Phytoremediation of Nitrate-Contaminated Groundwater by Desert Phreatophytes

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Abstract: Two native halophytic shrubs were evaluated for phytoremediation of a nitrate-contaminated aquifer at a former uranium mill site. The shrubs, *Sarcobatus vermiculatus* and *Atriplex canescens*, obligate and facultative phreatophytes, respectively, dominate the desert plant community. Stable isotope signatures suggested that both species are rooted into the nitrate plume, a depth averaging more than 10 meters. Aerial photography and ground sampling indicated that populations have responded positively to the elevated nitrate levels. We quantified the amount of water and nitrate these shrubs are removing from the plume, and constructed livestock exclosures to evaluate effects of grazing. The percent groundcover of grazed populations overlying the plume averaged 7% for *A. canescens* and *S. vermiculatus*. Percent groundcover inside the fenced exclosures increased by 50% per year over three years. Annual productivity per unit canopy area did not differ significantly between species or between grazed and fenced plants, however, *S. vermiculatus* had significantly higher nitrogen content than *A. canescens*, and fenced plants had higher nitrogen content than grazed plants. There would be a reduction of 4,137 kg nitrate per year if grazing was excluded from the 24 ha site.

Groundwater at the U.S. Department of Energy Uranium Mill Tailings Remedial Action (UMTRA) site located near Monument Valley, Arizona, has been contaminated with nitrate as a result of uranium milling operations that occurred between 1955 and 1968. The surface materials at the site, including tailings piles, leach areas and an evaporation pond, were removed from the site by January 1994. Currently, remediation of the groundwater is passive, using naturally occurring native phreatophyte shrubs throughout the 24 ha contaminated area. The nitrate cleanup standard is 44 mg/L. Nitrate levels in the center of the plume are as high as 1,200 mg/L. The total plume volume is 2×10^9 liters. Obligate phreatophytes such as *S. vermiculatus* can root as deep as 18 m while the rooting depth of facultative phreatophytes like *A. canescens* may exceed 8 m (Nichols 1993). The depth from the soil surface to the plume surface varies from 1.5 m to 26 m. The site is arid, receiving approximately 20 cm of precipitation annually. *A. canescens* is a valuable range plant for wild and domestic animals and is widely used for soil stabilization in arid region restoration projects.

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Both *A. canescens* and *S. vermiculatus* are heavily grazed by cattle and sheep. To determine the effects of grazing throughout the area of the nitrate plume, 24 plant pairs (either *A. canescens* or *S. vermiculatus*) of similar initial size were examined. An exclosure was constructed around one plant of each pair to prevent grazing while the other plant was left exposed to livestock. The canopy area of each plant was measured each year for 3 consecutive years at the end of the growing season. The total plant canopy area increased by approximately 50% per year for both *A. canescens* and *S. vermiculatus* that were fenced in the exclosures while the other plants remained unchanged in size.

By excluding grazing, the concentration of nitrogen in each species increased. For plants within the exclosures, the nitrogen content of *S. vermiculatus* was approximately 26 g/kg and 21 g/kg for *A. canescens*. Both plants decreased their average nitrogen content by approximately 1 g/kg nitrogen when exposed to grazing. Limiting grazing can increase the amount of nitrogen each species uses while increasing their groundcover, therefore decreasing remediation time.

To determine if plants are rooted in the nitrate plume, water extracted from exclosure plants and soils were compared with well water samples. Soil samples from a 1 m depth and stem samples from both *A. canescens* and *S. vermiculatus* were collected from inside the exclosures. Water extracted from the plant and soil samples were compared using stable hydrogen and oxygen isotope ratios. The isotope signatures of the plant samples indicate an older water source that is deeper than the 1 m soil samples.

The plant community established in the area over the nitrate plume was characterized using a line intercept method (Bonham 1989). The groundcover of the entire plume area was found to be 7%, with some areas of shallow groundwater having as high as 36% cover of *S. vermiculatus*. Low plant density and groundcover area can be attributed to current grazing practices and the application of herbicides sprayed during the surface remediation phase of the project. By excluding grazing from the 24 ha plume, biomass production would potentially increase to an estimated 25% canopy coverage within the next few years. At this level of cover, *A. canescens* would remove approximately 145 kg nitrogen/year and *S. vermiculatus* would remove 155 kg nitrogen/ year, or a total of 4,137 kg nitrate/year for both plants.

Several approaches for actively treating the nitrate contamination have been proposed, however, passive pump-and-treat remediation using the existing native plant population is currently the only remediation ongoing at the site. One alternative is active pump-and-treat using the contaminated water for irrigation of native plants or forage crops. The biomass yield would increase to 20 tons/acre using the contaminated water for irrigation. This substantially higher yield would remediate the site within 20 years.

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