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Author: Ogden, Lesley Evans

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Nanoparticles in the Environment: Tiny Size, Large Consequences?

LESLEY EVANS OGDEN

Nanotechnology is employed in applications as diverse as delivering drugs to cancer cells, increasing solar panel efficiency, and reducing biodiesel engine emissions. With an estimated global value of $1 trillion by 2015 (including related improvements in other industries), the nanotechnology economy is surging ahead. But nanomaterial research and development has outpaced the advances in knowledge about environmental impacts. Less than 1 percent of the published nanoparticle literature is focused on biological impacts. One such area of research is the effect of nanoparticles on aquatic life.

No greater than 100 nanometers in any one dimension, nanoparticles are smaller than human cells. Yet, because of their relatively large surface area, they can have significant impacts.

As Ryan Otter, a biologist studying nanoparticle toxicology at Middle Tennessee State University, explains, "Imagine you take a large boulder and determine its mass and surface area to volume ratio. Now you take a hammer and you smash the rock. The accumulated mass of the resulting smaller pieces remains the same, but the surface [area] to volume [ratio] goes way up. Now take another hammer and smash all of those small pieces into tiny pieces. They still have the same [combined] mass, but the surface area goes through the roof. That's what nanoparticles are."

The vastly increased surface area leads to novel properties that may adversely affect organisms. Compared with their bulk parent materials, nanoparticles can be stronger, more reactive, more magnetic, or more conductive per unit of mass. Many metals are slow to react as fist-sized chunks, but in nanoparticle form, metals like iron, nickel, and cobalt are so reactive that they are actually pyrophoric: They ignite spontaneously in air.

One particle of concern is nanosilver, used in a variety of commercial applications, such as in socks and underwear as antibacterial odor suppressants. Effective at killing harmful bacteria, the nanosilver flushed into laundry water can kill beneficial microorganisms, too. Zack (Zhiqiang) Hu, professor of civil and environmental engineering at the University of Missouri, suggests that some of the crucial biological reactions within wastewater treatment plants and landfill bioreactors could be compromised if the background levels of nanosilver continue to rise.

Testing the impacts of silver nanoparticles on zebrafish, Otter has found increased fish mortality and heart abnormalities, which adds to a growing body of literature indicating toxicological effects of nanomaterials on other aquatic species, including fish, invertebrates, and algae.

Size-dependent nanoparticle toxicity has thus far been difficult to nail down. Results have been mixed. Otter suspects that this may be partly attributable to the large variation in particle sizes within the samples of a particular manufactured "size." This lack of size uniformity is not often accounted for in experimental work. Toxicological impacts are likely to be material specific, not just size related, explains Hu, who has studied nanoparticle toxicology since 2006.

Surprisingly little research has been focused on the impacts of nanoparticles on ecosystems, according to Chris Metcalfe, a professor at Trent University, in Canada, who, with his research colleagues, is exploring the environmental fate of nanosilver, nanoiron, and nanotitanium dioxide.

Metcalfe and colleagues have been investigating the impacts of nanosilver on lake-dwelling species. By placing plastic columns into lakes, they are examining the biological effects of nanosilver on plankton within these tube "mesocosms." Their preliminary data suggest that half of the nanosilver disappears from the tubes within 20 days. Its fate? That is yet unknown. Taking this experiment from the mesocosm to the whole-lake level is something that Metcalfe hopes will proceed this summer, despite the Canadian government's recent cancellation of funding for his intended study site, the internationally renowned Experimental Lakes Area. Such ecosystem-scale nanoparticle experiments are critical to detecting possible cascading effects that can be discovered only by scaling up to examine the interactions between multiple species.

Nanoecotoxicology remains in its infancy, and many knowledge gaps remain, but there is progress. The US Environmental Protection Agency is conducting nanoparticle safety research, and the Organization for Economic Cooperation and Development's (OECD) Working Party on Manufactured Nanomaterials was established in 2006. The OECD is also funding a nanoparticle-testing program focused on the physical, chemical, environmental, and toxicological properties specific to individual nanomaterials, as well as those properties intrinsic to all nanomaterials.

Nanoparticle bioavailability and the patterns relating toxicity to particle size, roughness, shape, charge, composition, surface coating, and physiological mechanisms are not well understood. These many unknowns provide intriguing questions for further research into this area of science in which small things can have large impacts.

Lesley Evans Ogden is a freelance journalist based in Vancouver, Canada. On a continual quest for fascinating science stories large and small, she can be found at lesleyevansogden.com *and on Twitter @ljevanso.*

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