Biodiversity change behind wide applications of nanomaterials?

Ming Chen, [a,b] Xiaosheng Qin [b,*] and Guangming Zeng [a]

[a] *College of Environmental Science and Engineering, Hunan University and Key Laboratory of Environmental Biology and Pollution Control (Hunan University), Ministry of Education, Changsha 410082, P.R. China*

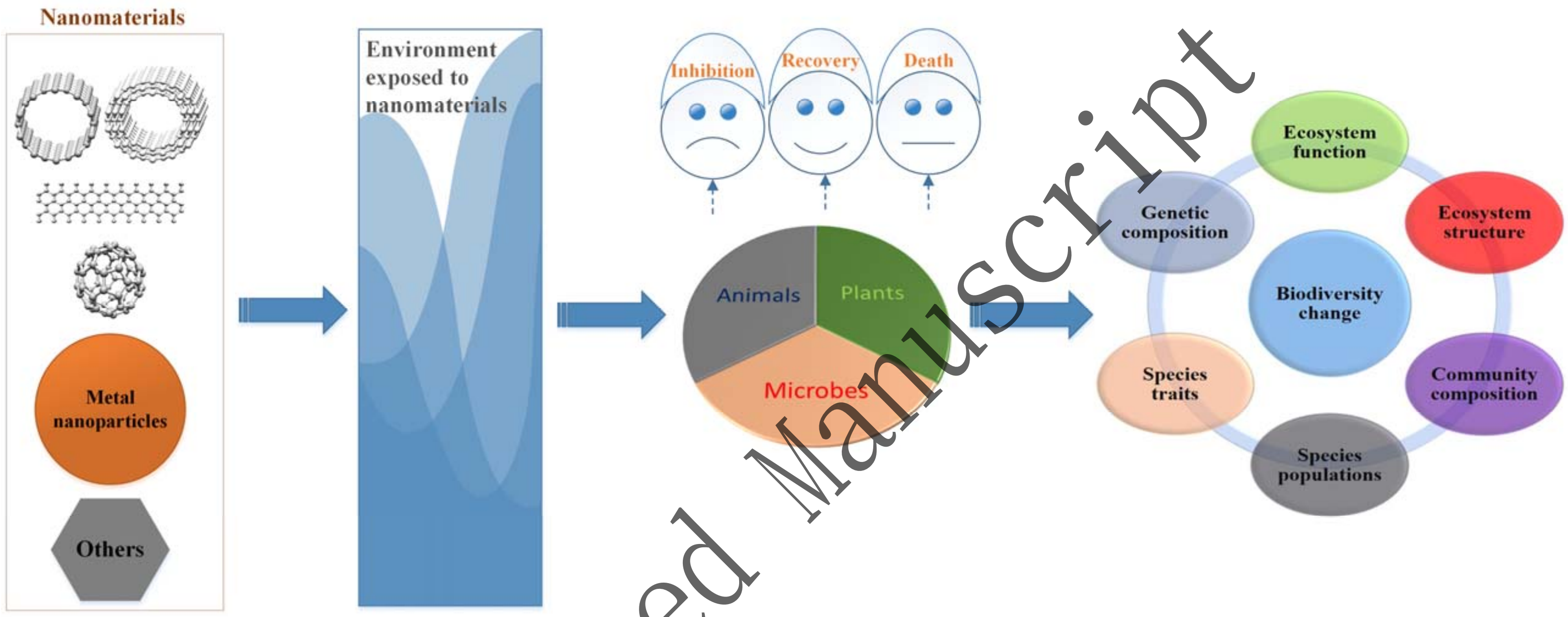
[b] *School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798*

Abstract

Nanomaterials, like carbon nanotubes, graphene, metal and metal oxide nanoparticles, are increasingly applied in a wide range of areas with numerous benefits to economy and society. Large-scale production and applications of nanomaterials can increase the possibility of exposure to living organisms, pose risks to human health and ecosystems, and potentially lead to biodiversity losses. Previous environmental impact and safety studies that targeted nanomaterials typically focused on their toxicity, fate and behavior; little attention was paid on biodiversity consequences. Evidence for acute biodiversity change derived from nanomaterials is very limited. Several organizations and researchers have started to discern the relationship between biodiversity and nanotechnology. Nevertheless, more efforts are desired to explore the impacts of nanomaterials on biodiversity.

Corresponding author: Associate Professor/Dr. Qin Xiaosheng, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798; Tell: +65-67905288; Fax: +65-67921650; E-mail: xsqin@ntu.edu.sg

Figure



Adverse biodiversity consequence induced by nanomaterials (single-walled carbon nanotube (SWCNT), multi-walled carbon nanotube (MWCNT), graphene, fullerene, metal nanoparticles and others). Biodiversity assessment can be performed under six essential biodiversity variable classes, including ecosystem structure, ecosystem function, genetic composition, species traits, species populations and community composition [1, 2].

Reproductive and developmental toxicity of nanomaterials

Global biodiversity has continually declined in the past decade (2000 to 2010) [1]. A prerequisite in impeding biodiversity losses is to collect as many decline reasons as possible. New emerging nanomaterials such as carbon nanomaterials and metal nanoparticles could be considered as one of these reasons, as reproductive and developmental toxicity of nanomaterials has been observed [3], possibly becoming a new threat to biodiversity. Among numerous nanomaterials [3, 4], single-walled carbon nanotubes (SWCNTs) can cause embryo death, angiogenesis inhibition and growth retardation in chicken [5]; multi-walled carbon nanotubes (MWCNTs) are able to lead to the death of zebrafish embryos and developmental arrest [3]; C_{60} can induce the abnormalities and death of mice embryos [6]. Carbon nanomaterials were reported to pose a threat to the reproduction and growth of invertebrates, such as *Daphnia magna* [7] and earthworms [8]. Dissemination of nanomaterials in soil and water may be detrimental to the growth of plants where they can accumulate and produce phytotoxicity. The growth inhibitions of red spinach by MWCNTs [9], and graphene-induced decrease in shoot and root lengths of tomato, red spinach and cabbage [10] have been revealed. In addition to carbon nanomaterials, the adverse impact of metal-based nanomaterials on the living organisms after environmental exposure also received significant attention. Metal nanoparticles such as nano-Ag and nano-TiO_2 inhibited the growth of *Lemna paucicostata* [11], and impacted the reproduction and development of *Drosophila melanogaster* and CD-1 mice [12]. The chronic toxicity of gold nanoparticles with different surface functionalities (21-day exposure) to *Daphnia magna* was investigated, indicating that it experienced decreased reproduction or reduced body size [13].

Biodiversity change may occur if normal reproduction and development of species are prevented.

Compositional shifts in microbial communities caused by nanomaterials

Evidence from microbial community studies also supports that nanomaterials would result in biodiversity changes. Soil microbial community composition significantly shifted with the treatments using metal-based engineered nanomaterials, where the biomass of Gram-positive bacteria, Gram-negative bacteria and fungi significantly decreased as compared to the control without these nanomaterials [14]. The bacterial community structure or composition was changed by Ag nanoparticles in sewage sludge [15]. The incorporation of TiO_2 nanoparticles in soil decreased the diversity in bacterial community [16]. Rodrigues et al. [17] reported that soil fungal community could not recover after soil was exposed to SWCNTs, and soil bacterial community was transiently influenced. The authors further reported that fungi and bacteria related to nutrient cycling in soil were adversely affected by SWCNTs. Another study done by Priester et al. [18] showed that nanomaterials inhibited the growth of nitrogen-fixing bacteria. Taking the previous findings together, the native nutrient cycling and ecosystem functions may be altered in the presence of nanomaterials. After an extensive literature review, Simonin et al. [19] suggested that biodiversity losses and microbial community variations in the environment containing nanomaterials are associated with nanomaterials.

Behaviors and acute-chronic toxicity of nanomaterials

The adverse effects of nanomaterials on the biodiversity and environment can be affected by multiple factors, such as sensitivity and exposure time (short- and long-term).

Nanomaterials refer to the materials at approximately 1-100 nm nanoscale, which have a large modification of physico-chemical properties and exhibit different behaviors as compared to bulk chemicals or materials [11]. The small size makes them capable of more easily entering the cells in contact with proteins and other molecules than bulk chemicals and materials [20, 21]. Nanomaterials may induce more serious adverse effects on living organisms. For example, nano-Ag, nano-ZnO and nano-TiO_2 have shown to have more toxic effects on the survival, reproduction and growth of earthworms than bulk metal forms in soils amended with sewage sludges [22]. Both acute and chronic exposure experiments of nanomaterials over short and long periods of time were carried out, showing that the effects of nanomaterials on tested organisms are often different between acute and chronic treatments [23-27]. For example, in a study related to MWCNT exposure in *Daphnia magna*, the sensitivity of chronic lethality hazard testing is more than 5 times that of the acute toxicity of MWCNTs [25]. Also, Panacek et al. [23] demonstrated that Ag nanoparticles presented the acute toxicity to *Drosophila melanogaster* at high concentrations above 20 mg L^{-1} and chronic toxicity at a low concentration of 5 mg L^{-1}. The observed differences between these two treatments are due to highly dynamic features of ecosystems, environment, and the interactions between nanomaterials and the tested organisms.

The road ahead

Overall, despite limited information on biodiversity consequence of nanomaterials, the available data point to the fact that wide applications of nanomaterials would lead to biodiversity change. Thus, there is an urgent need to assess biodiversity change caused by various nanomaterials under environmentally realistic conditions, especially those used widely, e.g. carbon nanomaterials, and Ag, ZnO and TiO_2 nanoparticles. Biodiversity like climate, air and water is global. Nanomaterial applications are also global. These two "globalities" require us to make more cooperated and coordinated efforts all over the world. Before taking actions to protect biodiversity from nanomaterials, the consensus methods and standards for measuring the impact of nanomaterials on biodiversity need to be made [28]. It is crucial to develop related regulations and policies to prevent the biodiversity losses derived from nanomaterials, as the current environmental regulations often do not take into account the nanomaterials [28, 29]. Moreover, establishment of reliable models is fundamental to predict the interactions between nanomaterials and the living organisms and their effects on biodiversity [30].

Acknowledgments

The study was financially supported by the National Natural Science Foundation of China (51508177, 51521006, 51378190), and the Program for Changjiang Scholars and Innovative Research Team in University (IRT-13R17).

References

[1] E. Turak, I. Harrison, D. Dudgeon, R. Abell, A. Bush, W. Darwall, C.M. Finlayson, S. Ferrier, J. Freyhof, V. Hermoso, Biol Conserv, (2016) http://dx.doi.org/10.1016/j.biocon.2016.1009.1005.

[2] H.M. Pereira, S. Ferrier, M. Walters, G.N. Geller, R. Jongman, R.J. Scholes, M.W. Bruford, N. Brummitt, S. Butchart, A. Cardoso, Science, 339 (2013) 277-278.

[3] M. Ema, K.S. Hougaard, A. Kishimoto, K. Honda, Nanotoxicology, 10 (2016) 391-412.

[4] M. Ema, N. Kobayashi, M. Naya, S. Hanai, J. Nakanishi, Reprod Toxicol, 30 (2010) 343-352.

[5] D. Roman, A. Yasmeen, M. Mireuta, I. Stiharu, A.-E. Al Moustafa, Nanomedicine, 9 (2013) 945-950.

[6] T. Tsuchiya, I. Oguri, Y.N. Yamakoshi, N. Miyata, Febs Lett, 393 (1996) 139-145.

[7] M.M. Alloy, A.P. Roberts, Ecotoxicol Environ Saf, 74 (2010) 1839-1843.

[8] J.J. Scottfordsmand, P.H. Krogh, M. Schaefer, A. Johansen, Ecotoxicol Environ Saf, 71 (2008) 616-619.

[9] P. Begum, B. Fugetsu, J Hazard Mater, 243 (2012) 212-222.

[10] P. Begum, R. Ikhtiari, B. Fugetsu, Carbon, 49 (2011) 3907-3919.

[11] E. Kim, S.H. Kim, H.C. Kim, S.G. Lee, S.J. Lee, W.J. Sang, Toxicol Environ Health Sci, 3 (2011) 1-6.

[12] N.A. Philbrook, L.M. Winn, A.R. Afrooz, N.B. Saleh, V.K. Walker, Toxicol Appl Pharmacol, 257 (2011) 429-436.

[13] J.S. Bozich, Environ Sci Nano, 1 (2014) 260-270.

[14] J.D. Judy, D.H. McNear Jr, C. Chen, R.W. Lewis, O.V. Tsyusko, P.M. Bertsch, W. Rao, J. Stegemeier, G.V. Lowry, S.P. McGrath, Environ Sci Technol, 49 (2015) 8751-8758.

[15] B.P. Colman, C.L. Arnaout, S. Anciaux, C.K. Gunsch, M.F. Hochella Jr, B. Kim, G.V. Lowry, B.M. McGill, B.C. Reinsch, C.J. Richardson, Plos One, 8 (2013) e57189.

[16] Y. Ge, J.H. Priester, L.C. Van De Werfhorst, J.P. Schimel, P.A. Holden, Environ Sci Technol, 47 (2013) 14411-14417.

[17] D.F. Rodrigues, D.P. Jaisi, M. Elimelech, Environ Sci Technol, 47 (2013) 625-633.

[18] J.H. Priester, Y. Ge, R.E. Mielke, A.M. Horst, S.C. Moritz, K. Espinosa, J. Gelb, S.L. Walker, R.M. Nisbet, Y.-J. An, Proc Natl Acad Sci U S A, 109 (2012) E2451-E2456.

[19] M. Simonin, A. Richaume, Environ Sci Pollut R, 22 (2015) 13710-13723.

[20] A.A. Shemetov, I. Nabiev, A. Sukhanova, Acs Nano, 6 (2012) 4585-4602.

[21] M. Chen, G. Zeng, P. Xu, Y. Zhang, D. Jiang, S. Zhou, Environ Sci Nano, 4 (2017) 720-727.

[22] E. Lahive, M. Matzke, M. Durenkamp, A.J. Lawlor, S.A. Thacker, M.G. Pereira, D.J. Spurgeon, J.M. Unrine, C. Svendsen, S. Lofts, Environ Sci Nano, 4 (2017) 78-88.

[23] A. Panacek, R. Prucek, D. Safarova, M. Dittrich, J. Richtrova, K. Benickova, R. Zboril, L. Kvitek, Environ Sci Technol, 45 (2011) 4974-4979.

[24] C.M. Zhao, W.X. Wang, Environ Toxicol Chem, 30 (2011) 885-892.

[25] J.K. Stanley, J.G. Laird, A.J. Kennedy, J.A. Steevens, Environ Toxicol Chem, 35 (2015) 200-204.

[26] I. Blinova, J. Niskanen, P. Kajankari, L. Kanarbik, A. Käkinen, H. Tenhu, O.-P. Penttinen, A. Kahru, Environ Sci Pollut R, 20 (2013) 3456-3463.

[27] M. Sakamoto, J.-Y. Ha, S. Yoneshima, C. Kataoka, H. Tatsuta, S. Kashiwada, Arch Environ Con Tox, 68 (2015) 500-509.

[28] G.B. Sub-Committee, Global Biodiversity Sub-committee of the Global Environmental Change Committee (09), 14 (2009).

[29] T. Faunce, A. Watal, Nanomedicine-Uk, 5 (2010) 617-632.

[30] A.J. Makarucha, N. Todorova, I. Yarovsky, Eur Biophys J, 40 (2011) 103-115.

Dr. Ming Chen is an assistant professor at School of Environmental Science and Engineering, Hunan University, and a former research fellow with School of Civil and Environmental Engineering in Nanyang Technological University, Singapore. He obtained his Ph.D. in environmental engineering from Hunan University in 2014 and is the associate editors or Editorial Board Members of several ISI journals. His research interests include biodegradation of nanomaterials, organic pollutants and lignin, and environmental impacts of nanomaterials.

Dr. Xiaosheng Qin is currently an Associate Professor with School of Civil and Environmental Engineering in Nanyang Technological University, Singapore. He obtained his PhD degree from University of Regina, Canada in 2008. He serves (or served) as the Associate Editors or board members for several international journals. His research interests cover the topics of urban environmental modelling, water resources systems planning and management, and climate change impact assessment.

Dr. Guangming Zeng has been the head of the School of Environmental Science and Engineering at Hunan University since 1996. He received his PhD degree from Wuhan University in 1988. He was invited as reviewers for over 50 journals and has over 320 scientific publications (journal & conference papers) with total citations at 23870 and H-index at 72. He is also the Most Cited Chinese Researchers in 2014-2016 according to Elsevier's statistics. His current research interests include toxicity, environmental applications and potential risks of nanomaterials.