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Tracing Tributyltin Degradation in Sediments: Integrating Multi-Isotope Labelling, Microbial Community Dynamics, and Sediment Geochemistry

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Tributyltin (TBT), once extensively used as a biocide in antifouling paints, was released into the aquatic environment for decades. Due to its toxicity to non-target organisms, TBT has been banned for almost two decades and is classified as a priority hazardous substance under the EU Water Framework Directive. Nevertheless, TBT is still detected in aquatic environments, particularly in sediments where it exhibits high persistence and degrades at slow rates, from years to decades. Regulatory bodies and coastal management authorities therefore continue to seek strategies to mitigate its long-term environmental impact.

To address and manage TBT contamination in the environment, it is essential to understand its environmental behaviour, particularly the processes that determine its persistence in sediments. Although numerous studies have investigated this issue, the factors controlling long-term persistence of TBT, as well as the mechanisms and kinetics of its degradation, are still not fully understood. This study therefore aims to elucidate the degradation pathways of TBT in sediments and to clarify the roles of benthic microbial communities and sediment properties in these processes.

Natural sediments were incubated for 180 days under controlled oxic and anoxic conditions. To trace each transformation step in the degradation pathway TBT→DBT→MBT→inorganic Sn, isotopically labelled compounds were applied, with each species enriched in a distinct tin isotope (^{117}Sn-TBT, ^{118}Sn-DBT, ^{116}Sn-MBT). Changes in concentrations over time were monitored to elucidate the transformation mechanisms and to calculate kinetic rate constants. To identify the key drivers of BuT transformations, microbial community structure was characterised, and temporal shifts in community composition were assessed. In parallel, sedimentological, mineralogical, and geochemical properties of sediments were determined.

The results indicate that TBT degradation occurred predominantly under oxic conditions. Microbial community dynamics exerted a more significant control on TBT degradation than sediment properties. The degradation mechanisms varied among sediments, suggesting site-specific controls on transformation pathways. Shifts in microbial community composition followed a consistent pattern in sediments exhibiting efficient TBT degradation. Furthermore, TBT-resistant bacterial strains were isolated, and their enrichment was pronounced in sediments where TBT degradation was observed.

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