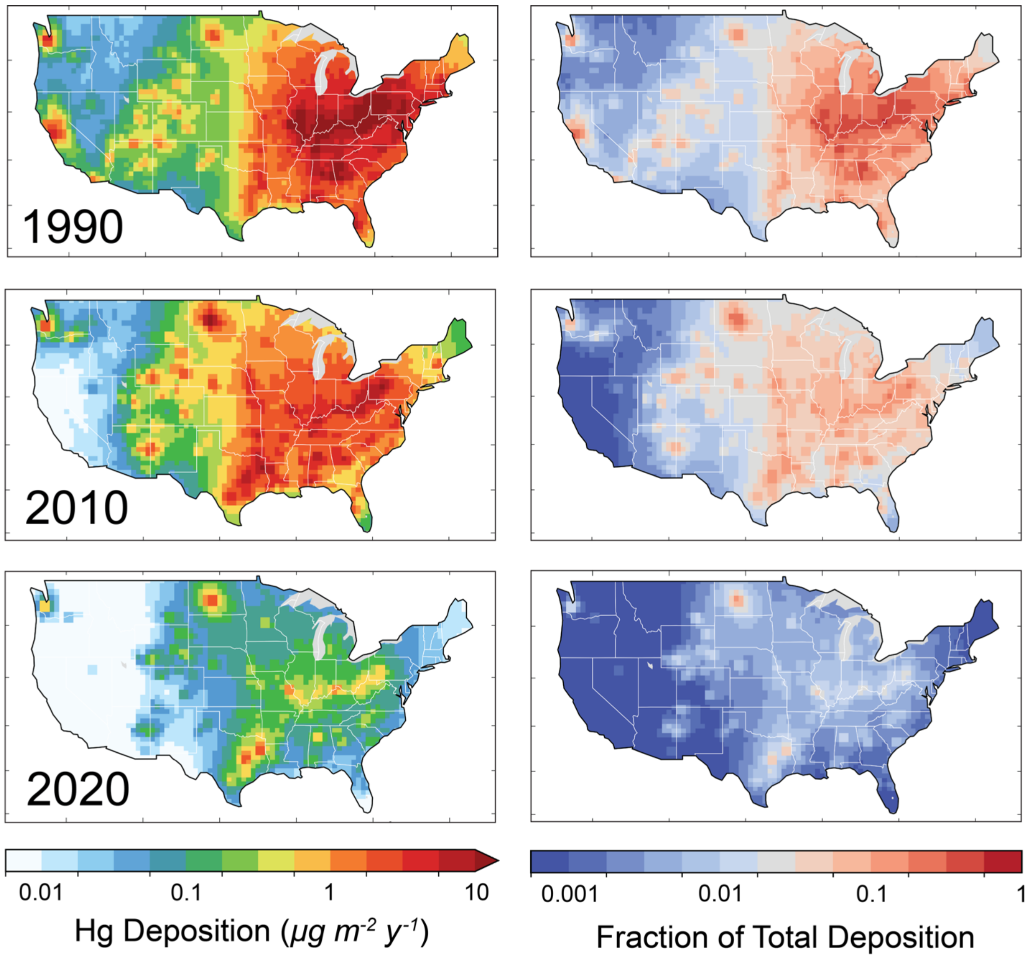

Figure 6 |Simulated mercury deposition to U.S. ecosystems resulting from electric power generation (l*eft*) and the utility attributable deposition fraction (*right*). Simulations are based on the new atmospheric chemistry described in Shah et al. (2021), implemented in the GEOS-Chem global atmospheric chemistry model. Simulations were performed for 1990, 2010, and 2020 and are arranged chronologically from top to bottom.

The fraction of mercury deposition to the U.S. from U.S. emission sources has declined from a surface area-weighted mean of 23-35% of total deposition in the 1990s to 1-5% in 2020, reflecting the success of domestic mercury regulations and emissions control strategies. Mercury emissions from global sources have been increasing over the same period, resulting in a less dramatic decline in the overall magnitude of deposition than domestic releases (Figure 7).

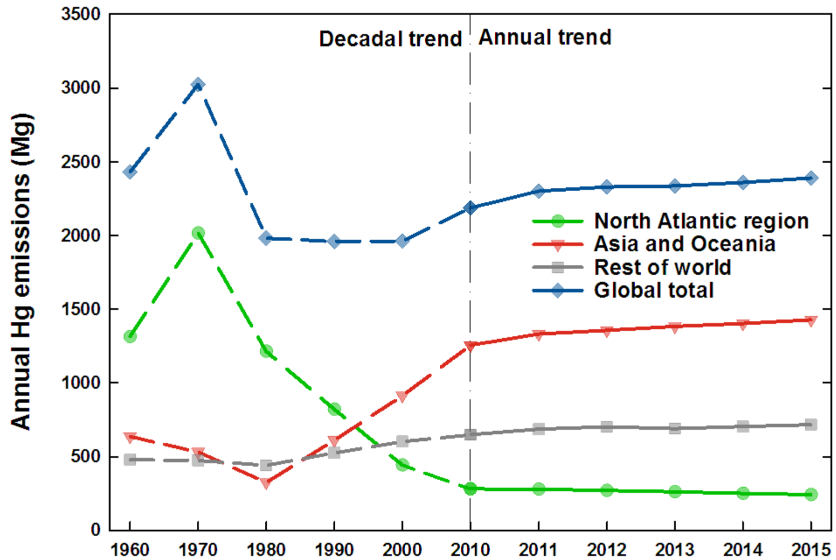

Figure 7 | Decadal changes in global emissions of mercury from anthropogenic sources. Figure from Streets et al. (2019).

Recommendation: Updated atmospheric models that reflect best-available understanding of atmospheric mercury emissions, chemistry, and transport should be used for an updated analysis of utility-attributable deposition, the fraction of total U.S. deposition attributable to utilities, and the proportion of deposition from global sources. We recommend implementing the updated atmospheric redox chemistry for mercury within the CMAQ model used by EPA for the 2011 MATS RIA. We expect that these updates will result in an increase in mercury deposition declines attributable to U.S. utilities and associated benefits.

3. Accumulation of Utility-Derived Mercury in Fish Consumed by U.S. Individuals

State-of-the-Science: Most mercury exposure in the U.S. population is associated with seafood consumption. A major limitation of the analysis in the 2011 MATS RIA was that only benefits associated with reductions in the accumulation of utility-derived mercury in freshwater fish caught by recreational anglers were quantified. Most people in the U.S. consume fish supplied by the commercial market, with more than 80% from estuarine and marine ecosystems (Sunderland et al., 2007; 2018). Mercury emitted from U.S. coal-fired power plants is transported to domestic water bodies across the country, including both freshwater and coastal ecosystems. A substantial fraction of commercial market fish consumed in the U.S. is from domestic harvests of estuarine fish on North Atlantic and North Pacific coasts (Figure 8).

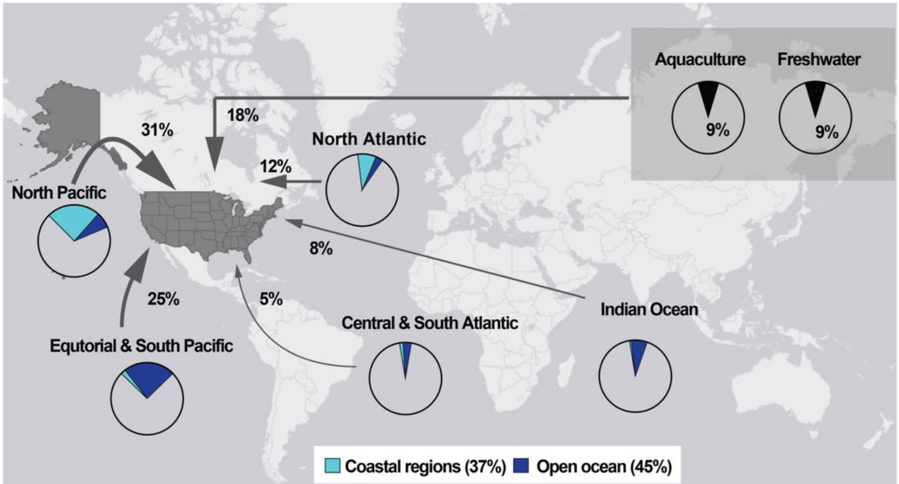

Figure 8|Sources of U.S. population mercury intake from the commercial seafood market. Figure from Sunderland et al. (2018).

In the MATS RIA, EPA stated that it was “virtually impossible” to quantify utility-derived mercury in fish and outside of those consumed by recreational anglers. Yet the RIA also acknowledged that most of the seafood consumed by U.S. individuals is obtained from the commercial market. We propose an approach for addressing this pathway for the general population of U.S. seafood consumers.

First, we recommend establishing a baseline mercury exposure level for all individuals aged 18+ in the U.S. using NHANES data for 1999/2000 or 2001-2018 based on their reported number of seafood meals (Figure 9). Exposure reflects the product of mercury concentrations in consumed fish and the amounts of fish consumed. Women of childbearing age and all individuals aged 18+ can be separated in this analysis for later calculation of the relevant health endpoints (i.e., neurocognitive or cardiovascular health endpoints). EPA calculated the number of individuals who are recreational anglers in the 2011 RIA for each state based on survey data from the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation maintained by the Department of the Interior. This population should be separated (subtracted) from the rest of the U.S. population categorized as general seafood consumption to avoid double counting of exposure estimates.

Since NHANES is statistically representative of the U.S. population, these data can be used to estimate numbers of individuals and distributions of exposure that reflect different seafood consumption preferences that result in higher or lower mercury exposures. Dietary intake rates can be estimated by grouping individuals by their reported number of seafood meals (Figure 9).

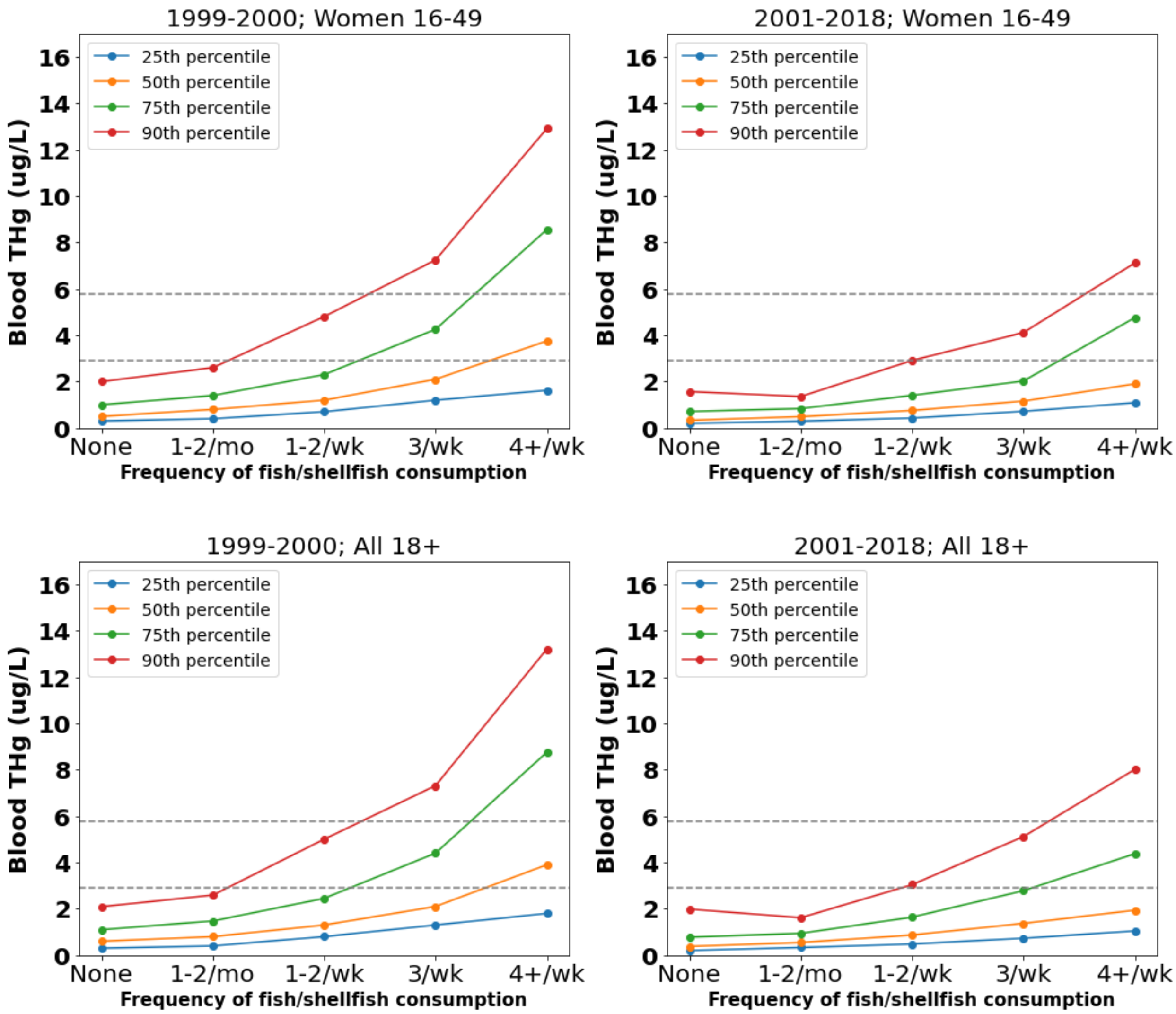

Figure 9|Percentiles of exposure indicated by blood total mercury levels as a function of seafood consumption for all individuals aged 18+ in the U.S. Dashed lines correspond to EPA's reference dose (RfD) for methylmercury (upper dashed line) and proposed revised RfD after accounting for imprecision in exposure biomarkers (lower dashed line) based on the analysis by Grandjean and Budtz-Jorgensen (2007). Data from CDC/NHANES (https://wwwn.cdc.gov/nchs/nhanes/).

Next, a probabilistic version of EPA's one compartment toxicokinetic model (Li et al., 2016) based on best estimates of model parameters and their uncertainty could be used to back calculate the ingested dose of methylmercury that corresponds to observed blood mercury levels. The fish meals corresponding to each dose can be simulated by assigning probabilities of consuming different types of seafood based on U.S. market preferences and their corresponding mercury concentrations and optimizing these selections to match the ingested methylmercury dose (Figure 10). The fractions of each seafood category harvested from domestic ecosystems are available in Sunderland et al. (2018), providing an indication of methylmercury in ingested seafood from coastal and freshwater systems that are affected by changes in utility emissions of mercury.

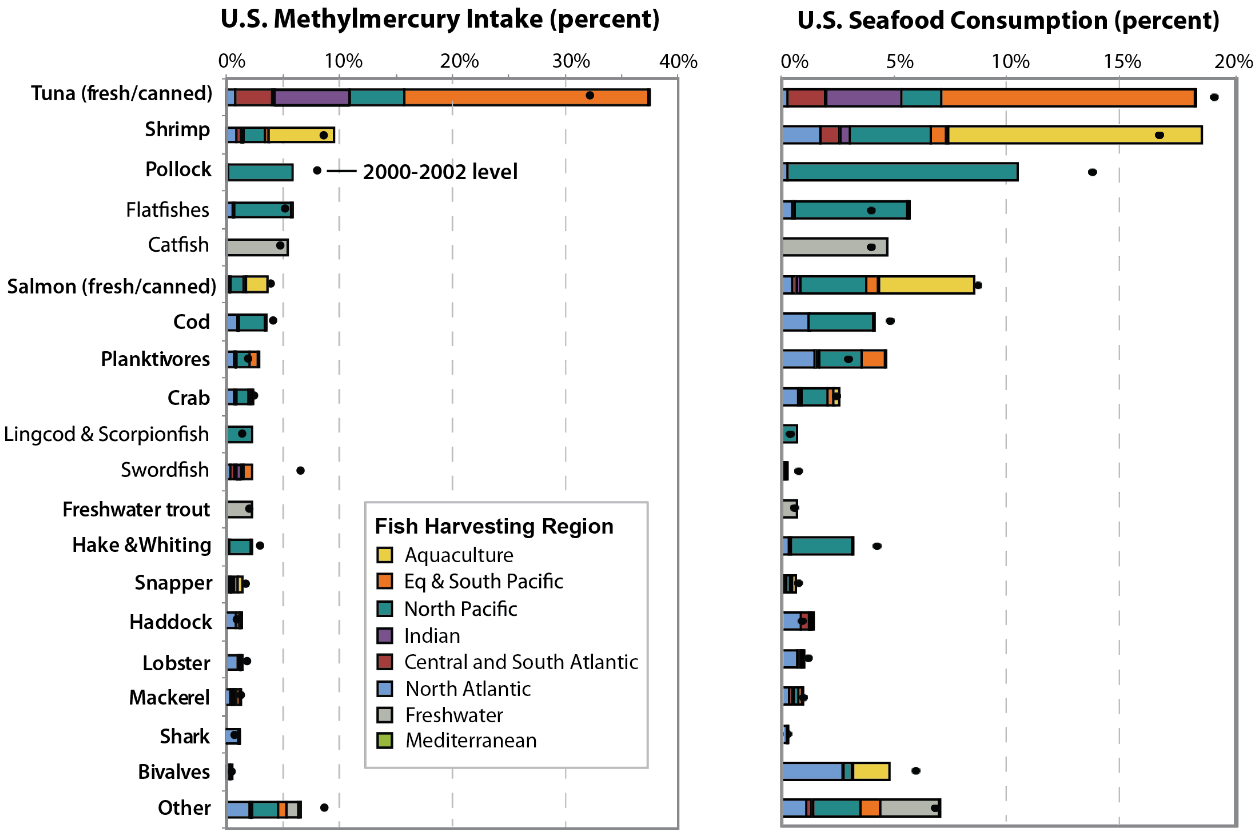

Figure 10|Seafood categories and their ecosystem origins for population-level methylmercury intake (*left*) and seafood consumption (*right*). Figure from Sunderland et al. (2018).

An approach for characterizing the relationship between changes in mercury emissions from coal-fired power plants and deposition to U.S. ecosystems was described in section 2 of this white paper. In the MATS RIA, a proportional change in freshwater fish mercury concentrations with shifts in atmospheric mercury deposited to freshwater ecosystems was assumed. We propose the same approach could be used for both coastal and freshwater fish for the revised analysis. This approach is reasonable because scientific research now shows that most methylmercury accumulated in coastal fish is derived from the water column rather than a sediment source, and therefore will respond more rapidly to shifts in atmospheric inputs than previously expected (Chen et al., 2014; Sunderland et al., 2010; Schartup et al., 2015). The potential lag times of both freshwater and estuarine ecosystems could be explored using sensitivity scenarios for response times characterized in prior work (Knightes et al., 2009; Harris et al., 2007; Lepak et al., 2019).

Recommendation: We recommend that EPA analyze the exposure pathway for methylmercury for the U.S. general population that includes domestic commercial market seafood consumption that is affected by utility emissions of mercury, in addition to that for recreational anglers. An approach for conducting such an analysis is outlined above. This approach will result in a more accurate assessment of the population that is affected by methylmercury exposure from controlling mercury emissions from U.S. power plants. Such an analysis would also support estimates of changes in methylmercury exposure by population subgroups.

4. Health Benefits Associated with Reducing Mercury Emissions from Utilities

4a. Cumulative Effects

State-of-the-Science: EPA's RIA for the 2011 MATS rule only considered the health effects associated with utility-attributable mercury exposure without accounting for additional mercury exposure. Health effects from methylmercury exposure reflect the accumulated body burden and concentrations of this toxicant at active sites within the body. The human body is unable to distinguish utility-derived mercury from other sources and thus such an abstraction is difficult to justify from a health perspective. For other risk-based decisions, a "relative-source contribution" (RSC) is commonly used to account for exposures to a pollutant that originate outside of the pathway being considered for regulation. For example, recreational fish consumption advisories for methylmercury commonly assume a default relative source contribution (RSC) of the recreational fishing activity of 20%, with 80% of exposures assumed to originate from other sources (US EPA, 2000). Given the ubiquity of mercury in the environment, it is essential to account for exposures from all sources when considering potential health effects, especially if a threshold such as the reference dose (RfD) is used for such assessments. Inputs of utility-derived mercury together with mercury from other sources may result in an exposure individual above the RfD and regulations may prevent an individual from exceeding the RfD. Such a methodology would confer a higher monetized value than when benefits are estimated without accounting for cumulative exposure. Not accounting for cumulative exposure may also perpetuate the disproportionate burden borne by some communities.

Recommendation: EPA should account for cumulative exposure to mercury, in addition to utility mercury exposure, when estimating the benefits of reducing mercury emissions. This could be accomplished by developing a utility-attributable RSC. Such an approach would better capture the full health benefits of emission regulation.

4b. Reference Dose

State-of-the-Science: A critical factor affecting the assessment of benefits for the 2011 MATS RIA was the choice of health endpoints considered in EPA's analysis. EPA's RfD for methylmercury is based on a benchmark dose for IQ impacts observed in longitudinal birth cohorts from the Faroe Islands that studied children exposed to methylmercury during pregnancy (NRC, 2000). Full IQ was chosen as the benchmark dose health endpoint by the National Academies Panel established to derive the RfD, in part, because of its consistency with effects observed in other studies. However, IQ was not the most sensitive neurocognitive impact of methylmercury exposure documented in the literature in 2000, when the Panel produced its report. When calculating the RfD, EPA relied heavily on an epidemiological study of a Faroe Island cohort (Grandjean et al., 1997). The most sensitive endpoints from this same study were for tests related to word retrieval and acquisition and retention of verbal information. As EPA acknowledged in its 2019 proposal to update the Integrated Risk Information System (IRIS) assessment of the health effects for methylmercury, the original RfD established for methylmercury is now outdated. Further, subsequent studies have shown that correcting for the negative confounding of omega-3 fatty acids in seafood on neurodevelopment results in a steeper dose-response relationship between methylmercury exposure and IQ (Choi et al., 2008).

Neonatal studies conducted in the United States, Europe, China, and Japan have consistently found low-level exposure to methylmercury below the RfD established by EPA to be associated with adverse neurobehavioral development (Lederman et al., 2008; Oken et al., 2008; Vejrup et al., 2018; Jedrychowski et al., 2006; Wu et al., 2014; Gao et al., 2007; Suzuki et la., 2010). For example, a study conducted in Boston showed adverse effects associated with prenatal methylmercury exposure on memory and learning, especially visual memory, in children (Orenstein et al., 2014).

Although many studies of methylmercury toxicity focus on prenatal exposure because fetal brains are developing and thus more vulnerable, effects of adult exposures have also been documented. A key concern with exposure in adults is that it may accelerate age-related declines (Rice and Barone, 2000). Fine-motor function and verbal memory are compromised among adults who are exposed to elevated amounts of methylmercury, which is consistent with outcomes observed in children with prenatal exposures (Yokoo et al., 2003). This observation makes the general population exposure analysis discussed in Section 3 even more important for a revised benefits assessment.

Recommendation: EPA should expand the suite of health endpoints considered in its analysis to quantify the health benefits for sensitive neurocognitive outcomes such as memory, delayed learning, and behavioral impacts, in addition to IQ, for both children and adults. The effects on these endpoints below the RfD should be analyzed and included in the benefits estimate. The dose-response relationship between IQ and methylmercury used in the original analysis should be updated to reflect the latest scientific understanding. Specifically, a steeper dose-response relationship is expected following correction for the confounding impacts of omega-3 fatty acids.

4c. Cardiovascular risks

State-of-the-Science: High concentrations of methylmercury in blood and tissue samples have been associated with acute coronary events, coronary heart disease, and cardiovascular disease (Virtanen et al., 2004). The 2000 NRC report concluded that methylmercury accumulates in the heart and leads to blood pressure alterations and abnormal cardiac functions (NRC, 2000). Subsequent research has strengthened these findings. An expert panel convened in 2011 to study the health effects of methylmercury concluded that there was sufficient scientific evidence to incorporate cardiovascular health benefits in EPA's regulatory assessments (Roman et al., 2011). According to the panel, methylmercury is both directly linked to acute myocardial infarction and causes intermediary impacts that can contribute to myocardial infarction risk (Roman et al., 2011). The intermediary impacts include oxidative stress, atherosclerosis, heart rate variability, and to a certain degree, blood pressure and hypertension. Two systematic reviews of the association between methylmercury exposure and heart disease showed that methylmercury enhances production of free radicals resulting in a long-lasting range of effects on cardiac parasympathetic activity, such as myocardial infarction, hypertension, blood pressure, and death (Genchi et al., 2017; Hu et al., 2021). Additionally, the effect of prenatal methylmercury exposure on blood pressure is more pronounced among children with lower birth weights. Comparing boys who had a mercury cord blood concentration of 10 ug/L to those who had 1 ug/L, heart rate variability was found to decrease significantly by 47% (Sørensen et al., 1999).

Including cardiovascular health risks associated with methylmercury exposure is essential for a comprehensive benefits analysis. The number of children born per year in the U.S. with blood mercury levels that exceed EPA's RfD (hundreds of thousands) is much lower than the number of individuals (adults 18+) in the U.S. population with hair Hg levels (1-2 ug/g) that exceed the threshold for increased risk of multiple adverse cardiovascular endpoints based on a recent systematic review of the literature (Hu et al., 2021). Furthermore, EPA has stated that it plans to look into identifying a RfD specific cardiovascular effects (US EPA, 2020b). Blood mercury exposure levels measured in NHANES suggest millions of U.S. adults are at risk of fatal heart attacks, and more than 10 million individuals are at risk of non-fatal ischemic heart disease (Figure 11).

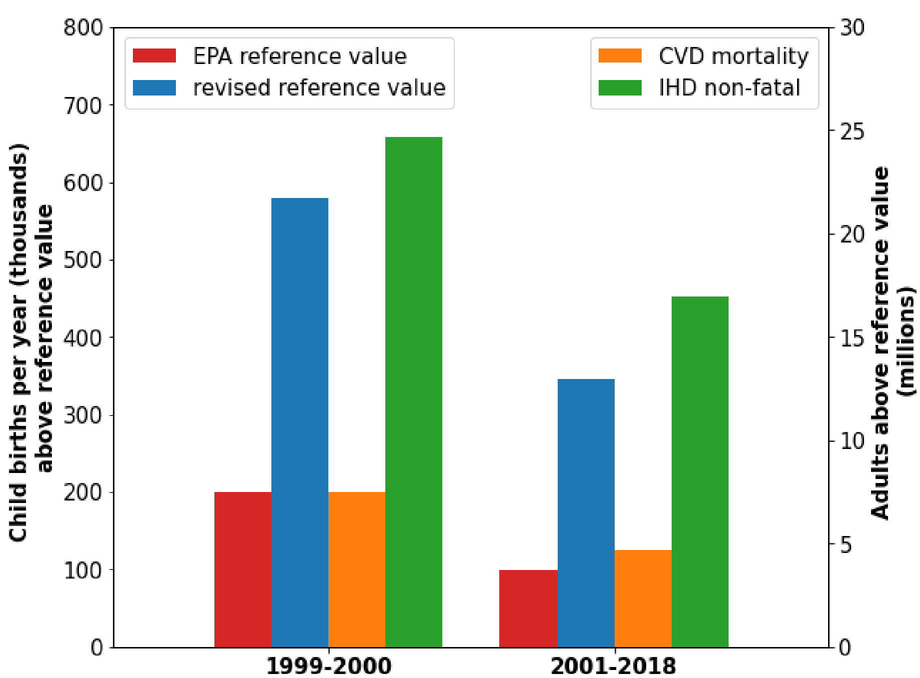

Figure 11|Number of U.S. individuals at risk for adverse health effects due to methylmercury exposure. Data are from CDC/NHANES blood Hg measurements, extrapolated to the entire U.S. population. The two left bars for each period show the number of U.S. children born each year that exceed the existing U.S. EPA reference dose (RfD) for methylmercury (red bar), and the proposed revision to the reference dose that accounts for imprecision in exposure biomarkers (Bellinger et al., 2013). The right bars reflect the population of adults (age 18+) at risk of impaired cardiovascular health due to methylmercury exposures that were identified in the systematic review by Hu et al. (2021). The orange bar represents the threshold where risk of fatal cardiovascular mortality increases, and the green bar represents the threshold for non-fatal ischemic heart disease.

Recommendation: Strong evidence for impacts of methylmercury exposure on cardiovascular health warrants the inclusion of cardiovascular impacts in the benefits assessment by EPA.

5. Roadmap for Residual Risk and Environmental Justice Assessment

State-of-the-Science: It is important to identify individuals who are most highly exposed to mercury and estimate any residual risks following implementation of the MATS rule (Figure 6). In the 2011 RIA, EPA estimated methylmercury exposures of recreational anglers, a sub-population that is typically highly exposed. For this analysis, EPA assumed that all women weighed 65 kg and consumed 8 g of seafood per day (0.12 g/kg body weight/day). This assumed rate is much lower than expected consumption rates among the highly exposed population and should be updated (Table 2).

Data on high-frequency seafood consumers are limited in NHANES to a few hundred individuals per survey cycle. To address this data gap, von Stackelberg et al. (2017) conducted a nationally representative survey of high-frequency fish consumers. The inclusion criterion for this study was consumption of more than 3 fish meals per week, which corresponds to the 95th percentile consumer in the NHANES survey. These data provide more appropriate seafood consumption rates for a residual risk analysis and suggest that values used in the 2011 RIA underestimate methylmercury exposure and associated health risks, especially for lower incomes households and those with less than a high school education.

Table 2|Consumption rates for high frequency fish consumers (>3 meals/week).

Description	**Mean (95% CI) (g/kg-day)**	**Mean (95% CI) (g/day)**
All participants	1.5 (1.4-1.6)	111 (106-116)
Recreational/self-caught anglers	1.7 (1.5-2.0)	130 (116-145)
Exclusively self-caught anglers	1.5 (1.2-1.9)	115 (392-138)

Less than high school education	2.1 (1.5-2.6)	149 (111-185)
Less than 20K household income	1.9 (1.6-2.2)	136 (112-156)

Data from von Stackelberg et al. (2017).

There is also evidence that disparities in methylmercury exposure exist in the U.S. population. For example, U.S. individuals who identified their ethnicity as "other" (i.e., Asian, Pacific and Caribbean Islander, Native American, Alaska Native, multi-racial and unknown race) consistently have blood mercury levels that are higher than other demographic groups between 2001-2018 based on NHANES/CDC data (Figure 12).

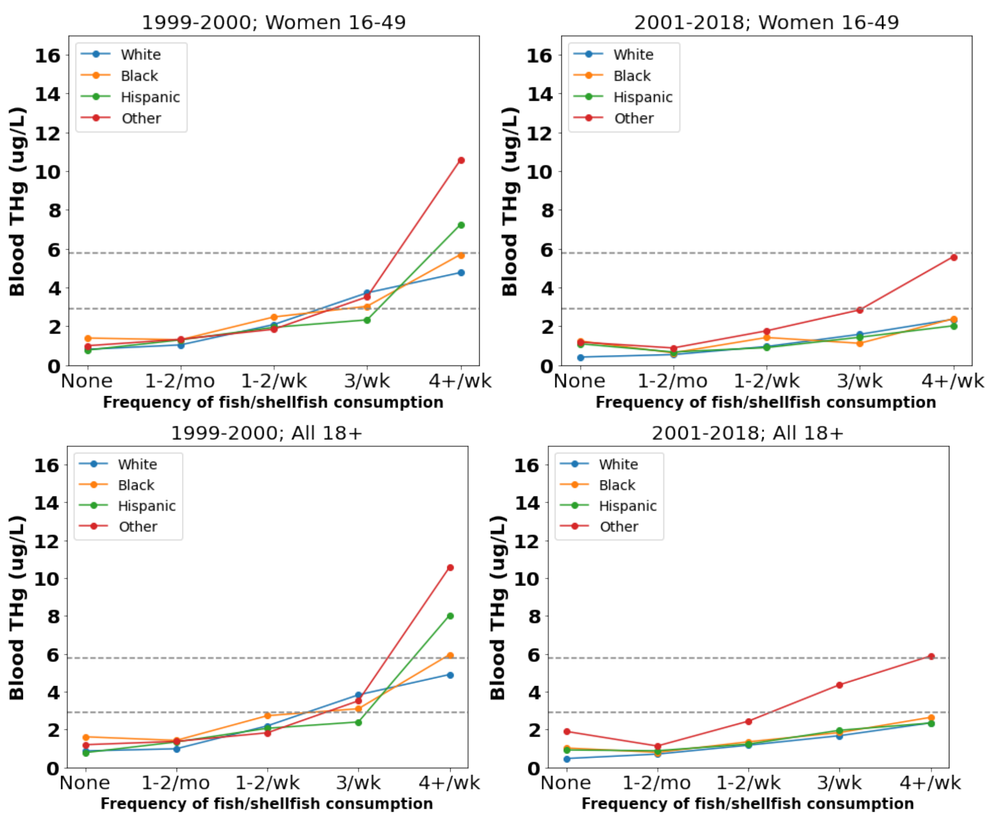

Figure 12| Blood mercury concentrations in U.S. individuals identifying with different ethnic groups. Data are from CDC/NHANES blood Hg measurements.

Recommendation: We recommend EPA leverage the consumption data provided here to estimate exposures of vulnerable groups more accurately. Further, we recommend that future residual risk analyses focus on the regions surrounding the 196 remaining EGUs in 2020 to determine if there are any adverse health effects, particularly for vulnerable groups proximate to these facilities. A more comprehensive consideration of environmental justice of methylmercury exposure is warranted.

6. Unquantified Benefits for Wildlife Conservation

State-of-the-Science: The health of fish and wildlife is impaired when they are exposed to mercury in the environment. Often following risk assessments on Superfund sites, the U.S. Fish and Wildlife Service collects data to assess impacts of mercury on fish and wildlife. This information can be used to pursue a National Resource Damage Assessment claim against the potentially responsible parties.

The Service, along with other federal, state, and tribal partners, acts as Trustees for natural resources in these claims. Trustees seek to identify the natural resources injured in association with methylmercury exposure, determine the extent of the injuries, recover damages from those responsible, and plan and carry out restoration activities. The latter action provides a means for monetizing the injury of mercury to fish and wildlife. The primary benefit of the Natural Resource Damage Assessment and Restoration (NRDAR) program is to achieve restoration of injured resources that is paid for by the responsible party (Figure 12). For example, an NRDAR settlement for fish and wildlife damages associated from mercury contamination from a chlor-alkali facility on an 80-mile stretch of the South River in Virginia was over $50M (www.naturalresources.virginia.gov/initiatives/dupont-nrdar-settlement/)).

While NRDAR has only assessed mercury releases into the environment at local levels, there are 35 sites at a national level. The impacts from atmospheric mercury deposition on fish and wildlife have not been assessed at the national level. Therefore, while the injury from environmental mercury releases to fish and wildlife has not yet been quantified nationally, information exists from past and current NRDAR efforts to model such impacts and ultimately monetize them based on options for remediation or restoration.

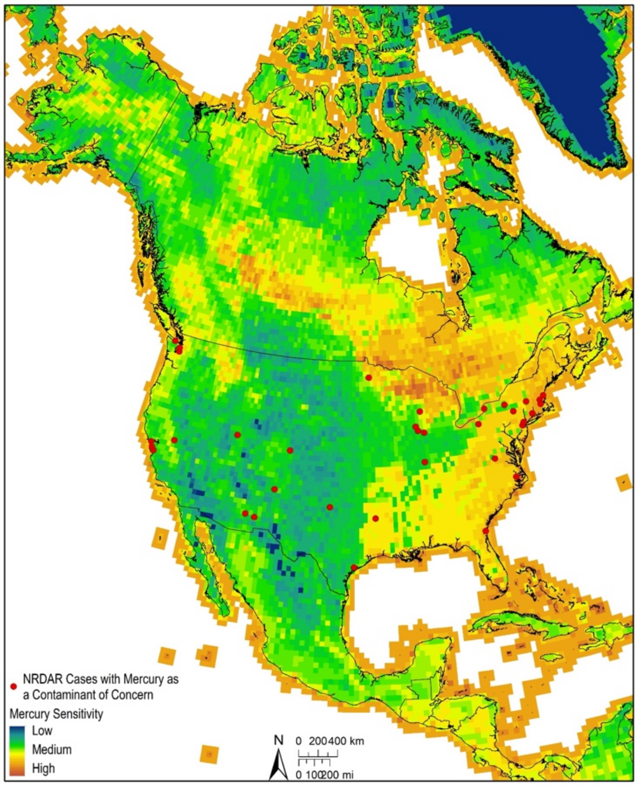

Figure 12| Map of North America showing degrees of ecosystem sensitivity to mercury inputs based on global models generated for the U.S. Department of State and United Nations Environment Programme (Biodiversity Research Institute, unpublished data). Superimposed on the map are 35 U.S. Department of the Interior Natural Resource Damage Assessment and Restoration Program (NRDAR Program) cases where mercury is a contaminant of concern along rivers, lakes, and coastal habitats. These NRDA sites may or may not have been monetized for damages to fish and wildlife associated with mercury deposition from coal-fired electric utilities.

Recommendation: We recommend EPA leverage methods developed by NRDAR for quantifying the impacts of mercury exposure on fish and wildlife to quantify the benefits associated with reduced utility emissions on a national scale. This injury assessment for fish and wildlife could be conducted by synthesizing the monetized damages determined from NRDAR assessments for sites of mercury contamination and scaling these values based on cumulative mercury release from industrial processes and site sensitivity to mercury inputs. The relative source contribution (RSC) for mercury deposition originating from emissions from coal-fired electric utilities, (outlined in section 2a) could be used to extrapolate monetized mercury damages to fish and wildlife from NRDAR settlements to the national scale impacts for natural resources in the U.S.

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