vegetation to increase crop and livestock yields, boosting economic well-being, and thereby incentivizing uptake of the intervention. The composted vegetation was used as a fertilizer, which increased both onion and pepper production. The vegetation could also replace conventional livestock feed — it was similar in quality to typically purchased feed, but was up to 179 times cheaper.

Environmental interventions such as this run the risk of having unintended consequences by disrupting a complex ecological web. The authors diligently looked for changes in water quality and chemistry and in human usage. The intervention did not seem to cause any deleterious environmental effects. The dense vegetation might have been a result of the construction of the Diama Dam, which altered water availability in a way that might aid vegetation growth, and the authors argue that the intervention restores the habitat to closer to its previous levels of vegetation.

This project demonstrates the creative potential at the intersection of scientific disciplines, and provides an admirable example of team science: in this case, a partnership of scientists from Senegal and the United States with diverse academic backgrounds — ecologists, economists and epidemiologists — working to develop and test innovative solutions in global health (*Nature* **525**, 308–311; 2015). The proposed intervention, after further research, could be considered as an option to complement the current mass drug-treatment campaigns for schistosomiasis. Achieving elimination will surely require more than drugs alone, and these multi-disciplinary environmental strategies will probably be key to any successful elimination efforts.

Key questions remain to be answered. First, will the positive health and economic effects seen in this study generalize to other locations in which schistosomiasis is prevalent? Although these findings are exciting, *Schistosoma* transmission is a complex and varied process. Factors such as variation in freshwater bodies and vegetation between locations and over time, human behaviour and environmental and ecological factors all affect transmission and might change the intervention's effect. Furthermore, assessing *Schistosoma* infection is challenging because diagnostics are at present imperfect, and because seasonal variation and other complexities affect measurement. Therefore, the conditions that produced the results here might not be present elsewhere, underscoring the need to carry out further research in other settings before the approach can be scaled up.

Second, will this intervention achieve high and sustained large-scale uptake in the real world? The field of public health is filled with examples of well-proven interventions that end up gaining limited uptake and generating 'response fatigue' over time. Any future implementation should be paired with close measurement and evaluation — preferably with further randomized trials, given the complexities of infectious-disease transmission — to ensure that the public-health benefit of this intervention is long term, robust and demonstrated at scale.

A compelling feature beyond the immediate health benefits of this approach is its tangible economic benefits for the community, which might position it well for adoption and uptake. However, navigating the translation of the findings into practice will be challenging.

The results of this study should invigorate the pursuit of environmental approaches to reduce the spread of infectious diseases. Such research is an example of a global health solution that breaks down the boundaries of academic siloes, and might pave the way for more innovative solutions.

**Nathan C. Lo** is in the Division of Infectious Diseases and Geographic Medicine, Stanford University, Stanford, California 94305, USA. **Benjamin Arnold** is in the Francis I. Proctor Foundation and in the Department of Ophthalmology, University of California, San Francisco, San Francisco, California 94158, USA.
e-mails: nathan.lo@stanford.edu; ben.arnold@ucsf.edu

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## In retrospect

# Sixty years since the report of global lead pollution

**Jerome Nriagu**

The 1963 discovery that even the vast oceans were highly contaminated with lead from car exhausts sparked debate and policy changes that benefited the health of millions — and revolutionized the practices of marine biogeochemistry.

In the early 1960s, the observation of a high concentration of lead in the surface waters of the Pacific Ocean off southern California sparked debate. Was it from a previously unknown geological source, or was it symptomatic of environmental contamination in the entire Northern Hemisphere, caused by emissions of lead compounds from industrial sources and car exhausts[1,2]? And if it was a symptom of worldwide contamination, then what were the risks to human health, especially in urban areas? The geochemical puzzle was solved in 1963 by Tatsumoto and Patterson[3], who reported in *Nature* that the oceans were being highly polluted with lead produced from the use of leaded petrol. The paper did not receive the acclaim that it deserved at the time, but it became a milestone in the public-health controversy surrounding the use of leaded petrol[4].

Tatsumoto and Patterson set out to show that the ocean was lead-free in pre-industrial times, because this would indicate that most of the lead in the contemporary ocean came from anthropogenic sources. They were not the first to study lead concentrations in the ocean, but two features made their study unique. First, they used highly sophisticated measurement procedures that could determine low levels of lead in seawater with a precision that was unattainable in most laboratories at the time. And second, the seawater samples were collected from five locations strategically chosen to capture the influence of lead emissions transported through the air from North America and Europe. The authors also measured lead in recently fallen snow taken from a mountain top in California, to estimate the baseline of atmospheric deposition of lead compounds at remote continental sites.

From the differences in isotopic composition of lead in the snow and of lead found in prehistoric sediments of the Atlantic Ocean[5,6], Tatsumoto and Patterson were able to 'fingerprint' the source of the lead in the ocean water. The concentration of silica in the snow was also determined as a measure of the amount of dust present; because the dust derives from natural mineral sources, this measurement allowed the authors to calculate how much lead from those sources could be delivered to the open ocean by dust. Taken together, the analyses confirmed that the lead contaminating the ocean did not come from natural sources, but that it was anthropogenic. It is remarkable that the discovery of massive ocean pollution by the aerial transport of lead from car exhausts was accomplished not by the analysis of reams of data from around the globe, but by using information painstakingly collected by the authors from a few judiciously selected locations.

The concentrations of lead in the snow samples exceeded the contribution expected from natural sources by a factor of 10,000 – providing strong evidence of extensive environmental lead contamination from anthropogenic sources, beyond that seen in the ocean. Moreover, the lead concentration in snow was 10–100 times higher than in seawater, suggesting that the lead in the water would have accumulated in just a small number of years. And the variation of lead concentrations with ocean depth broadly indicated that more lead was present in younger, shallower waters than in deeper, older waters, suggesting that it had arrived in the past few decades. Subsequent investigations have confirmed that, by the early 1960s, more than 95% of the lead in the lower-most atmosphere (the troposphere) and in surface waters of the North Atlantic had come from industrial and automotive sources[7,8].

Another key discovery in Tatsumoto and Patterson's study was that the lead concentrations widely accepted to be normal for seawater at that time (3,000–8,000 nanograms per litre)[9,10] were incorrect. The concentrations in the surface waters of the Mediterranean Sea were 200 ng $l^{-1}$, and just 40–90 ng $l^{-1}$ in the Atlantic. The authors' accurate measurements of low lead concentrations were achieved by stringently preventing contamination during sample collection and processing, and by using a method known as isotope-dilution mass spectrometry under clean-room conditions[11] (Fig. 1). Patterson went on to show that practically all reported concentrations of lead in open ocean waters, from studies carried out over a period of more than 40 years, were wrong – most of them by a factor of 1,000 or more[12].

The clean-room approach subsequently became indispensable in most investigations of trace elements in the ocean[13]. It allowed later studies to demonstrate reliably that the biogeochemical cycles of lead, and of many other elements in every ocean of the world, have been greatly affected by human activity. It also allowed researchers to show that the oceanic distributions of trace elements depend on oceanographic processes, and led to groundbreaking insights into contemporary and historical ocean chemistry and biology (see ref. 14, for example). The influence of Tatsumoto and Patterson's paper in revolutionizing the science of marine biogeochemistry is not generally appreciated.

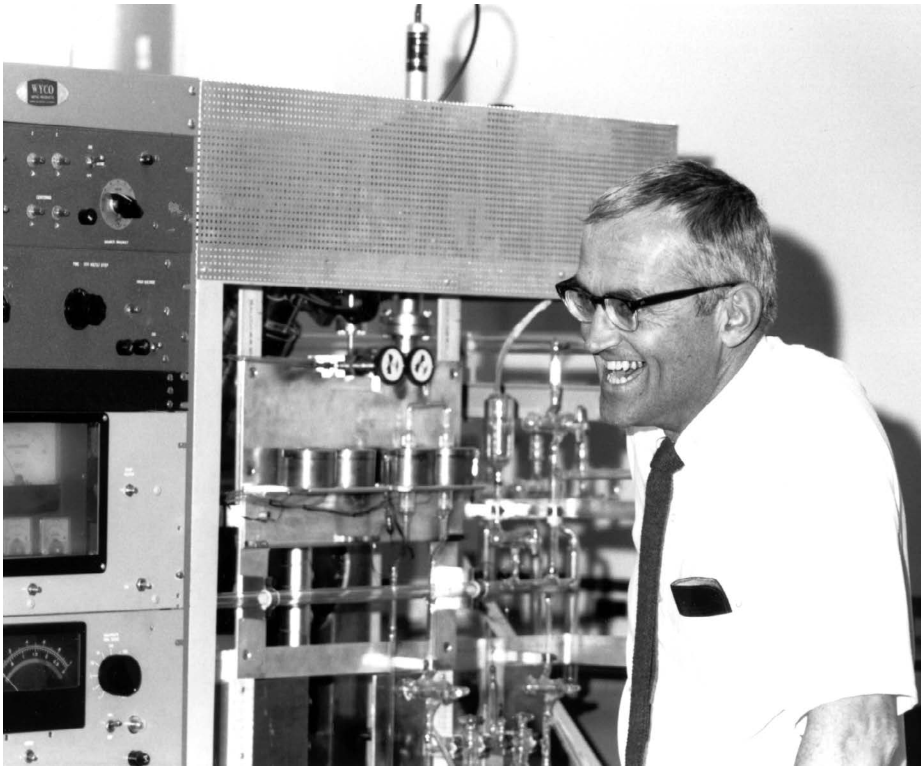

**Figure 1 | Clair Patterson with his analytical instruments.** Tatsumoto and Patterson's paper[3] exemplified the use of analytical protocols that transformed practices in the field of marine biogeochemistry.

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Using geochemical models and the estimated natural baseline data from the 1963 paper, Patterson and his group went on to infer that the level of environmental lead pollution was profound and potentially harmful[15]. Taken together, the findings had a big impact on the general public. By tying high lead concentrations mostly to automotive sources, the researchers showed that the pollution was a global problem. This helped to correct prevailing misinformation on the health risk of lead, and heightened the concerns of the US public regarding the human health effects of lead released into the environment.

> **"Just three days after the paper was published, the researchers' funding was promptly terminated."**

The 1963 paper marked the beginning of Patterson's research in the nascent field of environmental science, and of his advocacy for an end to the use of lead in petrol. In his 1965, landmark article[12], Patterson charged that the atmosphere of the Northern Hemisphere had become severely contaminated with lead; that the average burdens of lead in the human body were about 100 times higher than natural burdens; and that the average US resident was being subject to harmful and chronic lead exposure, mostly from car exhaust. Patterson accused the lead-additive industry of intentionally spreading misleading information about lead poisoning, and public officials of abrogating their duties by allowing the lead industry to regulate itself and by accepting its claims without vetting them. The 1965 article is generally credited with shifting the blame for childhood lead poisoning in the United States from lead paint to automotive sources[16].

At that time, the lead industry funded a lot of scientific research, and exerted a hegemonic control of publications. This served to perpetrate the belief that environmental lead pollution was not a health risk to the general population and was instead a necessary consequence of industrial and economic progress. Patterson was one of the first people to launch an effective challenge to the misleading public-health science surrounding environmental lead poisoning, by exposing the flaws in the scientific methods of the lead-additive industry and the faulty risk assessments of its allies[16,17].

Ironically, Tatsumoto and Patterson's work was partly funded by the American Petroleum Institute (which itself was financed mainly by the oil industries). Just three days after the paper was published, the researchers' funding was promptly terminated[17]. But Patterson's track record of meticulous and unassailable research, and the fact that his conclusions were being widely supported by other studies, enabled him to find other funders to continue his work.

We now know that the cumulative addition of millions of tonnes of lead additives to petrol set in motion 100 years of global lead poisoning that disproportionately affected children[16]. At its peak from the 1960s to the 1980s, more than 90% of all US children had blood lead concentrations of greater than 10 micrograms per decilitre, the maximum level then considered to be safe[18]. The poisoning caused more than 1.2 million premature deaths and resulted in costs that drained about US$2.45 trillion per year from the global economy (see go.nature.com/3r5eujj). Amendments to the US Clean Air Act in 1970 mandated the phased removal of lead from petrol, starting in 1975. However, it took another 46 years before lead was removed from petrol in all countries in the world[19] – demonstrating that the path to translating sound science into effective public-health policy is tortuous.

Data collected in the past three decades show that the removal of lead from petrol has been highly effective in reducing blood lead concentrations in the global population and that the benefit has been lasting[19]. Blood levels in most high-income countries are now less than $3\ \mu g\ dl^{-1}$, and are often lower than $1\ \mu g\ dl^{-1}$ (ref. 19). Widespread declines have also been recorded in middle- and low-income countries, but many children in those regions still have blood lead levels in excess of $5\ \mu g\ dl^{-1}$ (ref. 20) – partly as a legacy of the use of leaded petrol, but also as a result of exposure to other sources, such as lead-polluting industries and lead in plumbing and paints. The growing disparities in exposure between high- and low-income countries show that the history of global lead poisoning is not yet over.

Nevertheless, the huge declines in childhood lead poisoning and blood lead levels are a major public-health accomplishment. Ocean pollution was not cited as a reason for the 1970 amendments to the US Clean Air Act. However, Tatsumoto and Patterson's paper was the spark that lit the fire under regulatory agencies, forcing them to take action.

**Jerome Nriagu** is professor emeritus at the School of Public Health, University of Michigan, Ann Arbor, Michigan 48109, USA.
e-mail: jnriagu@umich.edu

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