Analysis of Soil Climate Regimes Through Time in Appalachian National Parks

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BACKGROUND

The Java version of the Newhall Simulation Model (jNSM, v1.6.0; USDA/NRCS, 2012a; 2012b) was used to derive soil climate regimes from long and short-term weather station records at National Parks and nearby cooperative network weather station sites. The project relied upon monthly climate records from CLIMOD (Northeast Regional Climate Center), Soil Climate Analysis Network (USDA/NRCS, 2012c), and the US Historical Climatology Network (HCN, Menne et al., 2012) sources. Soil climate regimes are a key component of *Soil Taxonomy* and the classification of soils, but the regimes have been largely treated as static parameters in the soil survey process and resulting published soil geographic databases. With ecosystem services, fire management, and environmental monitoring as major responsibilities for the National Park Service, we are developing a new approach to derive soil climate metrics that can support the mapping and soil survey process. These metrics can be used to: 1) identify equivalent soil climate environments and map soil climosequences, 2) recognize unique soil microclimates—rainshadows and orographic gradients, 3) construct drought histories through soil moisture regimes, and 4) quantify soil climate regime trends within parks and across soil landscapes for the NPS Vital Signs Monitoring Programs (NPS, 1010; 2012). Our research explores the soil climate parameters and thresholds in defining "near-perudic" and perudic environments, as well as rainshadow effects. Water balances and soil biological windows and, which are subcalculations of the soil moisture and temperature regimes in the jNSM, were compared across National Park locations and major land resource areas. This approach will be developed as a supporting methodology for adding value to soil survey information for the New River Gorge National River, Shenandoah National Park, and the Great Smoky Mountains National Park.

RESEARCH QUESTIONS

At macro- and meso-scales: Is there a need for ad hoc subdivisions of the Udic soil moisture regime to better reflect high moisture mountain environments ("Near-Perudic") and rainshadows in the Appalachians? Can these subdivisions of soil moisture regimes provide a suitable rationale for establishing climosequences in MLRAs (USDA/NRCS, 2006b)?

When progressing from Typic Udic to Near-Perudic and Perudic environments, will soil morphology and horizonation reflect climate as a soil-forming factor in soil organic matter accumulation, the leaching of bases, podzolization, and translocation of clays? Can we map equivalent climates of soil processes?

Can recognizing climatic variability and climosequences of soil moisture regimes enhance soil interpretations of forested ecosystems, fire ecology, potential carbon sequestration, leaching environments, and biological windows?

METHODS

The jNSM was used to model long-term climate records in Appalachian National Parks to derive soil climate histories and characterize soil moisture regimes. As inputs to the jNSM, monthly average air temperatures and total precipitation from NWS cooperative stations and long-term weather stations (~117 yrs; U.S. Historical Climatology Network, 2012) were compiled and modeled to derive the frequency of soil climate events on a calendar year basis. jNSM runs on weather stations relied upon the available water storage derived from the associated STATSGO2 (USDA/ NRCS, 2006a) map units. From the jNSM model runs, annual and summer water balances, potential evapotranspiration (Thornthwaite and Mather, 1955), and soil biological windows were derived as subcalculations of *Soil Taxonomy* (USDA/ NRCS, 2010). The results from jNSM provide climographs of water balances and summaries of annual time-steps for classifying soil climate regimes. A subset of nine weather stations (>600 jNSM runs) were summarized to describe the climosequences and near-perudic environments.

DEFINITIONS

Newhall Soil Moisture Regimes

Wetter Environments → Drier Environments

Perudic	Typic Udic	Dry Tempudic	Wet Tempustic	Typic Tempustic	Typic Xeric
PREC > PET in each month of the year; SMCS is completely moist throughout the year	SMCS is dry in some or all parts for less than 30 cumulative days	SMCS is dry in some or all parts for 30 or more cumulative days; not dry in all parts for as long as 45 consecutive days following the summer solstice	SMCS is moist in all parts for >45 d during the 4 months after the winter solstice; and not dry for >45 consecutive days after the summer solstice	SMCS is dry in some or all parts for 90 or more days cumulatively; it is also not dry in all parts for more than half the time when ST >5oC	SMCS is completely moist during more than 45 consecutive days after the winter solstice; and dries out 45 to 90 days in summer

Newhall Soil Temperature Regimes

Warmer Environments → Colder Environments

Thermic 15-22°C (59-72°F) Mesic 8-15°C (47-59°F) Frigid 0-8°C (32-47°F) Cryic <8°C (MSST <15°C)

Figure 1. Subdivisions of soil moisture and temperature regimes occurring within the study sites (Van Wambeke et al., 1992); SMCS = Soil Moisture Control Section.

West Virginia University

NRCS

Northeast Regional Climate Center

National Park Service

STUDY SITES AND GEOGRAPHIC CONTEXT

Our study sites were selected at the Great Smoky Mountains and Shenandoah National Parks, which represent the Northern (130A) and Southern Blue Ridge (130B) MLRAs (USDA/NRCS, 2006b), and the New River Gorge National River (Eastern Allegheny Plateau and Mountains, 127) to compare interannual variability of soil moisture and temperature regimes. All three national park lands are considered Udic and largely Mesic, except for the higher elevations (1280-1400 m; 4200-4600 ft) of the Great Smoky Mountains, which are classified as frigid (USDA/NRCS 2009). The three locations provide a range of soil landscapes classified as Udic, representing a series of climosequences in the Appalachians.

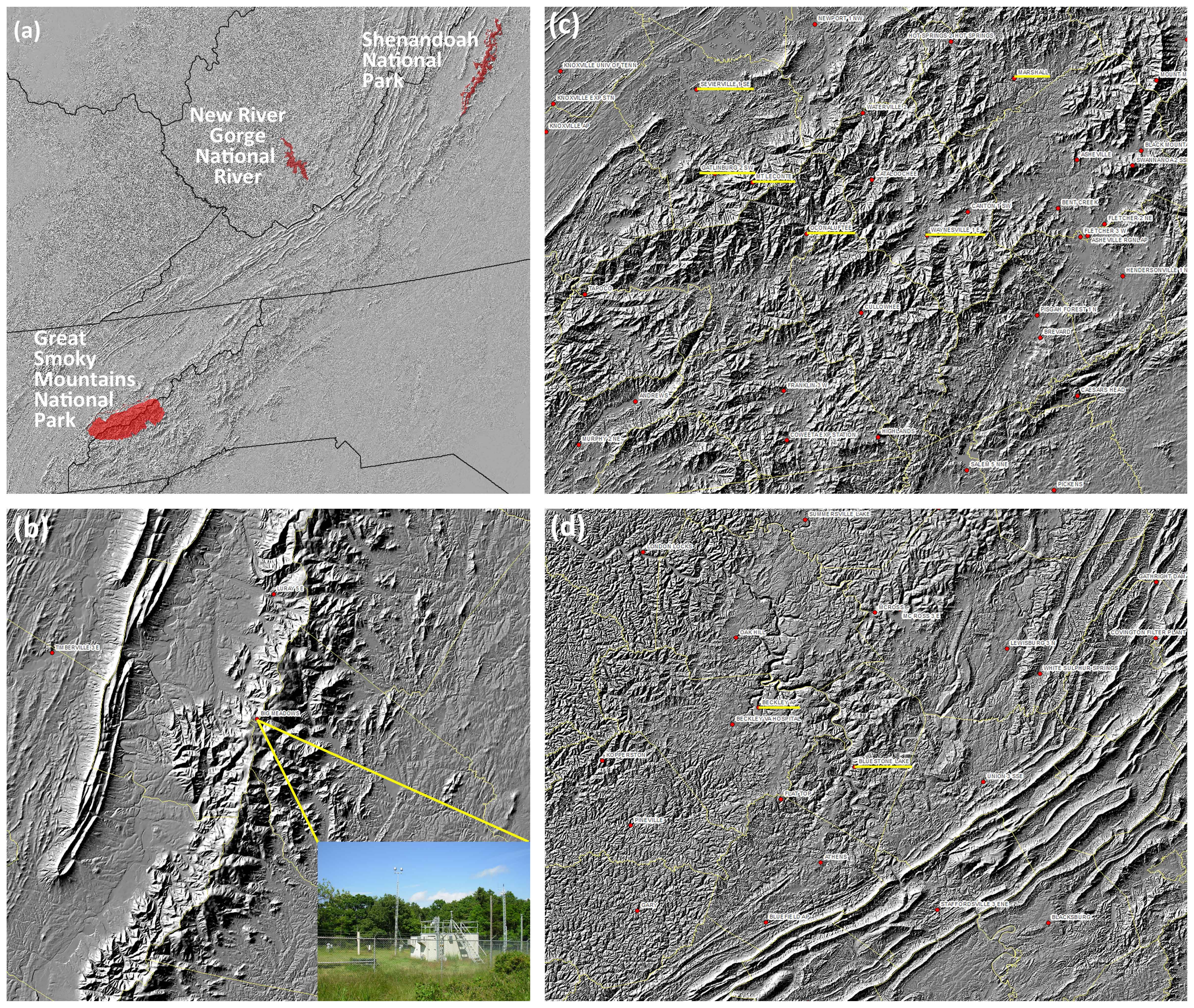
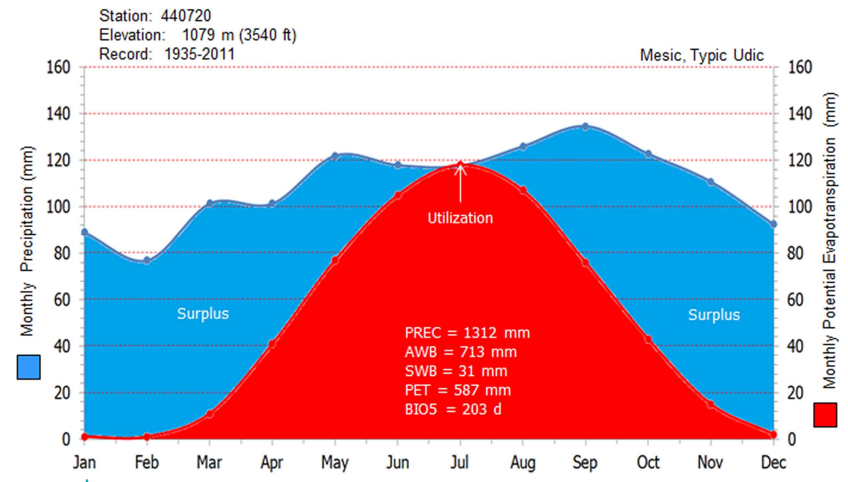


Figure 2(a-d). (a) Locations and physiography of the three study sites—(b) Shenandoah National Park (Big Meadows, VA), (c) Great Smoky Mountains (climosequence of Sevierville, Gatlinburg, Mt. Le Conte, and Oconaluftee), and (d) New River Gorge National River (Beckley and Bluestone Lake).

RESULTS AND DISCUSSION

Big Meadows, Shenandoah National Park "Near-Perudic" Example

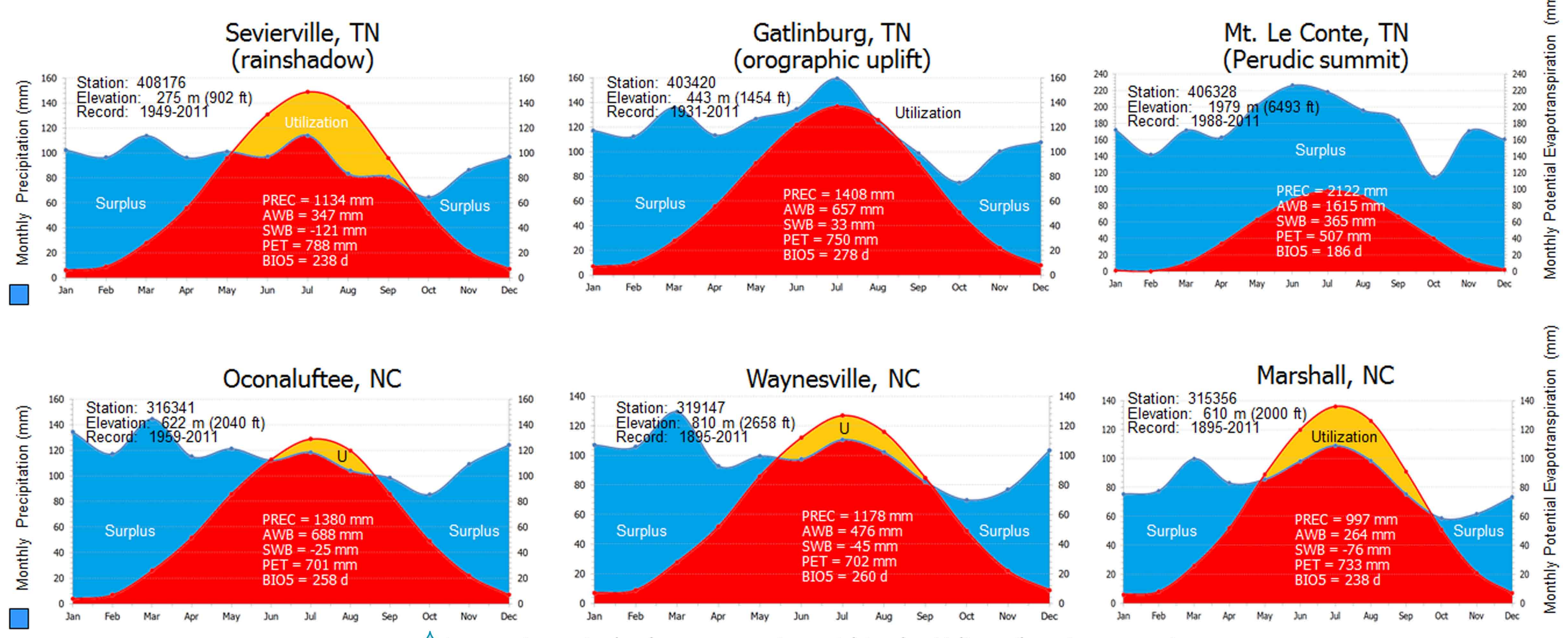


A trace of soil moisture deficit occurs in July; however, the summer water balance is positive (+31 mm) and resembles the perudic soil moisture from the "carryover"; the wet end of the Udic soil moisture regime that occurs in the higher elevations of the Appalachians

SMR	Years	%Freq	AWB	SWB	BIO5
			(mm)	(mm)	days
Perudic	4	5%	1047	203	203
Typic Udic	61	79%	730	44	210
Dry Tempudic	12	16%	520	-91	166
	77				
		Mean	713	31	203
Mesic	75	97%			
Frigid	2	3%			
	77				

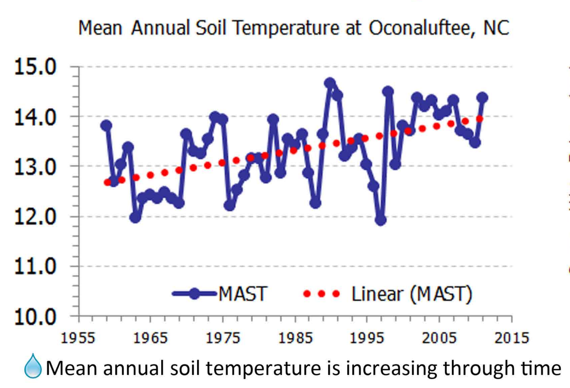
Based upon 30 year normals, Big Meadows will classify as dominantly Perudic; however, based upon interannual jNSM runs of the long-term record, this station will classify as dominantly Typic Udic; Dry Tempudic events are major drought years; a narrow range of soil moisture regimes

Great Smoky Mountains National Park Climosequences



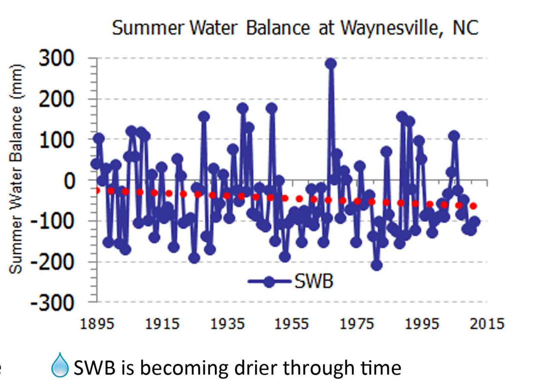
Increasing rainshadow expression within the Udic soil moisture regime

Mean Annual Soil Temperature at Oconaluftee, NC



Mean annual soil temperature is increasing through time

Summer Water Balance at Waynesville, NC



SWB is becoming drier through time

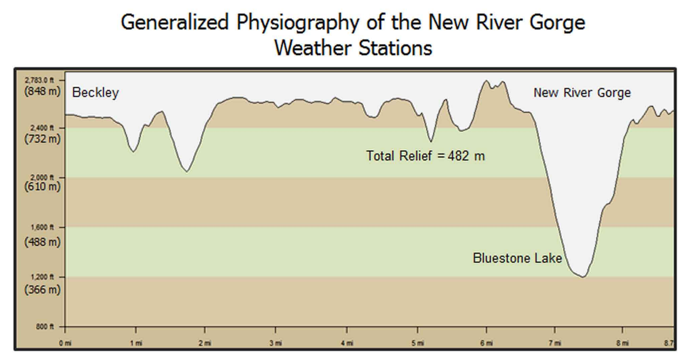
Summary of Soil Moisture Regimes at Marshall, NC

	Years	%Freq	AWB	SWB
Perudic	1	1	427	59
Typic Udic	61	54	331	-37
Dry Tempudic	33	29	251	-101
Wet Tempustic	14	12	112	-145
Typic Xeric	5	4	-79	-230
	114			
		Mean	264	-76
Mesic	86	75%	274	-71
Thermic	28	25%	230	-92
	114			

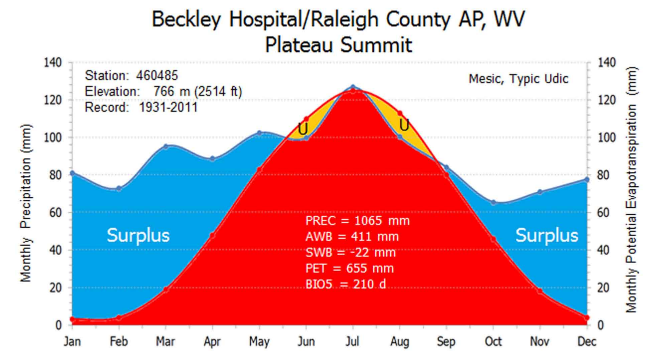
In this rainshadow site the thermic years are drier; the range of SMRs is Perudic to Xeric

New River Gorge National River

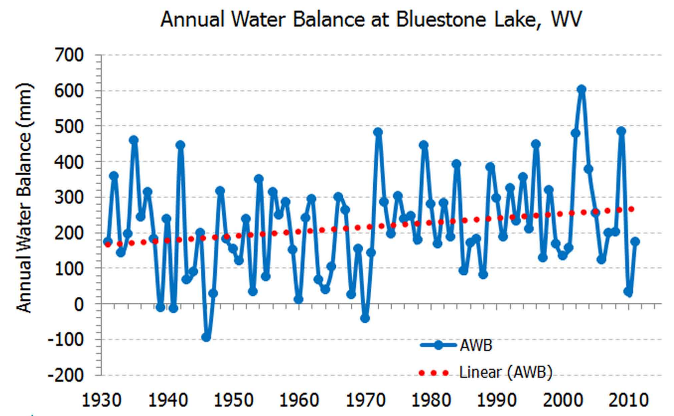
Generalized Physiography of the New River Gorge Weather Stations



Beckley Hospital/Raleigh County AP, WV Plateau Summit

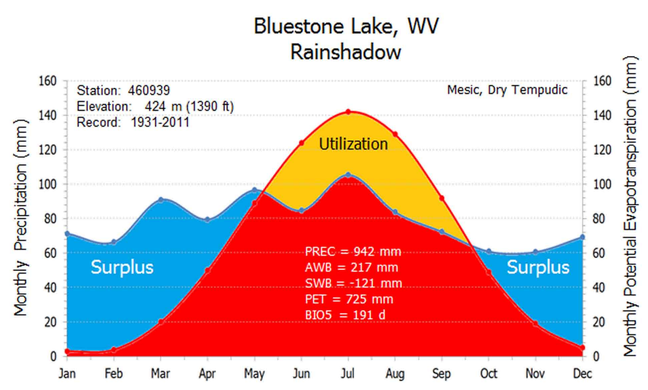


Annual Water Balance at Bluestone Lake, WV



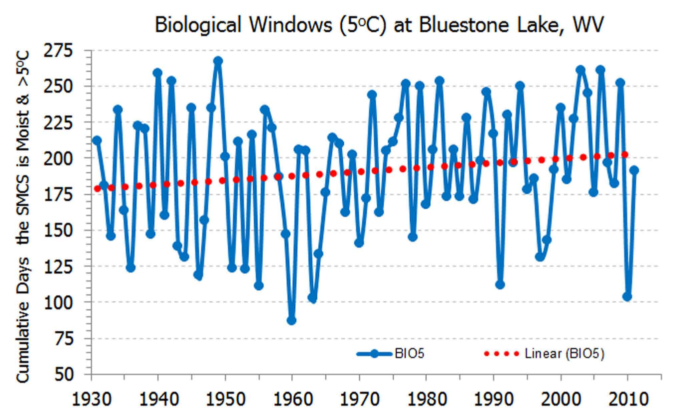
Increasing soil water balance in a rainshadow environment

Bluestone Lake, WV Rainshadow



Note the difference in the drying period of the rainshadow (Bluestone Lake) and plateau summit

Biological Windows (5°C) at Bluestone Lake, WV



BIO5 indicates that the window for soil microbial activity is lengthening through time

Beckley Hospital/Raleigh County AP, WV

SMR	Years	%Freq	AWB	SWB	BIO5
			(mm)	(mm)	days
Perudic	2	2%	643	110	233
Typic Udic	56	69%	460	6	226
Dry Tempudic	17	21%	309	-83	189
Wet Tempustic	6	7%	168	-148	119
	81				
		Mean	411	-22	213

Soil Moisture Regimes at Bluestone Lake, WV

SMR	Years	%Freq	AWB	SWB	BIO5
			(mm)	(mm)	days
Typic Udic	27	33%	323	-58	230
Dry Tempudic	34	42%	199	-137	195
Wet Tempustic	19	23%	114	-179	132
Typic Xeric	1	1%	-95	-196	119
	81				
		Mean	217	-121	191

SUMMARY AND CONCLUSIONS

The Udic soil moisture regime has been treated as a static property across the MLRAs; Soil Taxonomy also doesn't provide distinctions on the "wet-end" of Udic and transitions into Perudic environments

In the Appalachians, there are "Udic rainshadows" and high elevation "Near-Perudic" environments; Udic environments with strong orographic effects and lower drought frequency; Udic rainshadow environments are associated with all three national parks; higher frequency of Dry Tempudic + Wet Tempustic events in the New River Gorge (MLRA 127)

Near-Perudic environments at high elevations in the Appalachians fail the PREC > $PET_{(Jan...Dec)}$ criteria, but have significant summer moisture surplus; Mt. Le Conte met all perudic criteria, but not all high elevation summits in the Southern Blue Ridge (130B) will meet perudic criteria

Climosequences are useful concepts in constructing the analysis of soil climate regimes of national parks and neighboring soil landscapes in MLRAs

USHCN stations neighboring these park lands provide insights for recognizing long-term regional trends, adding historical context to NPS sites

Rainshadow weather stations have a greater range of soil moisture regimes and drought events (Ustic and Xeric years; higher intensity)

The Van Wambeke et al. (1992) subdivisions of soil moisture regimes provide additional resolution in building climosequences from weather stations; they identify landscapes of equivalent climate driven processes

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