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Plant water sources in the cold semiarid ecosystem of the upper Kherlen River catchment in Mongolia: A stable isotope approach

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Summary In the cold semiarid region of northeastern Mongolia, we used stable isotopes (^{18}O and D) to determine potential plant water sources during the 2003 growing season (June to September) in two habitats: montane forest and an elevation gradient from the forest to Kherlen river bank. The forest is dominated by larch (*Larix sibirica*) with patches of cinquefoil shrubs (*Potentilla fruticosa*). The latter also grow throughout the elevation gradient, while the larch grows only on the top slope. Poplar (*Populus* spp.) and willow (*Salix* spp.) trees grow only on the river bank. All plant and soil samples showed isotopic signatures similar to summer precipitation, which is isotopically heavier in summer than winter. In July and August, larch trees in the forest tended to shift their water uptake to shallow depths in response to recent rainfall, but during the remaining months (June and September), depths of water uptake were unclear. Further, both the larch trees and cinquefoil shrubs in the forest used water at similar depths, suggesting potential competition for water. Plants along the elevation gradient showed different patterns of water use: (1) in July, larch used recent rainfall only, but in other months, the pattern was unclear; (2) cinquefoil depended on rainfall from recent weeks (as in August), but sometimes used antecedent rainwater from one month prior; and (3) poplar and willow seemed to use water from the river (as in August) or from precipitation that fell a few weeks prior (as in

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September), but the factors controlling this unusual shift are unknown. This study contributes to our understanding of plant water use strategies in cold semiarid ecosystems, and provides baseline data for models designed to understand large-scale hydrological effects of global climate change.

Introduction

Water use strategies of plants and water transport in the soil—plant—atmosphere continuum are critical to understanding ecosystem functioning in arid and semiarid habitats where plant productivity is often limited by soil moisture (Noy-Meir, 1973; Webb et al., 1983). Moreover, they are intrinsically related to precipitation variability (Fischer and Turner, 1978; Breymeyer et al., 1996). Indeed, because precipitation is highly dependent on forest evapotranspiration (Salati et al., 1979; Savenije, 1995), deforestation and land cover changes will likely reduce precipitation, and thus, increase the risk of regional drought (Eltahir and Bras, 1994; Wang and Eltahir, 2000).

Isotopic compositions (D and ^{18}O) of different water pools in an ecosystem (soil, plant and atmospheric) can describe interactions between these water pools and biological and hydrological processes (Ehleringer and Dawson, 1992; Gat, 1996; Yakir and Sternberg, 2000; Dawson et al., 2002). For example, because, in general, plant roots do not discriminate against specific water isotopes during water uptake (exception: mangroves; see Lin and Sternberg, 1993), the isotopic composition of stem water can determine potential plant water sources (Wershaw et al., 1966; Ehleringer and Dawson, 1992; Brunel et al., 1995). Certain plants are thought to use different water sources in response to seasonal water availability (e.g. Ehleringer et al., 1991; Weltzin and McPherson, 1997; Jackson et al., 1999; Stratton et al., 2000), reducing competition for water and increasing the likelihood of plant survival during periods of water shortage (Noy-Meir, 1973; Ehleringer et al., 1991; Peñuelas et al., 2000).

Numerous studies have described plant water uptake in arid and semiarid habitats by applying isotope mixing models. For example, along the summer monsoon precipitation gradient in Arizona and Utah, USA, three dominant tree species in the pinyon-juniper community are known to use different water sources: *Pinus edulis* and *Juniperus osteosperma* were shown to use a large proportion of monsoon precipitation while *Quercus gambelii* used only deep soil water even in periods of recent substantial summer precipitation (Williams and Ehleringer, 2000). Moreover, in the semiarid Mu-Us desert, Inner Mongolia, China, native *Sabina vulgaris* and introduced *Salix matsudana* trees use relatively deep soil water as well as groundwater, whereas the shrub *Artemisia ordosica* uses shallow soil water only (Ohte et al., 2003). Afforestation in this desert area with *S. matsudana* might therefore cause irreversible groundwater loss because, compared to native plants, this exotic tree has relatively low water use efficiency (Ohte et al., 2003). In savanna communities, trees, shrubs, and grasses are able to coexist because, in general, trees and shrubs tend to use deep water sources while grasses tend to use shallow water; a pattern certainly related to the different root distribution patterns of these life forms (Noy-Meir, 1973; Walker et al., 1981; Sala et al., 1989; Le Roux et al., 1995; Scholes and Archer, 1997; Weltzin and McPherson, 1997; House et al., 2003; see Moreira et al., 2000, for an exception to this niche partitioning hypothesis).

The application of mixing models to estimates of plant water sources and their relative contributions has received both support (e.g. Brunel et al., 1995) and criticism (e.g. Thorburn and Ehleringer, 1995; Snyder and Williams, 2000; Phillips and Gregg, 2001; Phillips and Koch, 2002; Phillips and Gregg, 2003). Brunel et al. (1995), in a semiarid field situation, found that the total error involved in sampling, extraction and assumptions was <5‰ for D and <1‰ for ^{18}O, suggesting that these models are appropriate for determining potential plant water sources. However, mixing models do not provide information about the active root area or depths of plant water uptake; shortcomings recently overcome by Ogle et al. (2004) who proposed an algorithm for reconstructing the active root area and water uptake profiles, and by Romero-Saltos et al. (2005) who developed a model to estimate potential mean depths of plant water uptake from isotopic signatures of soil and stem water.

In the cold semiarid environment of northeastern Mongolia, research on water sources of dominant plant species is just starting. In the Kherlen River catchment area, larch (*Larix sibirica* Ledeb.) taiga forest dominates and plays an important role in the eco-hydrological processes of the entire basin (Li et al., 2005; Sugita et al., this issue). In this montane forest, Li et al. (2006) showed that during the growing season, according to ^{18}O signatures of plant and soil water, larch trees use water from the top 30 cm of the soil after rainfall events, but water from deeper layers when the topsoil water becomes scarce. In this paper, we attempt to confirm this pattern of water use using the model of Romero-Saltos et al. (2005) to estimate potential mean depths of water uptake, using soil and stem signatures of not only ^{18}O, but also D. We also determine plant water sources during the growing season along an elevation gradient from the montane larch forest stand to the bank of the Kherlen River. For this gradient scenario, we test the following two postulates: (1) during the growing season, recently fallen rainwater is the main source of water for plants growing along the mountain slope, and (2) river water is the main source of water for plants growing on the river bank.

Materials and methods

Study area

The study was conducted at Mongonmorit, Tov province, Mongolia, in the mountain catchment area of the Kherlen River, near the tower of the Rangelands Atmosphere—Hydrosphere—Biosphere Interaction Study Experiment