Modelling relationships between moisture availability and soil/vegetation zonation in southern Saskatchewan and Manitoba

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***Abstract*:** Analyses were performed to see how variations in moisture indices (Im) may be related to both vegetation and soil zonation in southern Saskatchewan and Manitoba. Analogous to the European steppe situation, south-central Saskatchewan moisture indices increase dramatically as one moves north towards boreal forest. Unlike the situation in eastern European, however, the Canadian prairies also exhibit dramatically increasing Im values as one moves from south-central Saskatchewan to eastern Manitoba. In the case of the south/north transect in south-central Saskatchewan, correlation analysis, between latitude as the independent variable and, each of mean annual precipitation, temperature, potential evapotranspiration and moisture indices (Im) values as dependent variable, gives r^2 values of .7157, .9237, .9038 and .8830 respectively, confirming that latitude, and therefore temperature variations, play the major role in determining Im values. By contrast, for the west/east transect from Saskatchewan to eastern Manitoba the equivalent r^2 values, using longitude as the independent variable, are .9170, .3516, .7190 and .9151 respectively, confirming the role played by longitudinal variations in precipitation in Im values. Similar relationships between Im values and soils and vegetation zone boundaries are found along both transects, and diagrams are presented to model these relationships.

Introduction

Following the early nineteenth century lead of Humboldt and Bonpland (1805), it became fashionable for vegetation studies to stress the role of climate in explaining regional or continental-scale

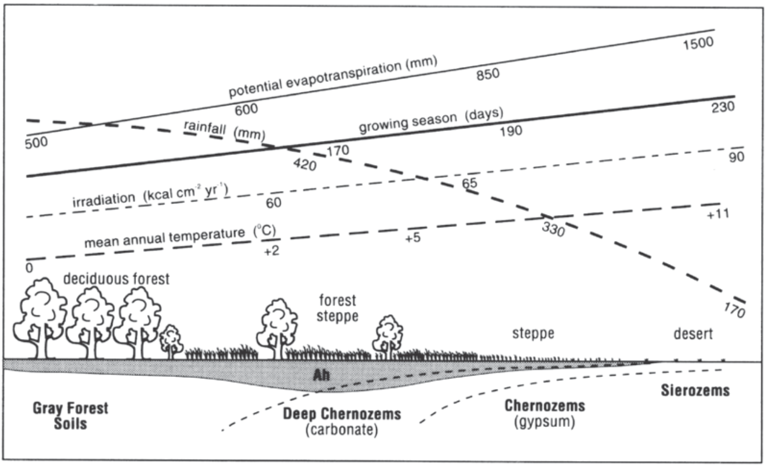

Figure 1: *A summary of energy-moisture variables important in the differentiation of vegetation covers and soil types in the east European lowlands (Figure 5.14 in Scott, 1995, which was modified from Walter, 1979, Figure 90).*

vegetation and soil patterns. Climate/vegetation relationships were the cornerstone of Dokuchaev's late nineteenth century studies on zonal soils in eastern Europe (Walter 1979), and in Köppen's famous climate classification (1918). More recently Walter (1979) has stressed the role of climate in world vegetation zonation, and the Ecoregions Working Group (1989) has expanded on his approach with its Ecoclimatic Regions system of vegetation zonation in Canadian. For the Canadian prairies, Joel (1933) noted a striking resemblance between the zonal character of Saskatchewan prairie soil profiles and those of eastern Europe, while Looman (1983) demonstrated that extant prairie vegetation type zonation is closely related to seasonal precipitation considerations. This current study is designed to compare moisture indices (the Im of Thornthwaite (1948), and the variables which dictate these indices, with extant vegetation and soils in the southern portions of Saskatchewan and Manitoba, using transects from xeric mixed-grass (short-grass) prairie to boreal forest. This study is also an attempt to adapt Walter's model (1979) for the Russian/Ukrainian steppes to the North American situation (Figure 1), and to see if there are any similarities between Im and steppe/forest boundaries as have been found in China (Fang and Yoda 1990). The final objective is the representation of this North American model in the form of pedagogically useful diagrams.

While Walter's model incorporates climate variables along a north-northwest to south-southeast transect from the deciduous forests on the cooler, moister side of the steppe, south through the steppe to the Caspian Desert, his model was summarized without the benefit of statistical analyses. The European steppes where Walter's model was developed and the Canadian prairies have some fundamental differences. While only a south-southeast to north-northwest (essentially latitudinal) transect from short-grass steppe to boreal forest is possible in eastern Europe, the Canadian prairies include both south/north latitudinal as well as west/east longitudinal transects from xeric mixed-grass prairie to forest (Figure 2). Differences between the two continents reflect the fact that while in eastern Europe the distribution of steppe and forest types extends latitudinally eastward into Siberia, in North America the moister northern aspen parkland margin only trends longitudinally east from Alberta into Saskatchewan where it then curves southeast into southern Manitoba before finally trending latitudinally due south through southeastern Manitoba into western Minnesota (Figure 2). Definitions for Canadian vegetation terminology are given in the caption to Figure 2.

While differences in climate between prairie and boreal forest seem obvious in explaining the boundary between them, differences within prairie/parkland cover types (i.e., xeric mixed-grass, mixed-grass, and tall-grass plus aspen parkland) appear less obvious due in part to a previous history of ungulate grazing and fire. Hildebrand and Scott (1987) conclude that the relationships between soil moisture deficiencies and tree growth on the pre-agricultural Canadian prairies were insufficient to adequately explain the prairie/parkland boundaries of the 1880's. They suggest that the effects of wildfire and herbivores (especially bison) may well have played a part in altering cover thereby detracting from an expected climate/vegetation correlation. Since the 1880's, however, following the cessation of large scale burning and the extirpation of the large herds of bison, aspen has spread into many of the moister mixed-

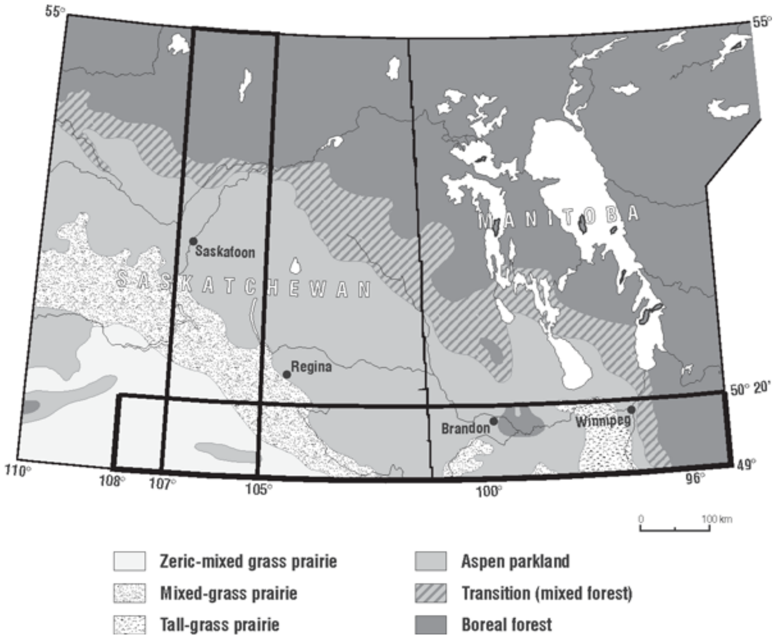

Figure 2. *Distribution of vegetation types in the Canadian prairies (modified from Scott, 1995). Added are the south/north latitudinal and west/east longitudinal transects used in the current study.* Xeric mixed-grass prairie is synonymous with short-grass prairie in Canada. Aspen parkland can include areas of mixed-grass and tall grass prairie, tall grass prairie (treeless) is restricted edaphically to the Red River basin in Manitoba. Transitional forest represents the transition from aspen parkland to boreal forest (where deciduous hardwood forest includes one-to-three of the four dominant prairie Province boreal forest conifers (following Zoltai, 1975). Mixed woods boreal represents the drier, often hardwood dominated, boreal forest (Rowe, 1972) of the Sub-humid Boreal Ecoclimatic Region, while the more humid boreal forest is generally dominated by conifers.

grass prairie areas forming parklands which better reflect extant climate.

Data Selection and Analysis

To prepare the south/north latitudinal transect data were obtained for climate stations from 49° 00' and 55° 20' north latitude, and between 105° and 107° west longitude (Figure 2). For the west/east longitudinal transect, data were obtained for climate stations between 108° to 95° west longitude, and from 49° 00' to 50° 20' north latitude. Mean annual precipitation (P) and mean annual temperature data come from the *Canadian Climate Normals 1961-1990* (Environment Canada, 1993). Only climate stations below 1,000 m a.s.l. and with either a complete 30 year record, or an adjusted 25-29 year record were selected. Annual potential evapotranspiration (PE) values were extrapolated from the " Annual PE" map (Figure 1.1 in Agriculture Canada, 1976, and detailed in Sly and Coligado, 1974). Moisture indices were determined using Thornthwaite's (1948) index where Im = (P/PE - 1)100. This index gives negative Im values where precipitation (P) is less than PE, Im is zero where P and PE are equal, and positive Im values reflect P exceeding PE. Vegetation cover types and soil great-groups are from maps published by the National Atlas of Canada (1999) and the Soil Research Institute (1972) respectively.

a) South/North Latitudinal Transect: Statistical analysis (using SPSS) of the climate data for this study consisted of four linear regressions, between latitude as the independent variable, and each of the following dependent variables; mean annual temperature, mean annual precipitation, PE, and Im. Twenty-five climate stations in this two-degrees of longitude swath from the U.S. border in south-central Saskatchewan north to La Ronge were used, with twenty one stations providing data on all four dependent variables. In the analysis minutes of latitude were converted to decimals of one degree. The r^2 values for these four regressions are given in Figure 3 together with an indication of soil and vegetation zone boundaries. All r^2 values were found to be significant at the 0.001 level.

b) West/East Longitudinal Transect: Statistical analysis consisted of four linear regressions between longitude as the independent variable, and each of dependent variables, mean annual temperature, mean annual precipitation, PE, and Im. Seventy climate stations from Val Marie in south-central Saskatchewan to the Manitoba-Ontario provincial boundary were used, with fifty one providing data on all four dependent variables. In the analysis

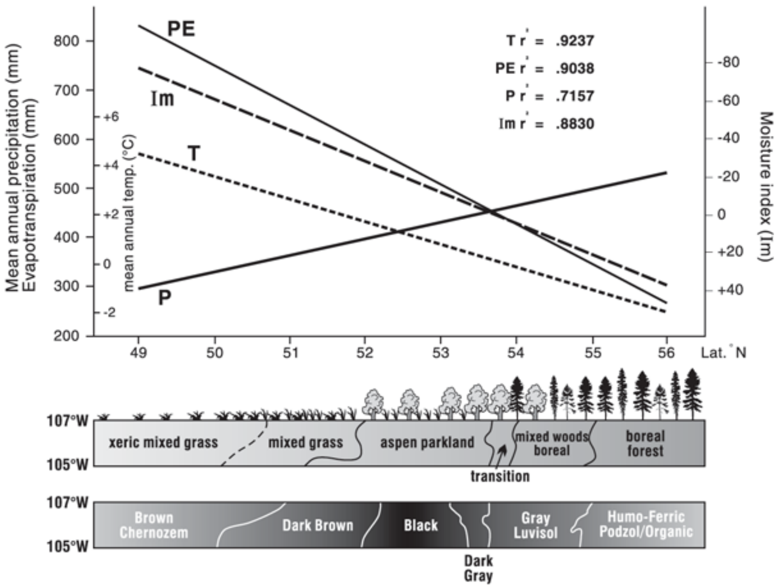

Figure 3: *South/north latitudinal transect from xeric mixed-grass prairie to boreal forest. Data from 105° to 107° W longitude, and between 49° and 55° 20' N latitude.* Boundaries for vegetation and soil zones in the bars below the graph come directly from the National Atlas of Canada (1999) and the Soil Research Institute (1972).

minutes of longitude were converted to decimals of one degree. The r^2 values for these four regressions are given in Figure 4 together with soil and vegetation data, and were found to be significant at the 0.001 level.

Conclusion

Data for the south/north transect is south-central Saskatchewan (Figure 3) show strong relationships between latitude and the four climate variables. Of interest is a much stronger temperature gradient associated with latitude (r^2 = .9237), than was found for precipitation (r^2 = .7157). As temperature impacts directly in the determination of both PE and Im, it would appear that the role

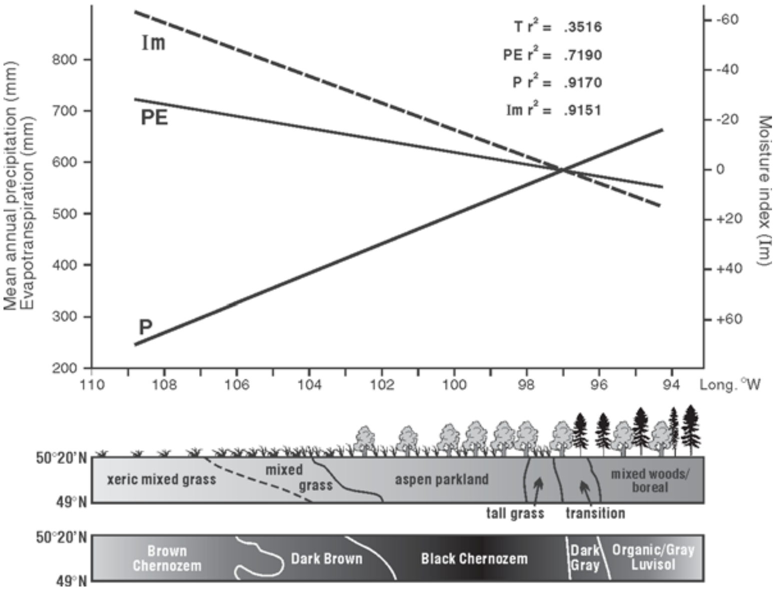

***Figure 4**: West/east longitudinal transect from xeric mixed-grass prairie to mixed woods boreal forest. Data from 49° - 50° 20' N latitude, and between 108° W and the Manitoba/Ontario provincial boundary (95° W).* Boundaries for vegetation and soil zones in the bars below the graph come directly from the National Atlas of Canada (1999) and the Soil Research Institute (1972).

played by latitude in depressing temperatures impacts significantly on both. Im values show a strong dependance upon latitude (r^2 = .8830) with the boundary between xeric mixed-grass prairie and mixed-grass prairie being where Im values are approximately -45. The boundary between Canadian mixed grass and aspen parkland is where Im values are -25, while Fang and Yoda (1990) obtained a value of -20 for this same transition in China. The boundaries between aspen parkland and transitional forest in this Canadian study, and in the China and east European studies (where PE and mean annual rainfall cross in Figure 1), are all associated with Im values of zero.

In Canada transitional forest is encountered where Im values range between zero and +5. While mixed woods boreal forest is associated with Im values of at least +5, this forest type is generally replaced by conifer-dominated boreal forest where Im values exceed + 20. It is not possible to compare the China study with the current one in terms of the transition to boreal forest as Fang and Yoda (1990) selected a northwest to southeast transect from steppe to temperate deciduous and evergreen forests. Not unexpectedly, boundaries between the Canadian Brown, Dark Brown, and Black Chernozems correlate well with grassland vegetation boundaries and Im values (Figure 3), although where Im values are strongly positive the relationship is less clear, probably reflecting other ecosystem modifying factors such as shield parent material, soil drainage, and forest fires.

With the west/east lomgitudinal transect (Figure 4) longitude produces a much higher r^2 with rainfall (.9170) than it did with temperature (.3516). It is suggested that for this transect it is variations in precipitation rather than temperature which accounts for the very significant association between longitude and Im values (r^2 = .9151). Again, boundaries between mixed-grass prairie and aspen parkland have Im values of -20, transitional forest coincides with Im values of zero to +5, and mixed woods boreal is found where Im values are greater than + 5.

This study confirms a high degree of prediction between Im values and both longitude and latitude along transects from xeric mixed-grass prairie to boreal forest. Soil zonal boundaries are also seen to reflect specific degrees of moisture stress or abundance, and there is a high degree of similarity between the Im values associated with Canadian vegetation boundaries and their eastern European and China equivalents.

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