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NOTE

Real-time monitoring of deadwood moisture in forests: lessons learned from an intensive case study

C.W. woodall, D.M. Evans, Fraver, M.B. Green, D.A. Lutz, and A.W. D'Amato

Abstract Attrù•utes of in including quantiw. and state of decay. influence numerous ecosystem such as wildfire tree regeneration. and nutrient cycling. Attributes of deadwood that Vary over subdiurnal time steps. including awisture. have not been routinely measured despite the profound effects they have on ecosystem To improve our understanding or forest deadwuyd subdiurnal moisture dynamics. we installe d an inten• Sive timedomain refkctometo• UDR) sensor network Ln a log and surrounding sou within a northern hardwood forest in New England. United States. Intensive monitoring during a partial growing season indicated that deadwood moxsture was dynamic bur similar ro rhar of surrounding soils ar IS-min inrervals, esËciaIIy during werring and drying evenrs_ Field resulrs and bench of the sample revealed numerous challenges when artempting to monitor deadwood moisrure With TDR Such as hererceneous and (or) advanced decay TDR moisture measuremenrs in logs. An emcient, TDR œnsor was demonsrrated to record deadwt»d and soi' moisture fluctuations, which provides an to renne high-frequency opportunity to r understanding of deadwood in the context of global change Such as changing precipitation regimes_

Key downed soil moisture. TDR sensors, wildnre, 'mod deccy_

: les du Mis mort en telles que la quantité, la position dans le paysage et I 'état de déco influencent omposition, plusÞurs de l'écosystème. comme le comportement du feu , la régénération des arbres et le nutrimenrs_ Les ecyclage des caractéristiques du bois mort qui varient en mnction d'échelles de remps sousdiurnes telles que I 'humidité n'ont pas été mesurées de âçon routinière malgré les effets qu'elles ont sur les Payessus de l'écosystème. Ann d'améliorer notre compréhension de la dynamique sous-diurne de l'humidité du bois mort en thret, nous avons installé un réseau intensifde capteurs utilisant la réflecrométrie à dimension (TDR) dans une bille et le sol environnant dans mie torer de reuillus nordiques en NouvelleAngIererre, aux Érars-Unis. Un suivi intensif durant une partie de la saison de croissance a montre que rhumidiré du t*is mort est dynamique mais semblable trlle du sol environnant intervalles de 15 min, surtout durant les épiso&s de m(llillage et de les resulrars Sur le terrain et l'analyse en laboratoire de la bille qui a servi d•echanrillon ont rail ressortir de nombreux défis lorsqu'on rente de taire le suivi de l'humidité dans le bois mort avec la TDR, tels que d•avancemenr et l'hétérogénéité de la carie qui réduisent la fiabilité des mesures d•humidiré par TDR dans les bilks. réseau le capteurs qui utilisent la TDR haute fréquence pour enregistrer les fluctuations de I • humidité dans le bois ax•rt et le sol a été 'knuyntrée. ce qui fournit une oppyrtunité de raffiner no tre compréhension de la dynamiq ue du dans le contate du changement gbbal dont changement des régimes de précipitation. [Traduit par la Rédaaionl

Mœs-dá : txis mort au sol, humidité du SOL capteurs TDR. de démmposirion du bois.

Introduction

Over the past decades. it has increasingly evident that deadwo«l plays a critical role in numerous ecosystem functions. including wildfire (SchcRnnageI et al. 2004). nutrient cycling (Harmon et al. 1986), tree rvgeneration OWlton and D'Amato 2011). wildlire habitat. and tungal and insect community dynamics (Stokland et al_ 2012) such findings. a funda• mental understanding of how deadwcx:d inte racts With weather, soi]. and vegetation at diurnal and time scaks is lacking. Such essential understanding will become increasingly important in a future ofglobal change in which insect outbœaks and climate change may incrrase trt•e mortality (i-e,, deadwood input) acmss the world•s forests (McDowe11 and Allen 2015). Further, such understanding could add to our current kncwledge of the forest carbon cycle, given the influence or moisture and temperarure on deadwood decomposition rates (law et al. 2018). The underlying mechanisms that relate deadwood attributes to fores t ecoystem funcrions such as the carbon cycle are poorly under• stood (Russell et al. 2015). especially over diurnal and subdiurnal time steps. Given the direct influence of deadwood moisture on cartx»n cycling, as well as deadwmd's indirect influence on soil conditions and vegetation (Goldin and Hutchinson 2014). we propose that investiganng and monitoring such deadwood attributes at high temporal resolurion is imperative.

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Deadwood can assume several forms in forest ecosystems. including standing dead trees, upturned mots, fine Woody material (FWM), and a)arse wcx)dy material (CWM) et al. 2019L For the of this study. we define CWM as atxweground dead and downed wocdy materials of at least 7.6 cm in diameter. following standard monitoring pmro.mls et al. 2019). Although deadwood other than (LWM is ck•arty a major driver or various stem prcResses such as wildfire (e.g.. fine woody sur• face fuels; Rothermel 1983b. here we initiate a study of real-time deadwocxl monitoring on CWM, as there are fewer constraints on the installation of se nsors with these larger materials. Sensor networks that collect relevant OVM moisture data underneath forest canopies at subdiumal time steps (e.g„ rainfall events) are absent, leaving a gap in cnlr understanding of iow CWM attri• bures change over short time scales. FurThermore, given that more episodic precipitation is projected as climate changes (Melillo et al. 2014). predicting how CWM moisture responds to new precipitation regimes will essential thr climate-adaptive forest management (e.g.. Nagel et al. 2017). Hence. improved CWM moisture monitoring techniques would not onb• tx•nefit forest ecosystem sciences. but also the management of wildfire and smoke in the context of global change.

Quanti9ing attributes of •VM such as moisture in near real time remains a major hurdle to wildfire and smoke management, resource conservation. and applied science efforts of the velY nature of leadwood. Although developments to ascertain CWM volumes via light detection and ranging (IiDAR) in 0Xn landscapes are promising (Jø•ce et al. 2019). in the under• stoly of intact forests remains elusive to remote sensing approaches. let alone the determination of its characteristics (e.g. state or decay and rmisture level). An initial exploration or the variability of CVAN moisture by destructively sampling individual LWM pieces indicated considerable variability in moisture '30%— 195% moisture dry weight) within individuals, perhaps driven by sun exposure, gmund a•ntact. and condition (Reinhardt et al. 1901). Likewise. Pichler er al (2012) thund substantial ranges in moisture by decay stage for temperate species. Drivers of this variability have not tRen well quantified. nor have parsimonious appmaches been suggested ror monitoring the moisture content of CWM across rx'pulations or interest such as individual forest stands subjected to drought and (or) episodic precipitation. Despite the critical need to monitor CWM moisture and related attributes in real time. comprehensive advances in terms or technology and fundamental science have not occurred.

Given the demonstrated knowledge gaps involving the high• frequency monitoring (Le„ subdiurnal) of attributes, the goal of this study was to investigate field-ready techniques for intensively monitoring CWM moisture in tenurrate forests. Our specific objectives were to (i) monitor the in situ, real-time moisture of a partially decayed study specimen and associated soil underneath and in proximity to the LWM sÇRcimen during a growing season using timedomain reflectometry DR) sensors antpled with a data logger system: evaluate variability in wood densiw throughout the svæcimen in relation to high• frequency monitoring objectives: and (fit) combine the field and bench analyses to suggest optimal configurations future ONM and soil field station arrays.

Methods

The study design involved a field deployment of a IDR sensor anay for one partially dec7yed sugar maple LACET sacch Marsh.) CWM piece (hereafter rvrerred to simpb• as a log) and surrounding soil concomitant with Iatxsr-atory evaluations of the CWM specimen's wo«l density. This design allowed evaluation of field deployment realities in combination with assessment or sensor rxrrormance, which together should facilitate futurv development of optimal field station sensor configurations.

Study site

This work was conducted at the Hubbard Brook Experimental Forest (HBEF) in the United States Department or Agriculturv (USDA) Forest Service's White Mountain National Forest, New Hampshire, united States (Fig. 1) (Holmes and Likens 2016). This experimental forest. which largely focuses on forest hydrology research. provided an ideal location for this study given the nearby long-term meteorological station (Bailey et al. 2003) and the compendium of published studies on HBEF forest dynamics (e.g.. Holmes and Likens 2016) related to this study's objectives. Given that HBEF is a second-growth noLthern hardwood forest dominated by sugar maple. yellow birch (Betula alleghaniensis Brit• ton), red spruce (Picea rulpns Sarg.). and American beech (Fagis gran"ia Ehrh_) (Bailey er al. 2003; Holmes and Likens 2016), sugar maple was chosen as the study species, as it is an ecologi• cally and economically important species in the region.

Moisture me asurement

We used IDR sensors (Acclima 315L. Acclima. Meridian. Idaho. USA) in our study design. TDR utilizes measurements of the speed at which electromagnetic waves propagate through a medium. in this case. soil and wood. Because the velocity at which these waves travel is influenced by the medium's dielectric constant. and because this constant differs between water and a medium, estimates of velocity provide accurate estimates of volumetric moisture content IVMC) of a medium. A summary equation of this calculation can be expressed as

$$(1) \quad B. = \quad — tta(1 \frac{T - T_{ref}}{400})$$

in which is soil VMCÄ e is the velocity ora wave in a vacuum; b is a validation coefficient; L is the length of the TDR sensor (in this case, 15 tt and tro are the times at which the wave leaves and returns to the sensor, respectively; and T and soil temperature and a reference soil temperature (Ledieu et al. 1986). respectively. The selected TDR sensor measures VMC (0.1% resolution) and permittivity (0.1 unit resolution) and is capable of reporting data via the SDI-12 (serial digital interface at 1200 baud) digital protocol with a read time of 1.0 s.

Study log description

To fully evaluate TDR across a sensor array in the field, we located a study log in HBEF•s Watershed 3, which was established in 1958 as a hydrologic rererena• catchment and has an area of 42 ha, a south-racing aspect, a slope or 16^0, and mean annual precipitation or 1324 mm (Bailey et al. 2003). The water budget, based on long-term measurements. indicates that 62% of the precipitation that enters the watershed leaves as stœamflow and 37%leaves as evapotranspiration (Bailey et al. 2003). Soils are dominated by Spodosols of sandy loam to loamy sand texture derived from glacial drift parent materials (Holmes and Likens 2Œ16). After a thorough search of the watershed. we selected the study log because of its moderate size (37 cm diameter at large end, 104 m length). moderate decay status (decay class 3 of a five•class system; Woodaller al. 2019), and importantly. its alignment perpendicular to slope (potent-ialb' intercepting downslope runoff), with only SOX of its lengh in contact with the ground (Fig. 2).

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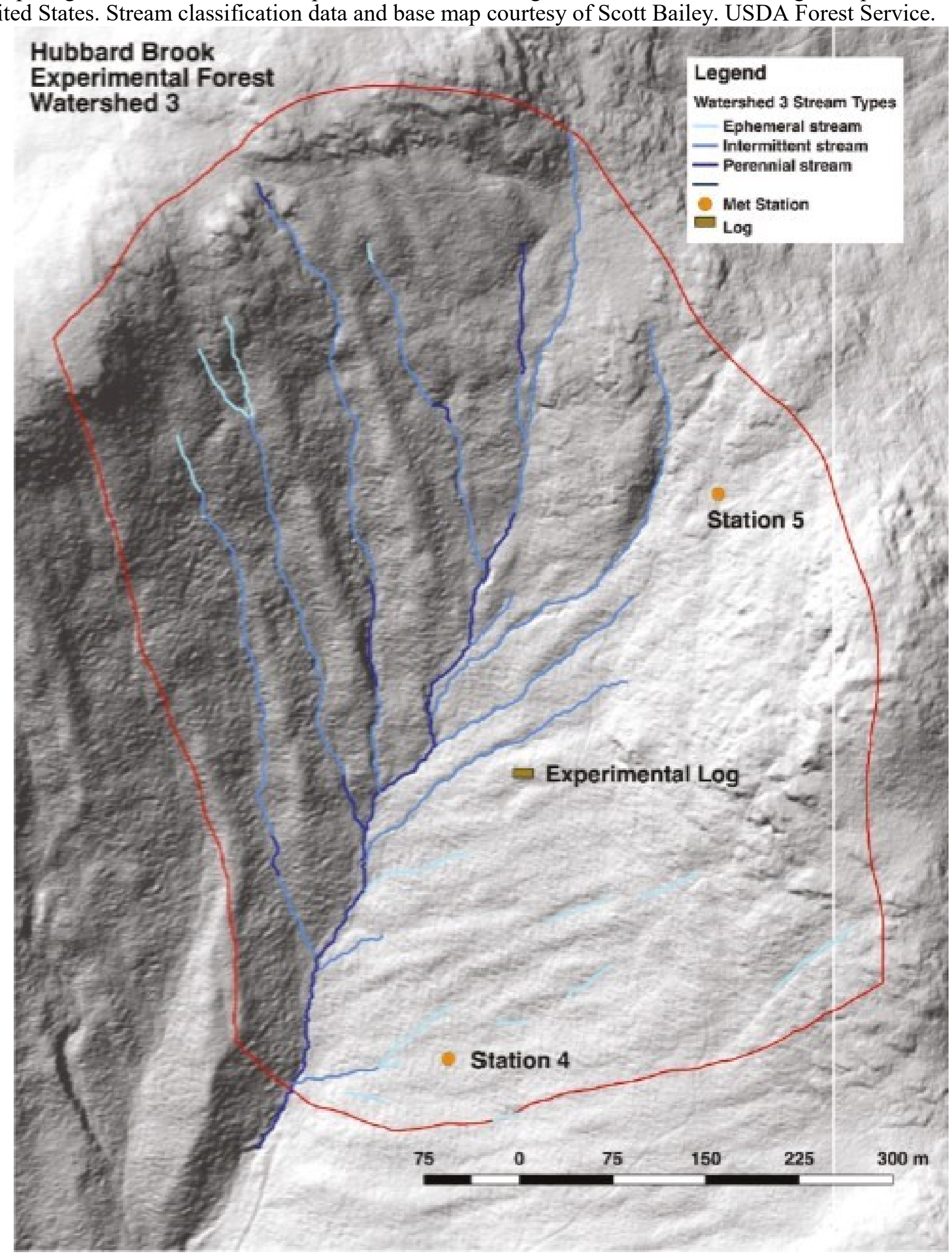
Iäg. I. Location of sampk log within Watershed 3 and proximiw of meteorological stations at Hubbard Brg»k Experimental Forest (HBEF). New Hampshire. United States. Stream classification data and base map courtesy of Scott Bailey. USDA Forest Service.



Sensor design and data œtrieval

A total of 62 sensors were deployed across the entire sensor array. We placed SO IDR sensors within the soil along five S m long transects arrayed perpendicular to the log and separated from each other by 2 m (Fig. 2). At each we installed a TDR sensor at depths of 10 and 20 cm into the mineral soil hori• zon_ We separated these sensors along each transect by I m. Thus, 10 soil TDR sensors were installed for each transect (Fig. 2).

TDR sensors were also inserted into the log itself at 12 locations. To install these we drilled three 15 cm guide holes (4.366 mm (11164 inch) drill bit size) into the log at each point using a drill template with sensor tines installed dirvctly into the log. Because of the partially decayed of the several TDR sensors could fully inserted into the log. with minimal lengths (ma— jority <2-5 on) Of the prong remaining outside or the log.

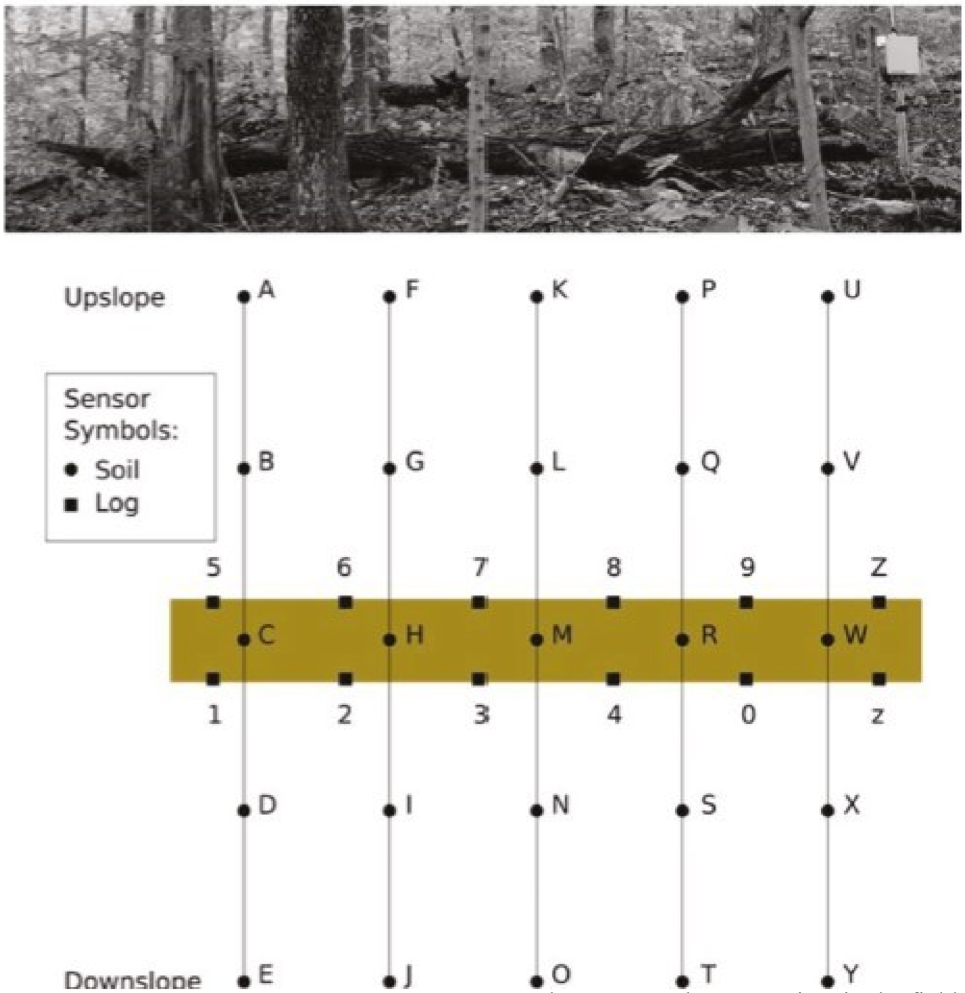
Measurements from each mR sensor were taken 15 min, beginning on 6 June and ending on 17 2018. Each IDR sensor was given a serial digital interface address (SDI-12) and a'nnected to an data logger (Mayfly vO.5b. Stroud Water Research Center. Avondale. USA) _ We constructed three control to house three data loggers. each of which could be connected to as many as 24 •IDR sensors. B2cause the IDR sensors requirvd between 6 and 15 V dirvct current (DC), we powered the sensor array using 12 V lead—acid rechargeable barteries_ Alto-gether. we collected over 2.4 million unique measurements during the held season.

Destructive sampling or sample log

On 17 October 2018. the sensors were removed, and 12 complete radial cross sections of the log (i.e.. -cookies") were collected for laboratory analyses of wood density and moisture content (for comparison with the last-recorded TDR measurements). Cookies were at the sensor locations, sealed in plastic wrap, and transported immediately ro a laboratory, where they were weighed while moist. At the same time. cookie thickness was measured at 10 or more locations amund the perimeter or each a»kie. and outlines of each cookie surfaces) were traced onto poster board after removing bark. These tracings werv scanned, and areas (in square centimetres) were determined using

Iäg. 2. Schematic of field-instalkd sensor array with image ofsample log relative to soil sampling transects. Soil transects were by

2 m. with soil sensors separated by 1m along each transect. with two sensors installed at depths of 10 and 20 cm at each location. Deadwood sensors were installed at upslope and downslope locations as close as practical to each soil transect. [Color online.]



Downslope

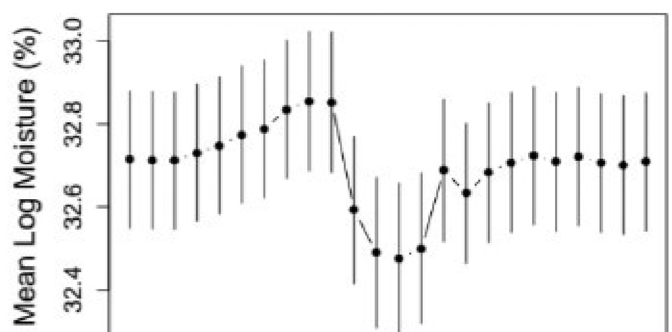
[mage] software (Rueden et al. 2017). The field (moist) volume or each cookie was determined as the prcxluct of mean ctx•kie surface area and mean thickness. were then dried at 75 oc for 2 weeks and weighed to obtain dry mass. Given the state of decay. portions of the cœ)kies precluded the use of physical measurements to determine dry volume. We thus determined dry volume by assuming shrinkage (Panshin and de Zeeuh 1980). From these volume and mass data. we determined mass moisture content. VMC. and sit-y (dry mass,'dry volume' for each the large range of variability in density that we observed within individual cookies. we cut deemed to epresent the lowest and highest densities from each (X)Okie. Cubes were measured (using a micrometer). redried. and weighed to determine density or each.

became friable upon drying, which
l measurements to determine dry
dry volume by assuming 9% shrink-
980). From these volume and mass
isture content, VMC, and wood den-
r each cookie. Finally, to document
in density that we observed within
cubes (mean ca. 35 cm³) of wood
est and highest densities from each
l (using a micrometer), redried, and
of each.

Results

Sensor field œsults

The TDR results across time in the field indicated successful tracking of deadwcod moisture in respJnse to meteorological events (i.e.. wetting and dryingl. In terms of the log sensor network, diurnal trends in moisture followed a pattern of in• creasing VMC until ICKY) hours. then a decline to a 'NC at



approximately hours. follmved an erratic increase in VMC until 24m hours (Fig. 3)_ The perturbations in the mean VMC

Fig. 3. Diurnal trends in mean volumetric moisture (VMC) of sugar maple bg (averaged across the growing Rason). Bars represent standard errœ.

Hour of the Day

trend line can attributed to individual rain events during the sampling season_ The soil sensors also demonstrated consistent diurnal patterns (averaged over the study period).

events. the abundant data from soil and log sensors resulted in a detailed array of VMC information (Figs. 5 and 61. For example. a —35 mm precipitation event in the early hours of22 August 2018 was reflected in almost all sensors with consistency in the soil VMC tRnd lines but with variation in absolute VMC estimates (Fig. 5). Given the variation in density

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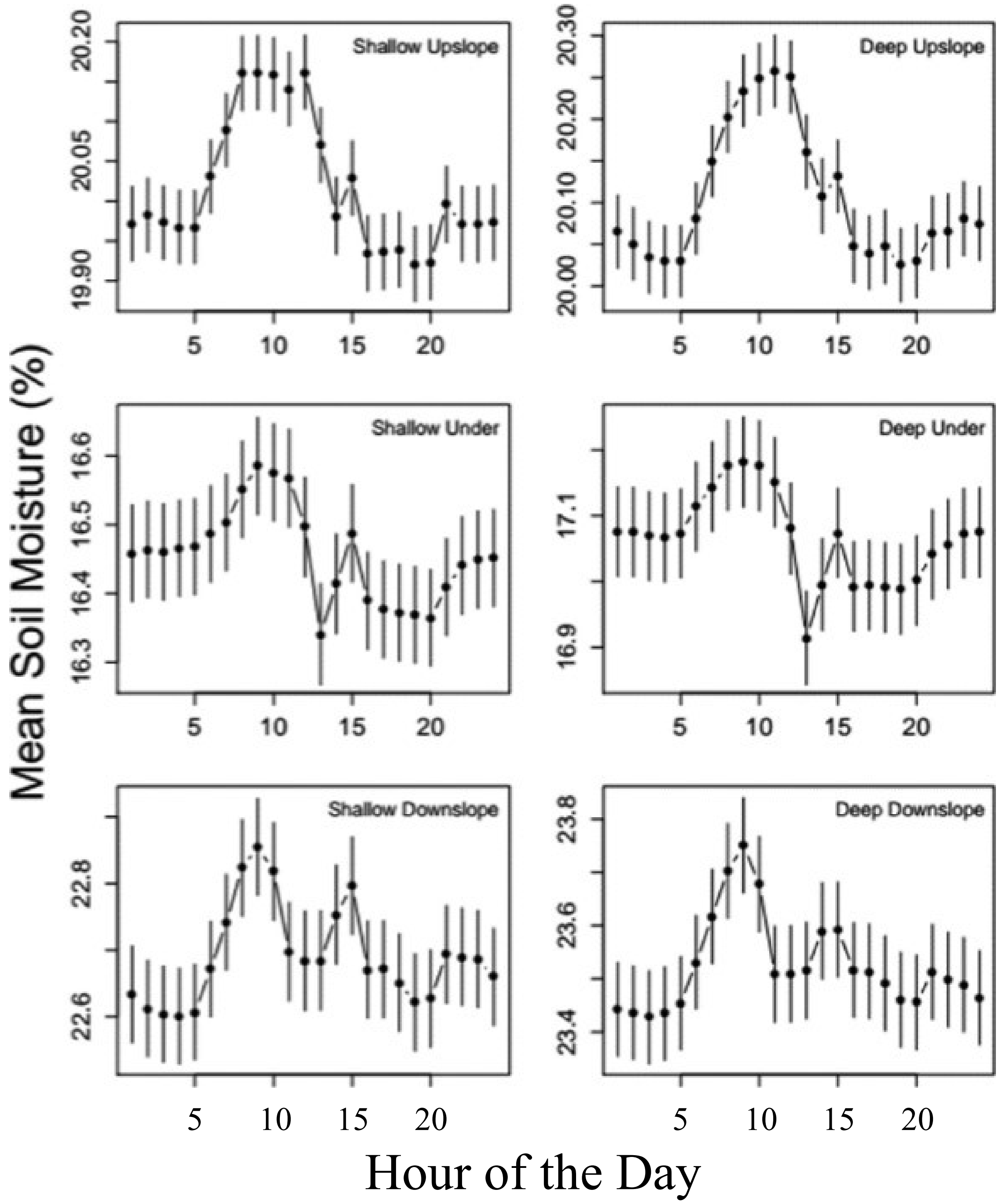
Fig. 4. Diurnal trends in mean VMC uxation reÞtive to a sugar maple log and sample Çth (shalbw 10 cm. deep 20 cmþ. Bars represent standard error.



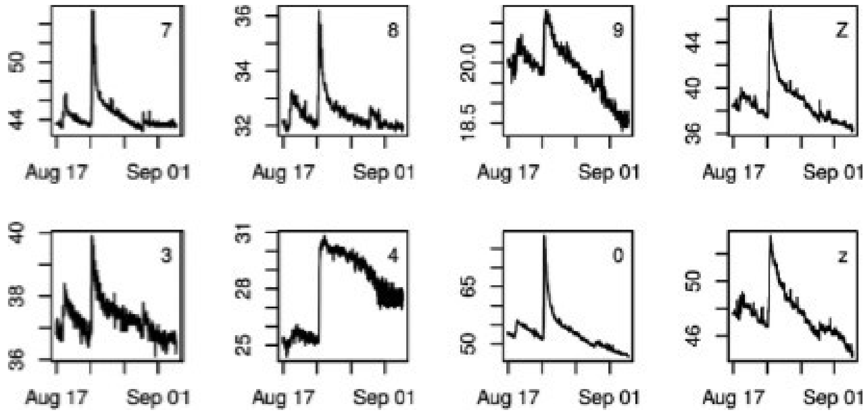
with the high• est VMC reached around hours consistently before the days warming started attenuating downslope down into the (10 and 20 cm depths) (Fig. 4). It was also observed that the VMC was lower underneath the than at the upslope and locations regardless of soil depth. In terms of subdiurnal patterns and resvxmse to individual precipitation

(i.e,, state of decay). diameter. and log ground contact. there was considerable variation in the absolute VMC of the log•installed but still with consistent reaction to the precipitation event A precipitation event 1—-5 mm) on 8 August 2018 during a longer dry spell indicated the tvsponsiveness of the TDR sensors while suggesting that log moistutv returned to pre-event levels within 24 h (Fig. 6).

Sample log attributes

Subsamples or the 12 cookies collected from the in situ sample log ror density determination revealed substantial withincookie variation. For example, ror five or the 12 cookies, the subsample maximum density was at least five times greater than the sul> sample minimum (Table I). Similarly, densities determined for entire (Table I. Total Density) varied considerably within the log. ranging from 0163 to 04" gcm— •_ We note that the published density for a sugar maple in decay class g is 0224 g-cm—g, with an uncertainty of ±0043 gem-a (Harmon et al 2mS); the maiian cookie

…urements during a ~35 mm precipitation event on 22 August 2018 at HBEF.



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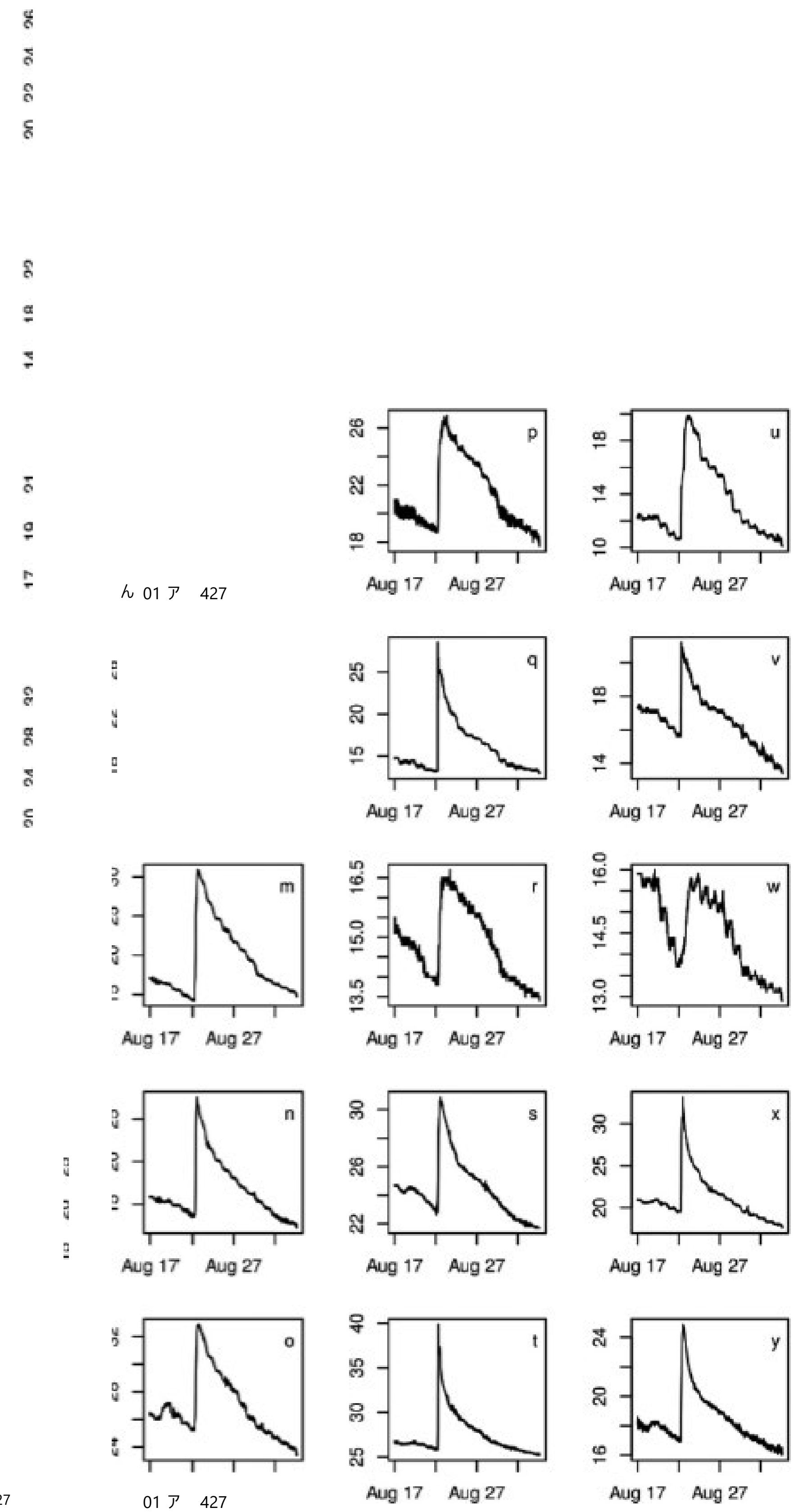

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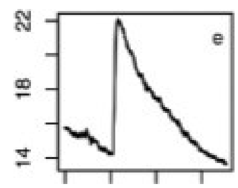

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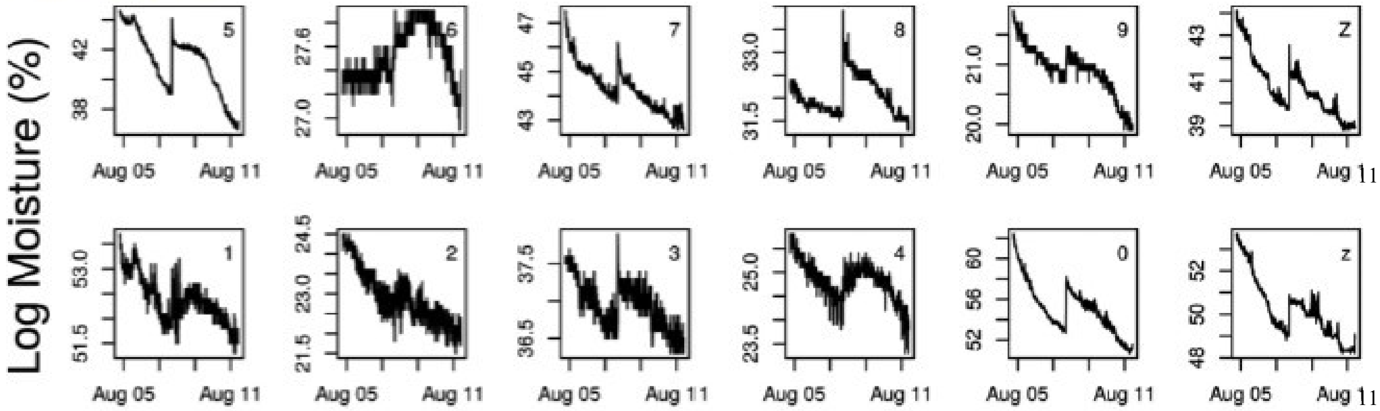

Fig. 6. Sample log volumetric moisture measurements during a ~5 mm precipitation event on 8 August 2018 at HBEF. All 12 sensor locations are shown (see Fig. 2).

Table 1. Attributes of the 12 radial cross sections collected from the partially decayed *Acer saccharum* log.

		Density (g·cm⁻³)			Volumetric moisture (%)	
Cross section	Volume (cm³)	Total	Minimum	Maximum	Manual (lab)	TDR (field)
0	3317.1	0.342	0.134	0.591	47.4	55.2
1	2627.4	0.477	0.424	0.556	42.3	57.2
2	4851.6	0.189	0.088	0.568	59.7	21.5
3	5626.1	0.185	0.104	0.551	57.4	38.7
4	3622.0	0.438	0.100	0.600	35.8	31.9
5	1981.2	0.417	0.274	0.541	47.2	48.3
6	2887.8	0.354	0.173	0.517	30.5	31.4
7	5763.5	0.163	0.120	0.584	57.9	45.2
8	4714.3	0.327	0.121	0.454	34.1	33.2
9	3221.0	0.278	0.101	0.589	46.2	20.4
z	2962.2	0.200	0.114	0.557	54.0	47.0
Z	2695.7	0.198	0.081	0.553	51.6	40.4

Note: Density was calculated by the formula dry mass/dry volume. TDR, time-domain reflectometry.

density from our 12 samples was gcm-g_ There was consid• erable variability manual and TDR VMC estimates (Pear• son's correlation (n = 0_10)_ A sensors had a nearly identical YMC as manually determined (cross sections 5, 6. and 8), whereas others were substantially different (cross sections 2. g, and 9) _ There was a strong positive correlation (r = 0.79) between total wood density ofeach cross section sample and the difference between the TDR VMC and manually derived VMC (i.e„ greater moisture discrepancies with greater decay).

Discussion

The same hurdles that apply to the real-time monitoring of live tree attributes (e.g.. diameter. Drew and Downes may be exacvrbated in the or downed dead trees. Whereas the architecture (i.e., wmd density and form) or a live tree is governed by envimnmental and mechanical cmnstraints (e.g„ Poorter et al. 20061, the architecture Of deadwood is one or breakdown by various fungal, microbial, and fragmentation pathways (Harmon et al. 1986; Stokland et al. 2012), which presents challenges to monitoring via sensors. We examined the roles that wood density and density variation. in concert with wetting and drying events. played in high-frequency and Iow£ost TDR measurement of deadwocxi VMC. Although such technology is only just emerging. it may seen as a complementary technique to forest inventory and (or) laser scanning technologies in which the volume (i.e„ structure) of downed leadwood can efficiently measured via laser scanning (Klockow et al. 2020) while Iow•cost sensor net• works provide complementary information on leadwood condi• tions (e.g. moisture).

Variation in densiw in particular confounded our VMC estimates_ The subsamples collected to examine density variation with individual cookies revealed considerable variation. often with a fivefold difference between minima and maxima. The most decayed portions represented threedimensional decay columns clearly delineated by interaction zone lines. Several of the least decayed portions may not have been colonized or de cayed at all. as their densities fall within the published ranges for nondecayed of this species (Harmon et al. 2008). Similarly. whole-cookie density varied markedly among the 12 cookies. ranging from 0.163 to 0.477 g•cm-3. Taken together. these results highlight the sizeable small-scale (i.e„ within and mediumscale (within log) variation that we feel is typical for in situ partially decayed logs (qualitative obsen'ations) that has implications for high-frequency moisture monitoring. That is. given the relationship between decay stage (i.e.. density) and water holding capacity (greater moisture with decay. Fraver et al. 2002). the density variation evident in our samples suggests that the exact placement of the tines (decayed versus nondecayed portions) strongly influences sensor readings.

This study's sensor array provided a relatively efficient technique for VMC measurement at short time steps (15 min) over a duration of —S months. As highlighted in the bench tests and sample log dissection. highly variable patterns of decay and concomitant variations in density and structure resulted in variations in absolute VMC. Although accurate measurements of VMC are needed for numerous applications. relative trends in VMC were similar across nearly all sample log sensors. Relative trends in V MC across the log-to-soil continuum (Goldin and Hutchinson 2015) may be valuable for assessing relationships be• tween these forest ecosystem components in the context of mete• orological events. During a relatively heavy rainfall event, there was consistent by almost all TDR sensors in terms of a

nearly immediate resrx)nse in and soil VMC. As the VMC exhibited faster wetting and drying than soil VMC, we propose that the advanced decay or the log enabled more rapid saturation or wood. Using TT)R in It*s with moderate to advancx•d decay may not prcwide accurate absolute measurements of VMC without extensive calibration (e.g.. Pichler et al. 2012) while affording per-haps accurate relative trends in VMC with implications regarding deadwocxl ecosystem functioning. Freshb' fallen logs and (or) logs in decay class I are most likely optimal for the application of IDR in monitoring deadwcx•d VMC dynamics where accurate trends in ab solute VMC estimates are needed. Set-ting aside applications for which accurate is needed (e_g_ wildfire behavior modeling SchcRnnageI et al. 2004). the times at which TDR measurements become erratic (because of decay rockets filling or draining of water) may serve as indicators of eco»-stem procesœs (e.g.. log saturation inhibiting decay'. A Ithough leadwood may present ad• ditional hurdles to sensor usage when compared with live trees, such hurdles may be recast as rvsearch opportunities to refine our understanding or fundamental forest ecosystem processes (e.g,, seasonal tœnds in deadwo«l carbon flux).

The diurnal results for both VMC acmss an sensors demonstrated their ability to track general trends in deadwood and soils acmss daily warming and cooling. Goldin and Hutchinson (2015) identified such diurnal trends in soils with respect to proximity to LWM pieces in Australia. In terms of subdiurnal tRnds in VMC. the sensor array was able to track the immediate response of deadwocxl and nearby soil respJnse to precipitation events. We pmvx•se that far fewer IDR sensors are needed for monitoring applications given the consistency in the relative trends in VMC observ ed across all the log and soil sensors. The of sensors depends not only on the application and requirements but also on the condition of the samples themselves_ Measure ment ofVNC in highly decayed logs and (or) heterogeneous soils will necessitate the use of moœ TDR whereas applica• tions in fresh logs and homogenous soils might require fewer than half a dozen TDR sensors. Given the ocvasional railurv or a TDR or improper installation. we suggest a minimum or two •mR sensors per each log or associated profile. Given the lag of deerxr soils tvsrx'nding to precipitation events, ifone were interested in soil resrx•nse, then shallower (ZIO cm) deployment or TDR sensors in the soil profile is œcommended.

This study has demonstrated the application or efficient and emerging •IDR techn0109' and an associated data logging system that can monitor subdiurnal VMC dynamics. An application of such technology would quanti$•ing the effect of projected changes in precipitation regimes lie.. climate change; Melillo et al. 2014) on soil and moistuR. Before such questions can be explored using IDR technolo»•. as used in this study. addirional research should conducted_ First. the effect of dead• wood piece size on TDR performance should be evaluated. Although the length of the TDR tines (15 cm) restricts application in smaller ŒVM pieces and more notably in IRrhaps rela• tionships can established to allow extrapolation of VMC of moderately sized to the range of piece sizeÝ Second. if freshly fallen is optimal for accurate TDR measurements of VMC the effect or drying in terms or checking should be evaluated. Third, if TDR are deployed beyond a grx»wing season. the effea or freezing e.'ents or snowpacks on TDR sensor arrays should be evaluated. Even if TDR sensors b+ anne nonfunctional at the point or freezing (Gasvoda 1998), this might an important indicator orecosystem function analogous to iœ-in and iceout measurenRnts of lakes (e.g.. Holmes and Likens 2016). Fourth. the effect of incomplete TDR sensor insertion on VMC measurement should be more fully evaluated. Fifth. although a drill template was used for inserting IDR tines into deadwocxl. perhaps alternative meth«ls should evaluated that enhance IDR performance and (on integrity (Le.. avoiding damage insertion and removal)_ Sixth, given the challenges in• volved with manually downloading data from data loggers in remote locations, wireless data transmission 'echnology should be evaluated as a means to increase the efficiency of data retrieval from TDR sensor arrays.

Conclusions

As ir has been suggested that global rates of tree mortality may increase and there is increased interest regarding the fate of dead• wood (i.e. balances), we expect increased focus on moni• toring the real-time attributes of deadwood fundamental to ecoystem processes (e.g, decay and (or) fire risk). Despite the increased need for deadwood assessments. the very nature of deadwood presents additional hurdles for its monitoring. We found that sensor measurements of deadwood VMC were highly variable across one intensively studied field sample because of variations in log density and structure. Despite this variability in absolute sensor measurements. results suggest that diurnal and subdiurnal trends in leadwood VMC can be monitored relatively inexpensively using TDR sensors coupled with widely available data loggers. Although logs with moderate to advanced stages of decay will confound the use of sensors for absolute assessment ofVMC. they may still prcwide valuable trend data in terms of log VMC resyn1R to meteorological events. It is recommended that ifaccuracy in log moisture is needed for fire risk assessments. then freshly fallen. nondecayed logs should be used as samples. Additionally. given the consistency in sensor readings across the various permutations of soil and log conditions. we suggest that a greatly reduced number of sensors (compared with that used in this study) may adequately characterize the moistuR dynamics of individual logs and the surrounding soil (e.g.. fewer than six sensors). Finally. although this study demonstrated the ability of TDR sensors to appropriately track log and soil VMC over subdiurnal time steps for forest monitoring and scientific purposes. additional research is needed to examine their application across a wide array of leadwood or soil situations coupled with field lim-

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