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Short Communication

Spatial and temporal patterns of soil water storage and vegetation water use in humid northern catchments

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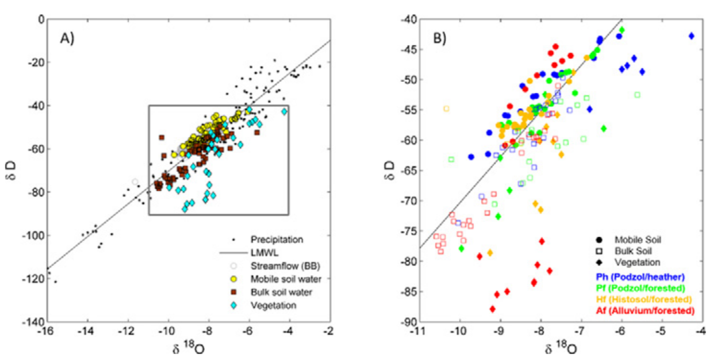
HIGHLIGHTS

- Plant-soil-water interactions in the temperate humid North are relatively unknown.
- Stable isotopes of soil and vegetation water revealed spatio-temporal patterns.
- In contrast to other biomes, we found little separation between soil water sources.
- Vegetation sources were constant temporally, but variable with landscape position.

GRAPHICAL ABSTRACT



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ABSTRACT

Using stable isotope data from soil and vegetation xylem samples across a range of landscape positions, this study provides preliminary insights into spatial patterns and temporal dynamics of soil-plant water interactions in a humid, low-energy northern environment. Our analysis showed that evaporative fractionation affected the isotopic signatures in soil water at shallow depths but was less marked than previously observed in other environments. By comparing the temporal dynamics of stable isotopes in soil water mainly held at suctions around and below field capacity, we found that these waters are not clearly separated. The study inferred that vegetation water sources at all sites were relatively constant, and most likely to be in the upper profile close to the soil/atmosphere interface. The data analyses also suggested that both vegetation type and landscape position, including soil type, may have a strong influence on local water uptake patterns, although more work is needed to explicitly identify water sources and understand the effect of plant physiological processes on xylem isotopic water signatures.

1. Introduction

Characterizing the dynamics of plant water availability and the mechanisms whereby plants access available water sources remain key challenges in ecohydrology (Asbjornsen et al., 2011; McDonnell, 2014). Insights into these processes are crucial for our understanding how precipitation is partitioned back into the atmosphere through

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evapotranspiration, or recharges ground water and generates runoff (Brooks et al., 2015; Tetzlaff et al., 2015). Many studies on the physical, chemical and biological aspects of plant, water and soil relations have advanced our understanding in previous decades (see e.g. reviews by Philip, 1966; Kramer and Boyer, 1995; Rodriguez-Iturbe and Porporato, 2004; Asbjornsen et al., 2011; Kirkham, 2014). Research from across a wide range of environments differing in climate, soil type and vegetation has shown that strong interactions between these properties (e.g. Jackson et al., 2000; Scott et al., 2000; Schwendenmann et al., 2015; Dai et al., 2015) ultimately control the temporal and spatial dynamics of plant water availability and uptake patterns. Stable isotope analyses of plant xylem water and various potential source waters have proved valuable in resolving some of the questions surrounding plant water uptake (e.g. Ehleringer and Dawson, 1992; Brooks et al., 2010; Goldsmith et al., 2012). Many of these studies have shown that plants can be highly opportunistic and adaptable in accessing water from the subsurface. For example, although not the general rule (Wei et al., 2013), it is well known that vegetation can switch from accessing shallower to deeper sources between seasons (e.g. Penna et al., 2013; White and Smith, 2015) or during periods of drought (Barbeta et al., 2015). Isotopically different vegetation water of co-existing species has also indicated niche segregation for water uptake in mixed stands (e.g. Rossatto et al., 2014; Comas et al., 2015; Schwendenmann et al., 2015).

Several recent studies have suggested that there may also be "ecohydrological separation" of distinct soil water pools (the "two water worlds" hypothesis) comprising plant-available water on one hand and water that drains to streams on the other (Brooks et al., 2010; Evaristo et al., 2015; Good et al., 2015a; Bowling et al., 2016). Physically, it has been proposed that this could represent water held at suctions greater than field capacity (in this context usually referred to as "plant available" water or "tightly bound" water) and waters held at suctions less than field capacity (mobile water), respectively (following e.g. Brooks et al., 2010; Orlowski et al., 2016a). The isotopic character of water held at these different suctions was found to be distinctly different, with tree water resembling the more fractionated tightly bound water. While questions remain on how and why plants may use tightly-bound soil water when more mobile water is available to their roots (Bowling et al., 2016), most efforts have focussed on the conditions that drive soil water separation. Recent meta-analysis (Evaristo et al., 2015) and global remote sensing efforts (Good et al., 2015a, 2015b) have shown that ecohydrological separation is widespread globally. However, more detailed studies in diverse environments have provided a range of alternative interpretations in relation to these differences in isotopic signatures. In climates with strong seasonality, bulk water (including the tightly bound water) isotopically resembled that of the first rain (Brooks et al., 2010; Goldsmith et al., 2012) or snowmelt (Gierke et al., 2016) after the dry season. It was hypothesised that this first water entered the smaller pores when they were dry and got locked (or was more tightly bound) throughout the rest of the season without significant mixing with additional precipitation inputs. However, recent work by Hervé-Fernández et al. (2016) in a rainy temperate zone in Chile, and by McCutcheon et al. (2017) in a semi-arid, snow-dominated landscape in Idaho demonstrated that during wet periods when soils are replenished there (temporarily) was sufficient mixing of water stored in the larger and smaller pores of the soil to infer that soil water was not clearly separated into two compartments. Furthermore, while Evaristo et al. (2016) did clearly demonstrate a distinct separation of two subsurface reservoirs in an environment with less seasonality in precipitation (Puerto Rico), some preliminary analyses from sites across higher latitudes in Europe with less marked summer drying did not show strong evidence in support of this (Scotland, Geris et al. (2015a); Germany, Schmid et al. (2016)). Furthermore, following earlier work by Allison and Barnes (Allison, 1982; Allison and Barnes, 1983; Barnes and Allison, 1983), Sprenger et al. (2016) have postulated that distinct pools of water may only exist at shallow depths, characterised by the maximum evaporation penetration depth, which depends on soil texture and the climatic conditions. They have further theorized that mixing of tightly bound evaporative fractionated water with newly introduced (mobile) water does occur and increases during the percolation process.

While disentangling the relative role and interplay of vegetation and soil properties on plant available water and the "(eco)hydrological partitioning" of subsurface water is a major focus of current work (Troch et al., 2013; McDonnell, 2014; Vereecken et al., 2015); low energy, humid northern regions have so far received relatively little attention (Tetzlaff et al., 2015), compared to e.g. (seasonally) high energy, water-limited ecosystems (Zeppel, 2013). In the former, water sources are often not limited (Rodriguez-Iturbe et al., 2007; Thompson et al., 2010). However, future climate projections include longer growing seasons and reductions in water availability (IPCC, 2013), so that increased knowledge on the soil-vegetation water interactions in these rapidly changing areas is urgently needed. Preliminary work in the Scottish Highlands failed to establish strong evidence in support of two separated soil water pools. Instead the results suggested that trees extract water from the uppermost part of the soil profile, which showed some evaporative fractionation effects in the summer months (Geris et al., 2015a). However, questions remain on how these interactions develop throughout the year and if these are consistent for different soil and vegetation types spatially distributed across the landscape.

Here, we report the results of a preliminary investigation of stable isotope dynamics in xylem water and potential soil water sources (mobile and less mobile) in four soil-vegetation assemblages in the Scottish Highlands. Our specific objectives were to: (i) assess annual dynamics of water stored in the soil by evaluating the isotopic character and possible interactions between more mobile and tightly bound soil water; (ii) evaluate the annual patterns in vegetation water uptake in the context of these soil processes; and (iii) examine how i and ii vary spatially in different soil-vegetation units.

2. Data and methods

We monitored soil and xylem water dynamics in four characteristic ecosystems within the Girnock Burn catchment (30 km^2) in the Scottish

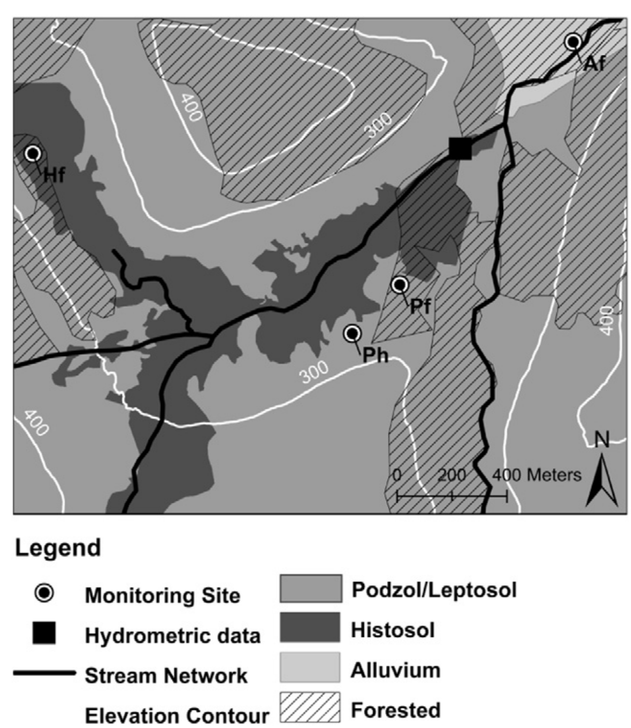

Fig. 1. Site overview showing the four sampling locations, the soil distribution and the forested areas.