THE RELATIVE SITE MOISTURE INDEX:

AN EXPANSION OF THE TOPOGRAPHIC

RELATIVE MOISTURE INDEX

by

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ABSTRACT

Soil moisture is an important factor influencing vegetation establishment and productivity. Several attempts have been made to develop an accurate means of characterizing soil moisture in the field without extensive monitoring. The Topographic Relative Moisture Index (TRMI), was developed as a tool for estimating relative soil moisture conditions in mountainous terrain using only slope characteristics. This study adds soil depth and soil texture parameters to the slope parameters of the TRMI, thereby creating the Relative Site Moisture Index (RSMI). This environmental scaler should be useful in non-mountainous environments, where the variability in slope characteristics is less than in regions of greater relief, to estimate relative soil moisture. These additional parameters should also increase the accuracy of the index in mountainous areas. Field measurements taken at Parfrey's Glen in southern Wisconsin are used to assess the accuracy of the RSMI. Analysis of the vegetation data collected indicate that the RSMI is a better predictor of soil moisture than the TRMI in this area.

INTRODUCTION

Soil moisture is an important environmental factor contributing to vegetation establishment and productivity (Barbour *et al.*, 1980; Vale, 1982). Several attempts have been made to develop an accurate means of characterizing soil moisture in the field without extensive monitoring. However, these techniques require extensive knowledge of either the water requirements of certain plant species or of weather and climate history (Parker, 1982). The Topographic Relative Moisture Index (TRMI), developed by Albert Parker, uses only slope parameters to calculate a numerical value which is representative of the relative soil moisture characteristics of a site. This eliminates the need for climate records and knowledge of specific plant moisture requirements. Consequently, the amount of time required to calculate soil moisture, relative to another site, is greatly reduced.

The TRMI consists of four basic slope parameters: topographic position (weighted from 0-20), slope configuration (weighted from 0-10), slope aspect (weighted from 0-20), and slope steepness (weighted from 0-10). Slope characteristics more conducive to soil moisture retainment are reflected by higher numerical values (Table 1). Calculation of the relative soil moisture of a site simply requires determining a value for each of the four parameters and then adding them to yield a final TRMI value between 0 and 60. This final value represents the general moisture characteristics of the site, with values near 0 representing xeric environments and values near 60 representing mesic environments.

The TRMI was developed for use in mountainous terrain where slope variability, and thus moisture availability related to slope characteristics, is great (Parker, 1982). However, by adding soil moisture and soil texture parameters, it is possible to make the index suitable for use in non-mountainous areas with locally varied relief, such as the driftless area of Wisconsin, without greatly increasing the amount of time required in the field to calculate index values. Even with the additional parameters, the index remains useful in assessing variable topographic situations; therefore, it is not intended for use in gently rolling terrain or in areas with little variation in local relief.

The new index, the Relative Site Moisture Index (RSMI) is presented and evaluated in this paper. Both of the supplementary parameters --soil depth and soil texture -- are weighted

Table 1 *Determination of Relative Site Moisture Index values*

TRMI:

Topographic position:

valley bottom	20
lower slope	15
middle slope	10
upper slope	5
ridge top	0

Slope configuration:

concave	10
concave/straight	8
straight	5
convex/straight	2
convex	0

Slope steepness (degrees):

<3.0	10
3.0 to 5.9	9
6.0 to 8.9	8
9.0 to 11.9	7
12.0 to 14.9	6
15.0 to 17.9	5
18.0 to 20.9	4
21.0 to 23.9	3
24.0 to 26.9	2
27.0 to 29.9	1
>30.0	0

Slope aspects (degrees azimuth):

19-26	20	81-89; 316-324	13	144-152; 253-261	6
27-35; 10-18	19	90-98; 307-315	12	153-161; 244-252	5
36-44; 1-9	18	99-107; 298-306	11	162-170; 235-243	4
45-53; 352-360	17	108-116; 289-297	10	171-179; 226-234	3
54-62; 343-351	16	117-125; 280-288	9	180-188; 217-225	2
63-71; 334-342	15	126-134; 271-279	8	189-197; 208-216	1
72-80; 325-333	14	135-143; 262-270	7	198-207	0

SUPPLEMENTARY PARAMETERS

Soil texture:

clay - silty clay	10
sandy clay	9
sandy clay loam	8
clay loam	7
silty clay loam	6
silt loam	5
loam	4
silt	3
sandy loam	2
loamy sand	1
sand	0

Soil depth (cm):

>100	10
75-100	9
60-75	8
46-59	7
36-45	6
26-35	5
18-25	4
12-17	3
8-11	2
4-7	1
0-3	0

from 0-10, with higher numerical values reflecting soil characteristics more conducive to water retainment (Table 1). The original TRMI parameters have not been altered.

Soil Depth

Soil depth plays an important role in the amount of soil moisture available for plant productivity. In general, deeper soils hold more moisture over longer periods of than shallow soils (Barbour *et al.,* 1980) and are therefore given higher numerical values in the index. Soil depth is determined using a hand-operated sample tube with an extension rod and t-handle. This type of sampler is readily available and is easy both to use and to carry in the field. The sample tube is simply pushed into the ground until it reaches bedrock or a depth greater than one meter. Once a depth has been reached, the researcher places his/her hand on the tube or extension rod at the ground surface and removes the sample tube from the ground. The distance from the researcher's hand to the bottom of the sample tube is then measured and recorded in centimeters; this is the soil depth. The depth is assigned a value consistent with the general procedure of Parker (1980) (Table 1).

The maximum depth of one meter was chosen for two reasons: (1) most shrubs, forbs and graminoids have the majority of their root mass within the first meter of soil and (2) establishment of new trees is strongly influenced by soil moisture above one meter; the time of establishment, with regard to the amount of moisture in the soil, is critical to tree survival. Therefore, moisture in the top one meter of soil is one of the primary environmental factors influencing patterns of vegetation. Scaling of the soil depth parameter was based mostly on field observations and laboratory analysis conducted by the author. Infiltration and drying times of several soil classes were observed for various depths.

Soil Texture

Soil moisture potential is largely dependent on soil texture (Barbour *et al,* 1980). For this reason, it is important for any site index to include a parameter which approximates, as closely as possible, the overall texture of the soil at a given location. The soil texture value in the RSMI is based on the standard textural class triangle of the United States Department of Agriculture (USDA). This type of classification was chosen because it is widely used by field scientists and presents a clear description of all possible combinations of textural classes. The twelve textural classes are assigned numerical values based on their moisture retainment abilities; soils with much clay and little or no sand have high values, whereas soils with much sand and little or no clay have low values (Table 1). Values are determined by hand texturing in the field using samples taken from the sample tube. The depth or number of depths to use as texture samples is discussed later.

CALCULATIONS OF THE RELATIVE SITE MOISTURE INDEX

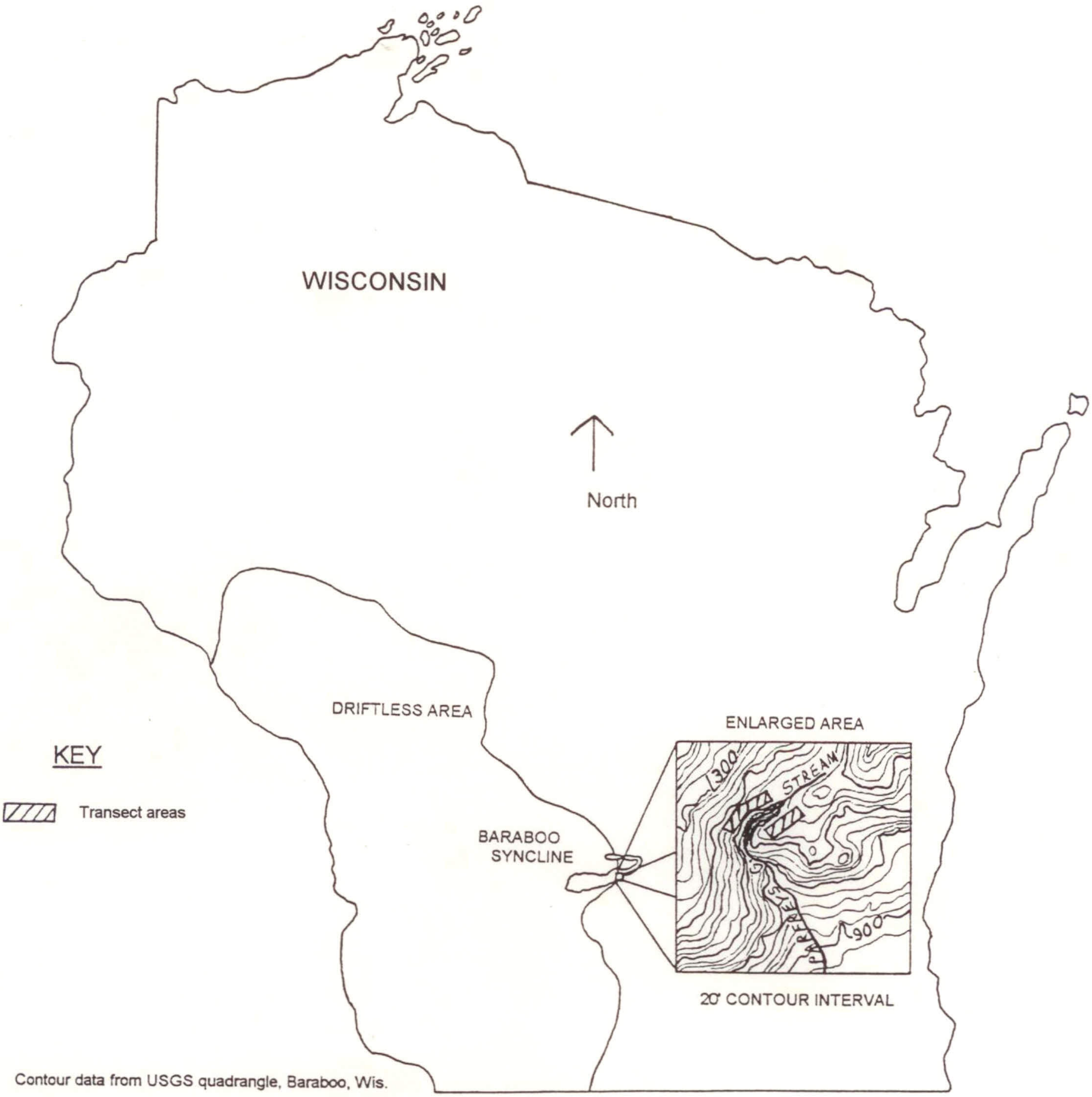
Values for the new index are calculated in the same manner as TRMI values. The maximum combined value of the TRMI and the supplementary parameters is 80 and the minimum is 0. It is difficult to work with RSMI values expressed as fractions, so I chose to express the values as decimals, which are more manageable. Simply dividing the sum of the six parameter values by 80 yields a final RSMI value; the minimum value is 0.0 and the maximum value is 1.0. In certain situations, to be discussed later, it may be necessary to eliminate one or more of the parameters from the index. If this is necessary, the maximum value of the parameter to be eliminated is subtracted from the denominator and a final RSMI value is calculated using the same equation. Likewise, if a parameter is added to the index, the maximum possible value of that parameter is added to the denominator.

METHODS

To assess the accuracy of the RSMI, field measurements were taken in the Parfrey's Glen Natural Area, which is located in the driftless area of western Wisconsin and is a unit of the Ice Age Scientific Reserve (Figure 1). Parfrey's Glen is a narrow, rocky gorge approximately 30 m deep with steep sides. The stream which formed the gorge flows approximately perpendicular to the ridge through which it has cut. The vegetation within and immediately surrounding the gorge is more typical of northern Wisconsin but exists here because of cold air drainage and minimal sunlight (Lange, 1989). The bedrock (exposed on the walls of the gorge) is Upper Cambrian quartzite conglomerate and sandstone conglomerate (Danziel & Dott, 1970). The top of the west side of the gorge is capped with material of the Late Woodfordian terminal moraine, while the east side is capped predominantly with sandy soils derived from bedrock. This area was chosen because of its highly dissected terrain and relatively shallow soils, which is similar to the mountainous environment in which the TRMI was developed in. Also, this preserved area has had very little disturbance (human or natural) over the past several decades, allowing disturbance to be disregarded as a modifier of the present vegetation.

I sampled the vegetation on both sides of the gorge during July and August of 1995. RSMI values were calculated for each plot on each transect during sampling. I developed a sample sheet on which I recorded vegetation data and each of the parameters. My sampling design consisted of six 30 m line transects, each containing three randomly selected points, which served as the center pivot points for 6 m circular plots in which the number and species of each tree and seedling were recorded. At each random point on the line, soil depth and soil

Figure 1


WISCONSIN
North
DRIFTLESS AREA
KEY
Transect areas
BARABOO
SYNCLINE
ENLARGED AREA
1300
STREAM
PARFREYS
900
20' CONTOUR INTERVAL
Contour data from USGS quadrangle, Baraboo, Wis.

texture were measured and recorded. Distance from the center point and diameter at breast height (dbh) of each tree were also recorded. Each circular plot contained a 1 m square quadrat in which the number of species and individuals of shrubs, forbs, and graminoids were recorded. The quadrats were always placed 10 cm to the right of the line in the upper portion of the 6 m circular plot. This eliminated any bias in the placement of the quadrats. A total of three transects were run on each side of the gorge, yielding a total of 18 plots for the study.

ANALYSIS AND RESULTS

From a comparison of vegetation form and tree species composition, I conclude that the east side of Parfrey's Glen is drier than the west side (Table 2). Shrubs and graminoids were more abundant on the east side than the west side and individual trees and forbs were more abundant on the west side of the glen. On the east side, 170 individual graminoids were located in the plots, while only 16 individual forbs were present. In comparison, 105 individual forbs but only 3 individual graminoids were present on the west side. Exactly 50 shrubs were present in the plots on the east side, while only 6 were located on the west side.

Tree species composition also varied considerably between the sides. *Acer saccharum* (Sugar Maple) and *Ostrya virginiana* (Ironwood) were the most abundant species on the west side, followed by *Populus grandidentata, Carya ovata, Quercus rubra, Quercus alba, and Crataegus mollis. Acer saccharum* and *Ostrya virgniana* are commonly found on moist upland soils (Little, 1980). The east side had fewer total species, and approximately 90% of all individual trees were *Quercus* (Oak), both *Q. rubra* (Northern Red Oak) and *Q. alba* (White Oak), and *Pinus strobus* (Eastern White Pine). *Quercus* is one of the dominant genera of southern xeric forests in Wisconsin (Curtis, 1971). *Pinus strobus,* which grows well on deep

Table 2

PLOT	**TRMI**	Position	Configuration	Aspect	Steepness	**RSMI**	Depth	Texture	**VEGETATION** TREES	SEEDLINGS	SHRUBS (# of species)	SHRUBS (# of individuals)	FORBS (# of species)	FORBS (# of individuals)	GRAMINOIDS (# of species)	GRAMINOIDS (# of individuals)
East ridge																
1	0.23	0	1	4	9	0.33	9	3	ps(3),qr(2)	ba(3),qr	1	2	1	1	1	45
2	0.20	0	1	4	7	0.29	9	2	ps(2)	qr(19),ps(5),ar(4)	1	7			1	56
3	0.20	3	1	4	4	0.28	8	2	ps(2),qa	ps(10),qa(11),qr(11)	1	4	1	2	1	44
4	0.42	0	1	17	7	0.43	8	1	ps(4),qa(2)	ps(8),qa(16),a(13)	1	3	2	7	1	21
5	0.43	1	1	17	7	0.44	8	1	ps(5),qa	ps(8),qa(18),a(13)	1	1				
6	0.43	3	0	16	7	0.39	4	1	ps,qr	ps(15),qr(16),a(8)	2	19	1	6	1	4
7	0.32	3	2	9	5	0.33	5	2	ps,ov	q(35),a(6),co,ba	1	5				
8	0.32	3	2	9	5	0.38	9	2	ps,qa,qr	q(52),ar(3),ov(4)	1	5				
9	0.27	5	0	9	2	0.29	5	2	ov(2),ps,qa	ps(2),q(21),ov(4)	1	4				
West ridge																
10	0.33	3	2	8	7	0.38	8	2	ov(5),pg	ov(2),ar(8),qa(3)			2	9	1	2
11	0.32	3	1	10	5	0.39	10	2	ov(3),as,pg	as(4),ar(6)			2	6		
12	0.33	3	1	11	5	0.40	10	2	ov(2),as(2),co	as(6),co(5)	1	5	2	3		
13	0.45	4	3	14	6	0.44	6	2	as(2),ov(2)	as(3),ar(5)			3	5		
14	0.47	4	3	16	5	0.45	6	2	ov(3),as,pg	ov(2),as(2),ar			2	7		
15	0.47	3	5	13	7	0.48	7	3	ov(4),as	ov(3),as,co			2	8		
16	0.53	4	4	17	7	0.49	5	2	as(4),ov(2),qr(2),qa	as(11),co(4)	1	1	4	21		
17	0.52	4	4	17	6	0.50	7	2	ov(2),as,cm	as(6),q(3),ov			5	22	1	1
18	0.55	4	5	17	7	0.51	6	2	as,qr,co,ov	as(10),ov(3),qr			5	24		

KEY:

a: Acer (species undetermined)
ar: Acer rubra
as: Acer saccharum
ba: Betula alleghaniensis
cm: Crataegus mollis
co: Carya ovata
ov: Ostrya virginiana

pg: Populus grandidentata
ps: Pinus strobus
q: Quercus (species undetermined)
qa: Quercus alba
qr: Quercus rubra

Number in ( ) following each species indicates the number of individuals of that species which were present in each plot. No number indicates only one individual.

and sandy loams in the northern forests of Wisconsin (Curtis, 1971), in southern Wisconsin, is often present on steep sandstone bluffs where species less tolerant of xeric sites with shallow soils have difficulty becoming established (Ziegler, 1995). The only other individuals found on the east side were two *Ostrya virginiana* trees. Several *Acer* seedlings were found on the east side, while several *Quercus* seedlings were counted on the west side.

In addition to moisture potential, nutrient availability and soil acidity are also important factors in vegetation establishment and productivity (Barbour *et al.*, 1980). The difference in substrate between each side of the glen, and an abundance of pine needles on the forest floor of the east side may have created a difference in nutrient availability and soil acidity between the sides. Along with moisture, these factors likely influenced the development of the vegetation patterns present around Parfrey's Glen today.

Vegetation data collected on both sides of the glen reflects the RSMI values. On the east side, RSMI values ranged from 0.28 to 0.44 with a mean value of 0.35. RSMI values on the west side ranged from 0.38 to 0.51 with a mean value of 0.45. When soil depth and soil texture are removed from the index and only the TRMI values are calculated, the east side mean value is 0.31 and the west side mean value is 0.44. RSMI value means were slightly higher than the TRMI value means, as was expected with the addition of soil depth and soil texture parameters. More importantly, the RSMI value means are more similar than the TRMI value means. This is the result of the similarity of the soil depth and soil texture values between the sides. The mean value of the soil depth parameter for both sides was 7.22. The east side soil depth values ranged from 5 to 9, while the west side values ranged from 5 to 10. The mean value of the soil texture parameter was 1.78 for the east side, with a range of 1 to 3, and 2.11 for the west side, with a range of 2 to 3. All of these environmental site assessments confirm the difference in moisture availability suggested by the vegetation, specifically that the west side is more mesic than the east side.

Differences between the TRMI and the RSMI are suggested by the individual plots. The drier east side (Figure 2) has only one plot (#6) where the RSMI value is less than the TRMI value, whereas the more moist west side (Figure 3) has five such plots. These five plots have both large RSMI values and TRMI values. Plot #6 also has relatively large RSMI and TRMI values, although there is one plot (#5) with an RSMI value which is 0.01 greater than the corresponding TRMI value, which is mostly an effect of rounding of the final value. The indices are better correlated on the west side than on the east side.

To evaluate the ability of each index to predict soil moisture, I correlated both the RSMI and TRMI values with the adaptation numbers of the dominant Wisconsin overstory trees (Curtis, 1971). For each plot, each individual tree and seedling were tallied by species and the number of individuals of that species present in a plot was multiplied by the corresponding adaptation number. This yielded a value for each species; if more than one species was present in a plot, these values were added to provide a final plot value. Dividing this value by the total number of trees present in a plot yielded a mean adaptation number for each plot (Table 3). *Crataegus mollis,* present in plot 17, is not assigned an adaptation number by Curtis (1971); it was therefore ignored when calculating the mean adaptation value for this plot. Seedlings of undetermined species of *Acer* and *Quercus* were assigned values of 8.5 and 4.5, respectively, which are the means of the range of adaptation numbers for the species present in this study area of both genera. Finally, the mean plot adaptation numbers (based on trees) were also added and

Figure 2 (east side)

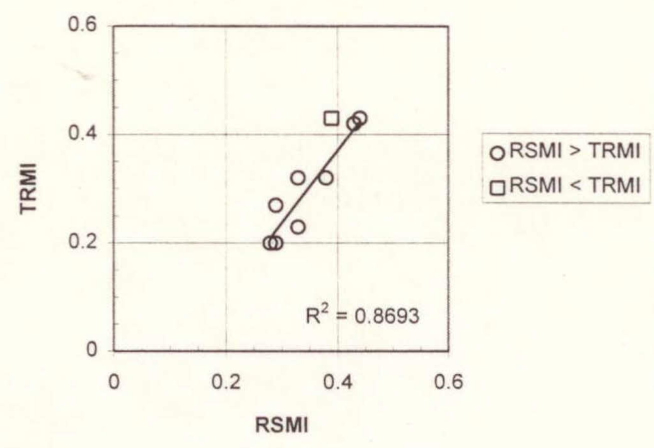
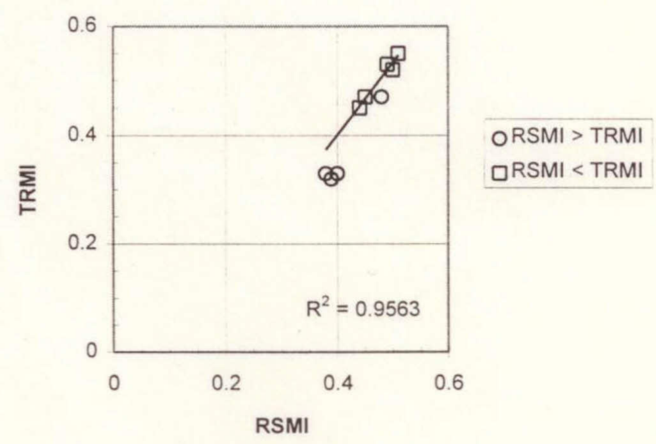


Figure 3 (west side)



divided by the number of plots on each side of the gorge to give a final mean adaptation number for the east and west sides of the glen.

The dichotomy between the east and west sides allows an assessment of the two indicies on aggregated data. Dividing the mean adaptational value of the east side by the mean adaptational value of the west side yields a value of 0.61. Likewise, dividing the RSMI value of the east side by the RSMI value of the west side yields a value of 0.77, whereas the same TRMI ratio yields 0.70. Therefore, based on the means of the mean adaptation numbers, the west side is approximately 39% moister than the east side. The TRMI approximates the west side to be 30% moister than the east side, whereas the RSMI approximates it to be only 23% moister. This result seems to indicate that in this study, the TRMI is slightly more accurate than the RSMI. Performing the same calculations using seedlings, the mean adaptational value of the east side divided by that of the west side produces a value of 0.69, which is very similar to the TRMI value of 0.70. This again seems to indicate that the TRMI is slightly more accurate than the RSMI.

. Regression analysis on the plot data, however, indicates that, overall, the RSMI values are better correlated with the mean plot adaptation numbers than the TRMI values. The RSMI values and the mean plot adaptation numbers of adult trees have a coefficient of determination of 0.30 (Figure 4), whereas the TRMI has a coefficient of determination of 0.26 (Figure 5). An even greater difference in coefficients of determination between the indices is indicated by the seedling data; the RSMI is 0.53 (Figure 6), while the TRMI is 0.43 (Figure 7). The correlation of index values and mean plot adaptational numbers of seedlings substantially improved with both indices. Although the difference between the coefficients of determination is modest,

Table 3 *Mean plot adaptation numbers*

TREES

East side PLOT#	1	2	3	4	5	6	7	8	9	mean
mean adaptation #:	5.20	5.00	4.50	4.50	4.75	5.25	6.75	4.67	6.38	**5.22**

West side PLOT#	10	11	12	13	14	15	16	17	18	mean
mean adaptation #:	7.83	8.00	8.30	9.25	8.00	8.80	10.21	9.00	7.13	**8.50**

SEEDLINGS

East side PLOT#	1	2	3	4	5	6	7	8	9	mean
mean adaptation #:	7.38	5.63	4.66	5.58	5.47	5.92	5.14	4.90	5.13	**5.53**

West side PLOT#	10	11	12	13	14	15	16	17	18	mean
mean adaptation #:	5.65	8.20	7.50	8.13	8.80	8.00	8.53	8.20	9.36	**8.04**

Figure 4 (Trees: east & west sides)

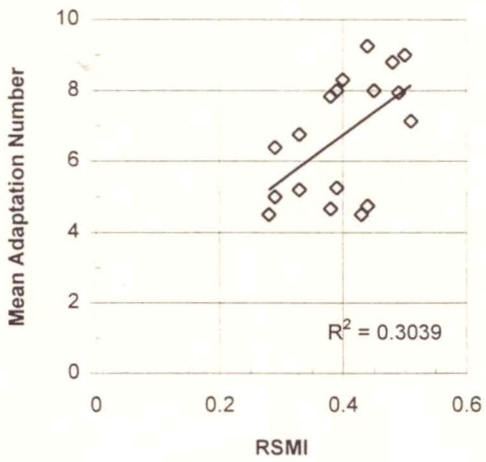
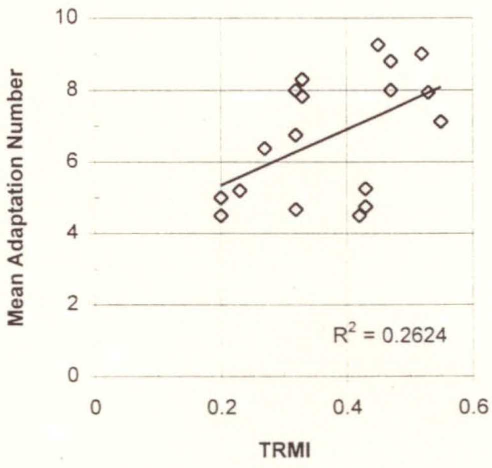


Figure 5 (Trees: east & west sides)



the additional soil parameters appear to improve the ability of the index to approximate relative soil moisture conditions in this study area.

The conflicting results of the ratio analysis and regression analysis lead to three possible conclusions regarding the accuracy of the indices in this study area: 1) the TRMI better approximates relative moisture conditions; 2) the RSMI better approximates relative moisture conditions; or 3) there is very little or no difference in accuracy between the indices. Adaptation numbers are themselves only an approximation of the water requirements of trees. Since both analyses rely on the same mean plot adaptation numbers, this possible source of error is most likely not the cause of the discrepancy between the results of the analyses. Both analyses compare the indices' moisture calculations with the mean plot adaptation numbers. The first analysis uses the mean side adaptation numbers (the means of the mean plot adaptation numbers) which, being an approximation of an approximation, provides a less reliable representation of the vegetation (and therefore moisture), thereby introducing some uncertainty into the results. This analysis also uses the means of the TRMI and RSMI values for both sides, introducing further approximations.

The result of regression analysis, while not using the means of the mean plot adaptation numbers, suffers from a similar problem, as it is based on the equation of a trend line, itself a kind of statistical mean of the mean adaptation plot numbers. However, this analysis does not use the means of the TRMI and the RSMI values. Because of this, regression analysis seems to provide a more accurate analysis of the ability of the indices to predict soil moisture. Therefore, in this study, I conclude that the RSMI provides a more reliable description of relative site moisture conditions.

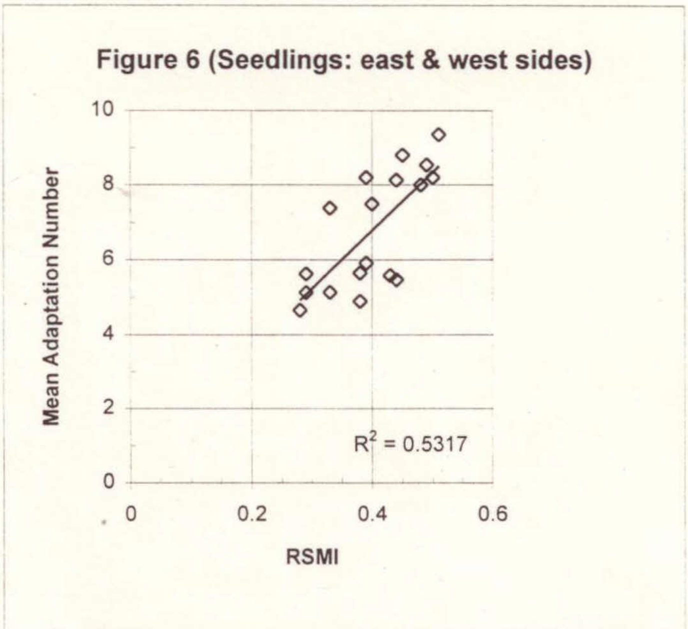


Figure 6 (Seedlings: east & west sides)
Mean Adaptation Number
10
8
6
4
2
0
0
0.2
0.4
0.6
RSMI
R² = 0.5317

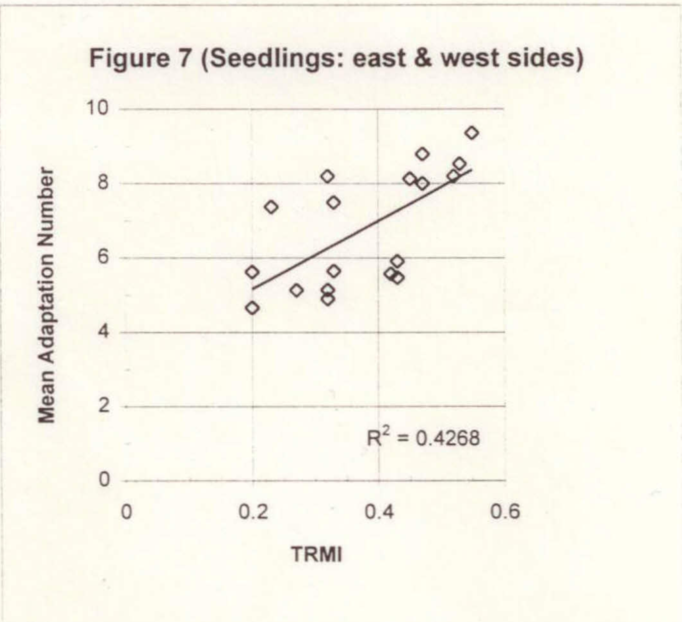


Figure 7 (Seedlings: east & west sides)
Mean Adaptation Number
10
8
6
4
2
0
0
0.2
0.4
0.6
TRMI
R² = 0.4268

DISCUSSION OF FIELD TECHNIQUES

Several problems may develop in calculating soil texture and soil depth in the field. Selecting the depth at which textural analysis should be conducted can be difficult. It is not advisable to set a standard depth for analysis even for a relatively small study area because soil regimes can be highly variable across short distances. Except in areas where the soil is known to be characterized by less than a few textural classes, texturing at only one horizon may lead to incorrect calculations of the soil texture parameter. Therefore, I advise taking several samples at each point. Accurate hand texturing requires training and is a fairly subjective matter regardless of the amount of training. If reliable hand texturing of the soil is difficult, I suggest collecting samples at several depths and, if possible, analyzing these samples in a soils laboratory or other facility capable of grain size analysis.

With regard to soil depth, it can be very difficult to calculate an accurate value in heavily wooded areas or in areas with rocky soils because a hand-operated tube sampler cannot push through obstacles such as large roots and large pebbles. Some soils, moreover, are difficult to penetrate even without such obstacles. Foot-operated subsoil probes are available which can penetrate hard soils, but these are not always practical in remote areas. If it is not possible to penetrate the soil due to subsurface obstacles, moving the probe several centimeters from the point usually gets around obstacles. This technique works well in most areas, unless large obstacles such as boulders are present. If difficult ground conditions are encountered (not the result of obstacles), I suggest using a sampling tube with a t-handle designed to be struck with a mallet. These are relatively inexpensive and are just as easy to use and carry as a regular sampling tube. Also, different tips, which are designed to penetrate a variety of soils are available for most sampling tubes. It is not recommended that depth to bedrock maps or soil depth maps be used as a substitute for field measurements because these are usually at a scale too coarse to be useful in local site investigations.

In areas where bedrock is exposed, or on talus slopes, soil often accumulates in fractures or between boulders which can make depth analysis a challenge. In such areas, if soil depth cannot be determined with a fair degree of confidence, it is best to omit this parameter from the final RSMI value calculation. Also, at this time it is not possible for the index to account for groundwater outflow from fractures in bedrock. In areas where bedrock is at or near the surface and such outflow exists, basic slope and soil parameters cannot accurately reflect the amount of moisture in the environment.

Finally, there is some covariation between the six parameters. That is, one factor may reflect qualities of another. For example, a valley bottom is assigned a maximum value of 20; valley bottoms typically have deep soil relative to upper slopes and side tops which typically have shallower soils. Therefore, the final RSMI value may be slightly inflated. It is difficult to calculate exactly the degree to which a value may be inflated or deflated from this overlap, as this will be dependent on the location. In any case, the researcher should be aware of the this and watch for any RSMI values which seem excessively high or low.

CONCLUSIONS

Parker (1982), in presenting the original TRMI, states that he is not arguing for the acceptance of his specific outline of the index, but rather underscoring the need for a direct and practical approach to measuring resources such as soil moisture. I wish to reiterate this idea here. The RSMI is a field technique which can be of great use to field ecologists, earth scientists, and forest and range managers. It is not meant to be a rigid set of rules for determining soil moisture. To the contrary, it is intended to be a set of *guidelines*; as mentioned, certain areas even within the types of environments the RSMI was intended for may require slight modifications to parameter scaling. Further field testing and comparison of the indices in several types of environments may be required to allow for more extensive use of the RSMI. This index is also intended to be supplemented. In the future, other parameters such as canopy shade could be incorporated into the index. It may be possible to incorporate the RSMI into a GIS or other earth science database and this is being considered for future study. Such a database could prove extremely useful in vegetation and climate modeling, as well as in other earth science research. It is my hope that the work presented here inspires future study which may further increase the accuracy and versatility of the index.

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Professor Thomas R. Vale (advisor) Susy S. Ziegler (my other advisor)
Bridget McCann (field assistant) Mark Fonstad (field assistant)

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