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A Zone Map for Mean Annual Moisture Balance in the North Central United States

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There are many climatic factors that can limit the adaptation of woody landscape plants. In the North Central United States, one of the most widely studied limiting factors is winter injury caused by low temperatures. Mean annual minimum temperature is the basis for the USDA Plant Hardiness Zone Map (Cathey, 1990), which is perhaps the most well-known guide for defining woody plant adaptation in the region.

Results from two, long-term evaluation projects (Widrlechner et al., 1992, 1998) to evaluate landscape trees and shrubs at multiple sites across the North Central United States indicated that minimum temperature was not the only important determinant of plant establishment and overall survival. Those studies demonstrated that mean annual moisture balance was another important factor influencing plant establishment and survival. In the first study (Widrlechner et al., 1992), statistical analyses of a ten-year trial of landscape plants introduced from the former nation of Yugoslavia revealed that the best predictive models to describe both initial plant establishment and overall survival relied on both winter minimum temperatures and annual moisture balance. In the second study (Widrlechner et al., 1998), similar analyses of the performance of landscape plants from northern Japan actually found that moisture balance at trial sites was of greater importance in determining plant establishment and survival than was each site's minimum temperature. This may be due to the fact that northern Japan has a climate with large moisture surpluses, and many woody plants from that region lack high levels of drought tolerance. Another factor that may have contributed to this finding was that this study was conducted between 1984 and 1995, an era marked by several severe and widespread drought events, including a devastating drought during the spring and summer of 1988 (Economic Research Service, 1989).

The statistical models tested by Widrlechner et al. (1992, 1998) used a moisture index developed by Thornthwaite and Mather (1955) as a measure of moisture balance. This moisture index, I_m, has also been employed in studies relating climatic factors to the distribution of plant communities in North America (Mather and Yoshioka, 1968). I_m is calculated on the basis of two variables, potential evapotranspiration and mean annual precipitation, with the following formula:

$$I_m = 100\ [(\text{mean annual precipitation} \div \text{potential evapotranspiration}) - 1].$$

Mean annual precipitation measures the cumulative amount of moisture received from the atmosphere. Potential evapotranspiration

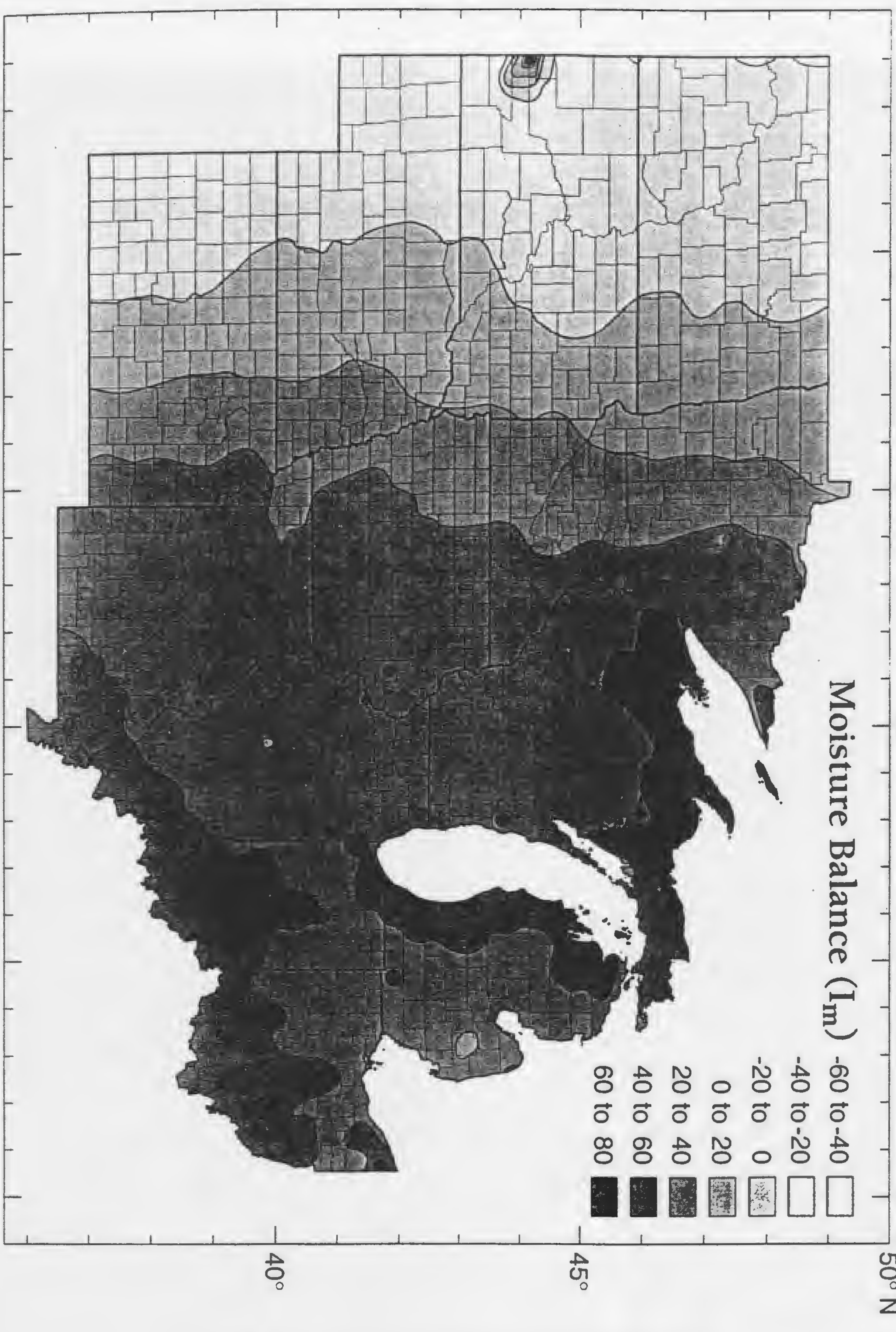

Figure 1. Moisture balance map of the North Central United States.

estimates the maximal amount of moisture that may be lost to the atmosphere from a given site. Many methods have been developed to derive such estimates. The method followed by Widrlechner et al. (1992, 1998) for determining potential evapotranspiration in the North Central United States was taken from the map, "Average Annual Potential Evapotranspiration" (Thornthwaite, 1948), which is based on a mathematical function of air temperature that is correlated with observations of actual water loss.

I_m, then, is calculated from the ratio between these two variables. Where the mean annual precipitation equals annual potential evapotranspiration, I_m is zero. It is positive where the mean annual precipitation exceeds annual potential evapotranspiration, reaching values of 100 or more in sites where the mean annual precipitation is at least double that of the annual potential evapotranspiration. It becomes negative where the mean annual precipitation is less than the annual potential evapotranspiration, reaching a theoretical minimum value of -100, but only in sites where there is no precipitation.

From a long-term perspective, I_m gives an estimate of the overall moisture surplus or deficit experienced at a given site and, thus, an indirect estimate of the moisture available for plant growth. But it gives no measure of seasonal or annual variability for moisture deposition or loss through evapotranspiration. Seasonal and annual variation are undoubtedly important determinants of plant adaptation, but, within the North Central United States, these issues are not as important as they would be when examined over a wider range of environments. Most sites in the North Central United States receive the majority of their precipitation during the growing season and are reasonably homogenous for this characteristic. Annual variability for precipitation and the frequency of drought within the North Central United States vary generally from east to west, with both the greatest variability in precipitation and highest frequency of drought found in the western part of the region (Court, 1974). Therefore, when comparing sites within a moisture balance zone, it is probably safe to assume that the western part of a zone is more variable and has a higher probability of drought than does that zone's eastern part.

Mather (1966b) produced a map of I_m values for North America. Unfortunately, his map's scale and broad zonation make it very difficult to apply to studies of landscape plant adaptation. To help overcome these limitations, I have created a new map of I_m values for the North Central United States (Figure 1), based on Thornthwaite's (1948) map, "Average Annual Potential Evapotranspiration," and on 1961-1990 mean annual precipitation data mapped by using a geographical model called PRISM (Daly et al., 1994, 1997) and made available through the Internet at: <http://www.ocs.orst.edu/pub/maps/Precipitation/Total/States/>. I developed the zones by first combining the two data sets at the same scale, then mapping those sites where isohyets (lines of equal precipitation) intersected critical values for potential evapotranspiration, and, finally, manually extrapolating the zones between the mapped points. Any map produced by this method should be considered only preliminary. In the future, once a fine-scale, geographical data set of potential evapotranspiration based on more recent temperature data is assembled, it should be possible to create computerized gridded estimates of I_m values and a more accurate and reliable map.

The zonation used in Figure 1 follows 20-unit intervals. Mather (1966a) also employed 20-unit intervals in his definition of climatic types for positive I_m values (Table 1) but used 33.3-unit intervals for negative values. I chose to map the -20 and -40 values, because they clearly show the locations of minimum I_m values (just below -40) found within the region.

Zones mapped in the western half of the region (Table 1) generally follow longitudinal bands, with the lowest values (i.e., largest moisture deficits) in western parts of Kansas, Nebraska, and the Dakotas. The main exception is caused by orographic precipitation and reduced evapotranspiration effects caused by the high peaks of the Black Hills of South Dakota. It is interesting to note that large portions of Michigan, Ohio, and Indiana share the same moisture balance zone as found in eastern Minnesota, eastern and central Iowa, and most of Missouri. A drier zone is first encountered in the vicinity of 94 or 95EW longitude, with progressively drier zones encountered westward toward the Rocky Mountains, which serve as a strong barrier to the flow of precipitation from the Pacific Ocean.

Zones mapped in the eastern half of the region (Table 1) do not follow longitudinal bands but instead consist primarily of the zone of I_m values between 20 and 40 away from the Great Lakes or the Ohio River valley and the zone of I_m values between 40 and 60 around Lake Superior, the western shore of Lake Michigan, and in the Ohio and lower Mississippi River valleys. There are also three small regions of an even wetter zone, the zone of I_m values above 60. These are located on Michigan's Upper Peninsula and in extreme northeastern Ohio and result primarily from lake-effect precipitation.

Based on past evaluations of landscape plants from the former nation of Yugoslavia and from northern Japan (Widrlechner et al., 1992, 1998), it may be worthwhile to combine moisture balance zonation with winter hardiness zones to develop a composite zonation system for the North Central United States. Such a composite zonation system also might be applied to other parts of the world that are being investigated as sources of new landscape plant introductions to the North Central region.

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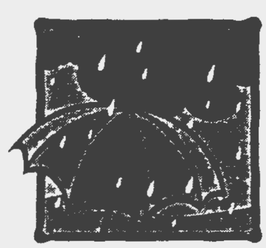
Table 1.

Moisture Balance Zones as Related to Mather's (1966a) Climatic Types

Mapped Zone	Primary Locations	Climatic Type
< -40	ND, SD	D - Semiarid
-40 to -20	ND, SD, NE, KS	D - Semiarid (-40 to -33.3) C_1 - Dry subhumid (-33.3 to -20)
-20 to 0	MN, ND, SD, NE, KS	C_1 - Dry subhumid
0 to 20	MN, IA, NE, KS	C_2 - Moist subhumid
20 to 40	MN, IA, MO, WI, IL, MI, IN, OH	B_1 - Humid
40 to 60	MI, IN, OH	B_2 - Humid
> 60	MI, OH	B_3 - Humid



visit there in February, 1999.

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Korean Mountain Ash (*Sorbus alnifolia*)

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Korean mountain ash is a small to medium sized tree with many outstanding ornamental features. Native to central China, Korea, and Japan, Korean mountain ash is not as well known as its European and American relatives. However, this tree's spring flowers, attractive foliage, and colorful, persistent fruit make it worth getting to know.

Growing 25 to 40 feet tall and 20 to 40 feet wide at maturity, Korean mountain ash fills a niche somewhere between small ornamentals and large shade trees. The tree's form varies from plant to plant but it generally has a broad,