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Editorial: Effects of metal contamination on ammonia-oxidizing microorganisms in a freshwater reservoir

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Ammonia-oxidizing microorganisms, including ammonia-oxidizing bacteria (AOB) and archaea (AOA), are important to the global nitrogen cycle. These microbes catalyze the oxidization of ammonia (NH_3) to nitrite (NO_2), the rate-limiting step in the biogeochemical cycling of nitrogen (Stahl and de la Torre, 2012). Effects on the activity of the ammonia-oxidizing microbes could ultimately influence the global nitrogen cycle. Low rates of ammonia oxidization may result in failure of nitrogen removal, leading to eutrophication in water ecosystems.

Studies have shown that the abundance and community structure of ammonia-oxidizing microbes are sensitive to arsenic (Cao et al., 2011), copper (Mertens et al., 2010; Wang et al., 2018), and mercury (Zhou et al., 2015). In these studies, the ammonia monooxygenase α-subunit (*amoA*) gene (Rotthauwe et al., 1997) was commonly used as a molecular marker for both AOA and AOB. The copy numbers of the *amoA* gene reflect the abundance of AOA and AOB, while variabilities in the sequences of *amoA* reflect the diversity of AOA and AOB.

The effects of metals and metalloids on AOA and AOB in the freshwater reservoirs are not as well studied as in soil, the marine environment, and wastewater treatment plants. AOA and AOB in freshwater sediment are closely related to human activity. Studies of AOA and AOB communities in the freshwater ecosystems will contribute to knowledge for the sustainable management of freshwater resources. Currently, how the metals and metalloids affect the ammonia-oxidizing communities in freshwater is not fully understood. An earlier study performed at the San Francisco Bay estuary showed that the abundance of AOA was not related to arsenic concentrations (Mosier and Francis, 2008). However, Cao et al. (2011) found that relatively low AOA diversities in mangrove sediments were associated with high arsenic concentrations (over 27 mg/kg). Further studies on the effects of different metals and metalloids of diverse concentrations on the ammonia-oxidizing microorganisms are needed.

Metal contaminations in lakes and rivers continue to be an environmental concern (Ye et al., 2018; Zhang et al., 2017). In April 2016, Lake Xiannv, a freshwater reservoir in southern China, was contaminated by an accidental spill upstream to the lake. The city of Xinyu, which obtained drinking water from this lake, had to temporarily shut down the municipal water. Following the spill, various environmental and ecological studies have been conducted, including a study by Li et al. (2019) that investigated the effects of high concentrations of metals and metalloids on the ammonia-oxidizing microbes in the freshwater sediments.

To study how ammonia-oxidizing microbial communities respond to the spill, Li et al. (2019) monitored the changes in the abundance and community structures of ammonia-oxidizing microorganisms in the contaminated freshwater sediments over time. A week after the spill, Li et al. started to collect samples from eight sites, ranging from the inlet to the outlet of Lake Xiannv. They repeated the sample collections from these eight sites on days 18, 106, and 266 after the spill. They assessed the abundance of the ammonia-oxidizing microorganisms in each sample by determining the number of copies of the *amoA* gene using quantitative polymerase chain reaction (qPCR). They studied the community structures of the ammonia-oxidizing microorganisms using high-throughput sequencing (Illumina HiSeq 2000) of the *amoA* gene.

Li et al. (2019) found that the concentrations of arsenic and cadmium in the sediments collected 18 days after the spill from six sites between the inlet and outlet were as high as 140 mg/kg. The concentrations of arsenic and cadmium decreased

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to below 20 mg/kg in sediment samples collected from the same sites 106 days after the spill. They also determined the concentrations of copper, lead, and zinc in sediment samples collected from all eight sites on four sampling times. They did not observe any consistent changes in the concentrations of copper, lead, and zinc.

Li et al. (2019) determined that the dominant ammonia-oxidizing organisms in the sediments of Lake Xiannv were AOA, not AOB. These results were understandable because in the mesotrophic freshwater Lake Xiannv, the low-level ammonium environment would not favor the growth of AOB, whereas a higher specific affinity of AOA for ammonia could support the growth of AOA in this environment (Erguder et al., 2009). Indeed, the AOB *amoA* genes were below the limit of detection of qPCR. These results are consistent with previous observations (Yang et al., 2016).

The abundance of archaeal *amoA* gene in the sediment samples collected on day 18 was 10^5-10^7 copies per gram of dry sediment. The number of archaeal *amoA* gene in the sediment samples collected on day 106 decreased to approximately 10^3-10^4 copies per gram of dry sediment. These temporal decreases in the abundance of archaeal *amoA* gene appear to coincide with the decreases in the concentrations of arsenic and cadmium in the sediment samples.

Toxic metals have also altered the AOA community structures. Li *et al.* classified sediment AOA into 5 clusters via phylogenetic analysis, according to the genetic similarity of *amoA* genes. By looking at the relative abundance of each cluster, they found that the community structures in day 266 was different from those in samples collected earlier. The portion of dominant AOA genus *Nitrosppumilus* decreased at the last sampling time point, which indicates a potentially adverse effect of the metals on organisms clustered with *Nitrosppumilus*.

Li et al. (2019) stated that the temporal change of AOA communities may also be affected by other factors, such as temperature (Sims et al., 2012). However, control samples, such as sediments collected before the spill, were not available to evaluate the effects of factors other than the toxic metals on the AOA communities. Meanwhile, the AOA abundance might be slightly different from the *amoA* copy number. As Kelly et al. (2011) noted that the *amoA* copy numbers may not be consistent in different AOA species.

The environmental monitoring data recorded in this research (Li et al., 2019) is important for understanding the effect of metal contamination on AOA in freshwater sediment. The data show that the spill of toxic metals had a profound effect on abundance and community structure of AOA. Other environmental factors and variables in different samples, for example, the concentration of each contaminant, concentration of ammonia, dissolved oxygen, and temperature, could also play a role. Establishment of quantitative correlations between each factor and the abundance of AOA may indicate whether changes in AOA are caused by metal contamination alone. Such study will require the collection of more samples and additional analyses through continued monitoring of AOA and environmental factors at Lake Xiannv over a longer period of time. Results of further studies will contribute to appropriate management of the freshwater system. In Lake Xiannv, AOA are the main organisms to mediate the oxidization of ammonia to nitrite. Effects on the AOA communities may result in a decrease of ammonia-oxidizing rates and disturbance of nitrogen cycle (Stahl and de la Torre, 2012; Huo et al., 2018; Yao et al., 2018). Therefore, consideration of the AOA communities and the effects of metal contaminations, such as the accidental spill, should contribute to the overall management of the freshwater reservoir.

REFERENCES

Cao, H., Li, M., Hong, Y., Gu, J.D., 2011. Diversity and abundance of ammonia-oxidizing archaea and bacteria in polluted mangrove sediment. Syst. Appl. Microbiol. 34, 513–523. https://doi.org/10.1016/j.syapm.2010.11.023.

Huo, S.L., Ma, C.Z., Xi, B.D., Zhang, Y.L., Wu, F.C., Liu, H.L., 2018. Development of methods for establishing nutrient criteria in lakes and reservoirs: a review. J. Environ. Sci. 67, 54–66. https://doi.org/10.1016/j.jes.2017.07.013.

Kelly, J.J., Policht, K., Grancharova, T., Hundal, L.S., 2011. Distinct Responses in Ammonia-Oxidizing Archaea and Bacteria after Addition of Biosolids to an Agricultural Soil. Appl. Environ. Microbiol. 77, 6551–6558. https://doi.org/10.1128/aem.02608-10.

Li, N., Chen, Y., Zhang, Z., Chang, S., Huang, D., Chen, S., et al., 2019. Response of ammonia-oxidizing archaea to heavy metal contamination in freshwater sediment. J. Environ. Sci. 77, 392–399. https://doi.org/10.1016/j.jes.2018.09.020.

Mertens, J., Wakelin, S.A., Broos, K., McLaughlin, M.J., Smolders, E., 2010. Extent of copper tolerance and consequences for functional stability of the ammonia-oxidizing community in long-term copper-contaminated soils. Environ. Toxicol. Chem. 29, 27–37. https://doi.org/10.1002/etc.16.

Mosier, A.C., Francis, C.A., 2008. Relative abundance and diversity of ammonia-oxidizing archaea and bacteria in the San Francisco Bay estuary. Environ. Microbiol. 10, 3002–3016. https://doi.org/10.1111/j.1462-2920.2008.01764.x.

Rotthauwe, J.H., Witzel, K.P., Liesack, W., 1997. The ammonia monooxygenase structural gene *amoA* as a functional marker: Molecular fine-scale analysis of natural ammonia-oxidizing populations. Appl. Environ. Microbiol. 63, 4704–4712 (https://aem.asm.org/content/63/12/4704).

Sims, A., Horton, J., Gajaraj, S., McIntosh, S., Miles, R.J., Mueller, R., et al., 2012. Temporal and spatial distributions of ammonia-oxidizing archaea and bacteria and their ratio as an indicator of oligotrophic conditions in natural wetlands. Water Res. 46, 4121–4129. https://doi.org/10.1016/j.watres.2012.05.007.

Stahl, D.A., de la Torre, J.R., 2012. Physiology and diversity of ammonia-oxidizing archaea. Annu. Rev. Microbiol. 66, 83–101. https://doi.org/10.1146/annurev-micro-092611-150128.

Wang, L., Li, Y., Niu, L., Zhang, W., Zhang, H., Wang, L., et al., 2018. Response of ammonia oxidizing archaea and bacteria to decabromodiphenyl ether and copper contamination in river sediments. Chemosphere 191, 858–867. https://doi.org/10.1016/j.chemosphere.2017.10.067.

Yang, Y.Y., Zhang, J.X., Zhao, Q., Zhou, Q.H., Li, N.N., Wang, Y.L., et al., 2016. Sediment ammonia-oxidizing microorganisms in two plateau freshwater lakes at different trophic states. Microb. Ecol. 71, 257–265.

Yao, X.L., Zhang, Y.L., Zhang, L., Zhou, Y.Q., 2018. A bibliometric review of nitrogen research in eutrophic lakes and reservoirs.

J. Environ. Sci. 66, 274–285. https://doi.org/10.1016/j.jes.2016.10.022.

Ye, L., Huang, M., Zhong, B., Wang, X., Tu, Q., Sun, H., et al., 2018. Wet and dry deposition fluxes of heavy metals in Pearl River Delta Region (China): Characteristics, ecological risk assessment, and source apportionment. J. Environ. Sci. 70, 106–123. https://doi.org/10.1016/j.jes.2017.11.019.

Zhang, Y., Han, Y., Yang, J., Zhu, L., Zhong, W., 2017. Toxicities and risk assessment of heavy metals in sediments of Taihu Lake, China, based on sediment quality guidelines. J. Environ. Sci. 62, 31–38. https://doi.org/10.1016/j.jes.2017.08.002.

Zhou, Z.F., Liu, Y.R., Sun, G.X., Zheng, Y.M., 2015. Responses of soil ammonia oxidizers to a short-term severe mercury stress. J. Environ. Sci. 38, 8–13. https://doi.org/10.1016/j.jes.2015.04.022.

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