Briefing paper prepared for a workshop to revise Army Regulation 70-38: Research, Development, Test and Evaluation of Material for Worldwide Military Operational Environments, Yuma Proving Ground, AZ, January 30-February 2, 2006

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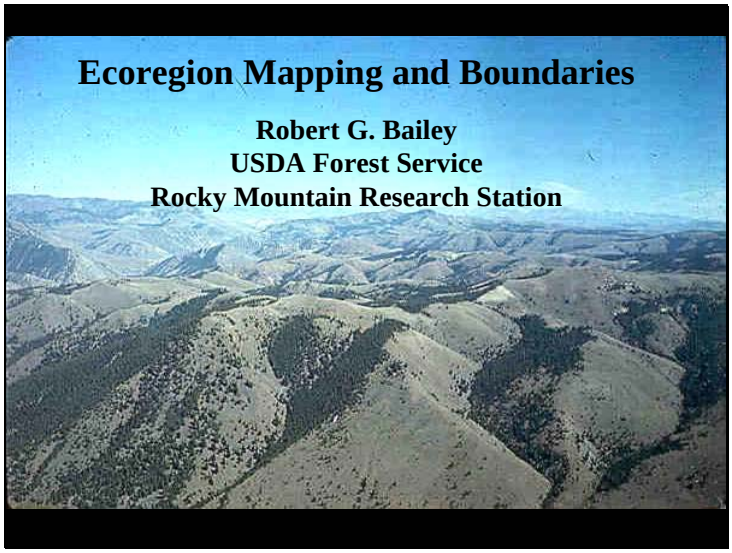

Ecoregion Mapping and Boundaries

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Abstract
Ecoregion maps show the earth's surface subdivided into identifiable areas based on macroscale patters of ecosystems. These ecoregions delimit large areas within which local ecosystems recur more of less throughout the region in a predictable pattern. For example, trees are found on north-facing slopes throughout the semi-arid mountains of the American West. This presentation summarizes the rationale I used in identifying ecoregion boundaries on maps of the United States, North America, and the world's continents. The geographic reasoning used in drawing boundaries involves 20 principles, which are presented to stimulate discussion and further understanding.

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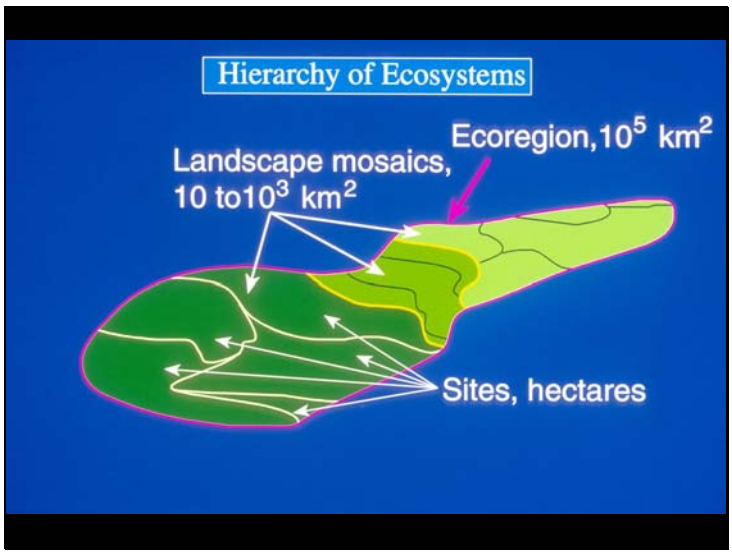

Groups of spatially related ecosystems can be considered an ecosystem of higher order and commonly greater size, which have proposed to call “macroecosystem.”

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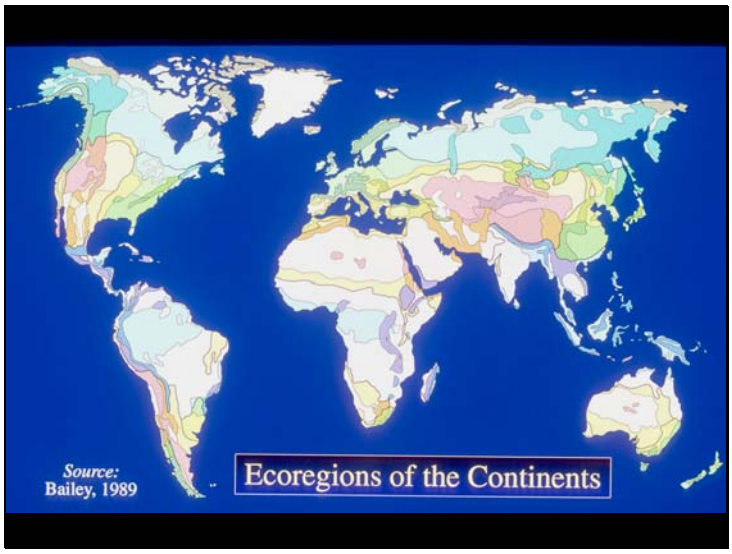

Schemes for recognizing geographic patterns in ecosystems at varying scales in a hierarchy have been proposed. The purpose of this presentation is to explain the rationale I used for mapping such units.

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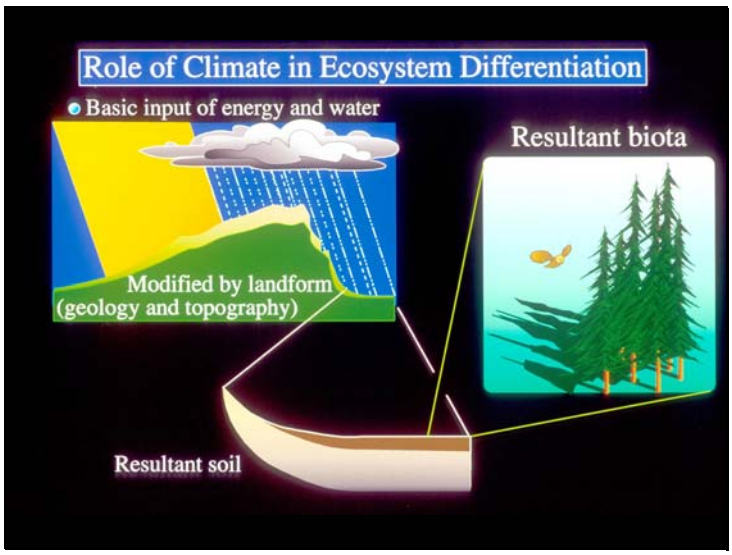

While the ecosystem concept implies equality among all the components of the system, all the components are not equally significant. Climate largely determines ecosystem boundaries. As it changes, the other components change in response. As a result, ecosystem of different climates differ significantly.

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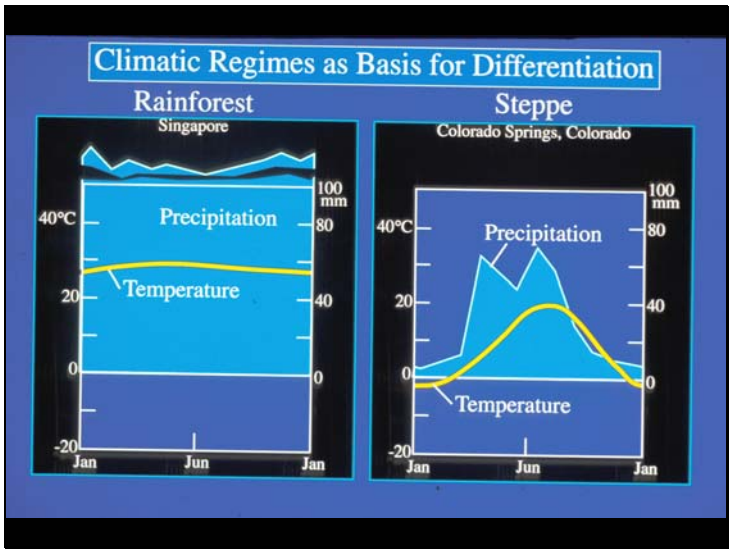

The most important climatic factor is the climatic regime, defined as the daily and seasonal fluxes of energy and moisture.

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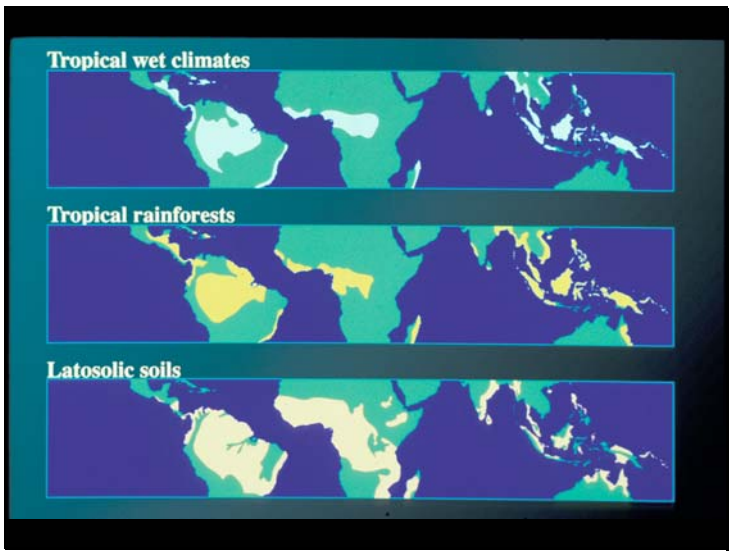

As these change, the kinds and patterns of dominant life forms of plants and animals change, as do the kinds of soils. For example, tropical rainforests have latosolic soils and are associated with hot and wet climates. Climate changes invariably alter hydrologic and erosion cycles plus life cycles. All this implicates climate as the most important factor to consider in setting ecoregion boundaries. From my working to capture climate-based ecoregions, I have discerned the following principles:

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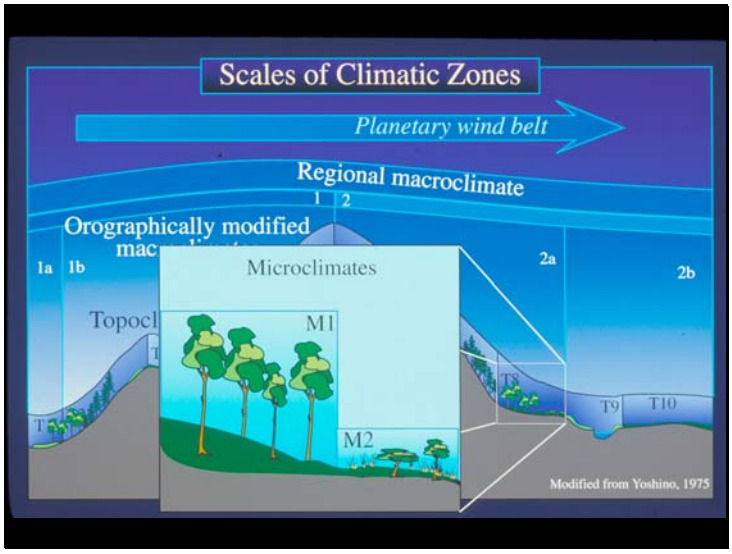

1. *The series of ecoregions should express the changing nature of the climate over large areas*. Unfortunately, climate varies within short distances owing to variations in local landform features and the vegetation that develops on them. It is necessary, therefore, to postulate a climate that hierarchically lies just above the local modifying irregularities of landform and vegetation. To this climate the term “macroclimate” is applied.

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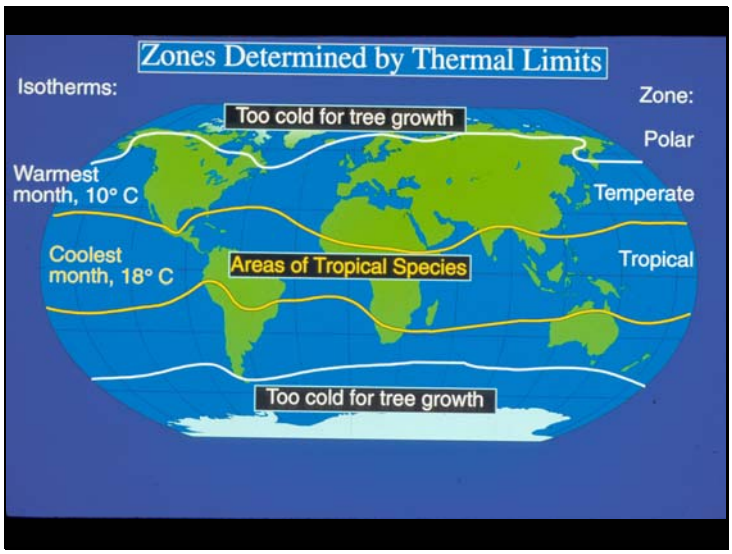

2. *Boundaries of ecoregions coincide with certain climatic parameters*, such are the thermal limits for plant growth. For example, the polar zone is a climatically determined ecological unit characterized by tundra. It's southern limit corresponds with the isotherm for the warmest month that is too cold for tree growth.

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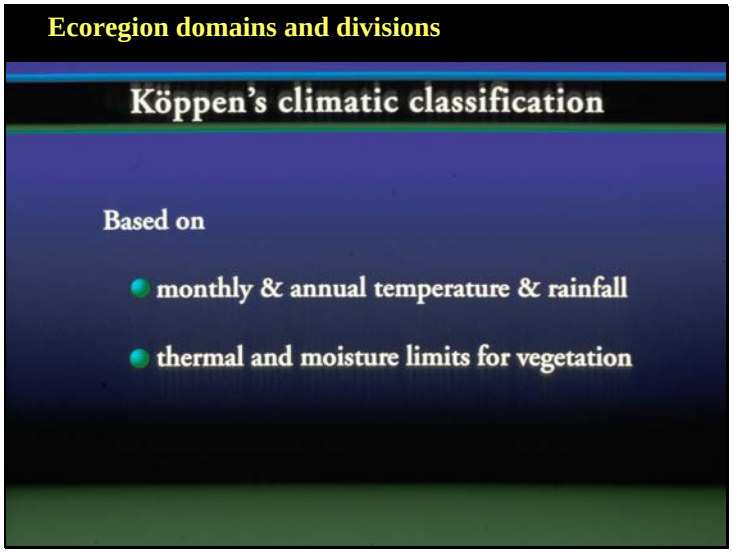

I subdivided the continents into ecoregions with three levels of detail. Of these the broadest, *domain*, and within them *divisions*, are based largely on the broad ecological climate zones of Koppen (as modified by Trewartha). I made some further modifications to better correspond with the distribution of vegetation and soil.

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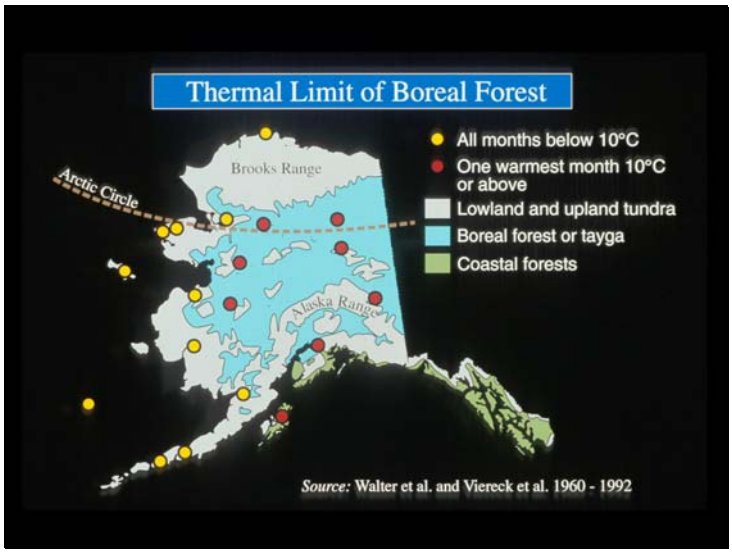

Thermal and moisture limits for plant growth and distribution determine the class boundaries chosen. For example, the boreal forest zone is a climatically determined ecological unit dominated by coniferous forest. The zones limit corresponds roughly with the isotherm for the mean daily temperature of the warmest month that is too cold for tree growth.

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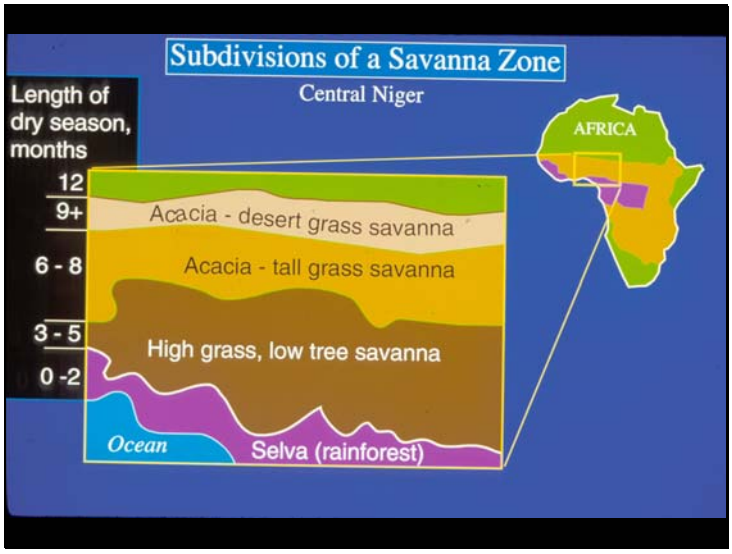

3. *Fine-scale climatic variations can be used to delineate smaller ecological regions*. It is possible to subdivide zones into finer units. Within the savanna zone, for example, *plant formations* can be distinguished based on variation in length of dry season. We refer to these as climate subtypes. These subtypes largely correspond to major plant formations, characterized by a broad uniformity both in appearance and in composition of

the dominant plant species. They form the basis for subdividing ecoregion divisions into *provinces*.

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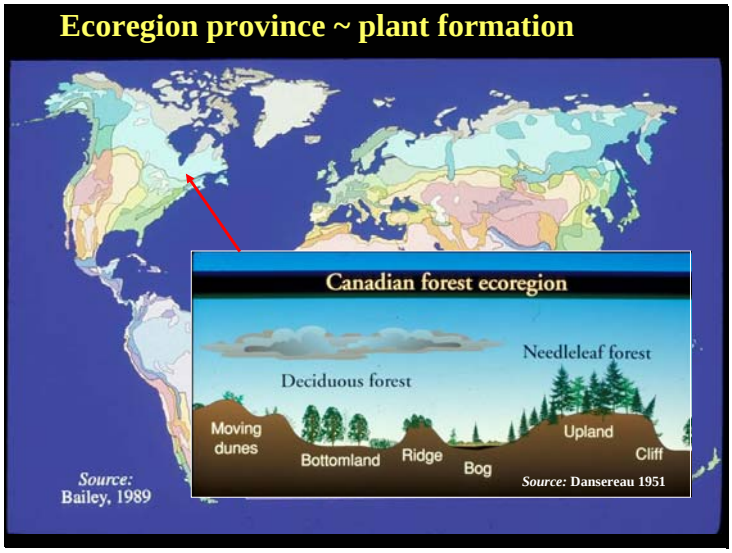

Generally each climate subtype is associated with a single plant formation. Of course, not all the space is taken up by the formation, for the nature of the topography will allow the differentiation into many habitats, and the percentage of the region occupied by the formation will depend upon the amount of well-drained upland. Other classes will occupy steep slopes that are hotter and dryer or cooler and moister, as well as bottomlands where the water lies near the surface. A formation class that broadly conforms to the climatic subtype is termed *zonal*. Local classes correlate with many of the variations from the zonal pattern and are termed *azonal*. One ignores these local variations in mapping climatic regions (and therefore ecoregions).

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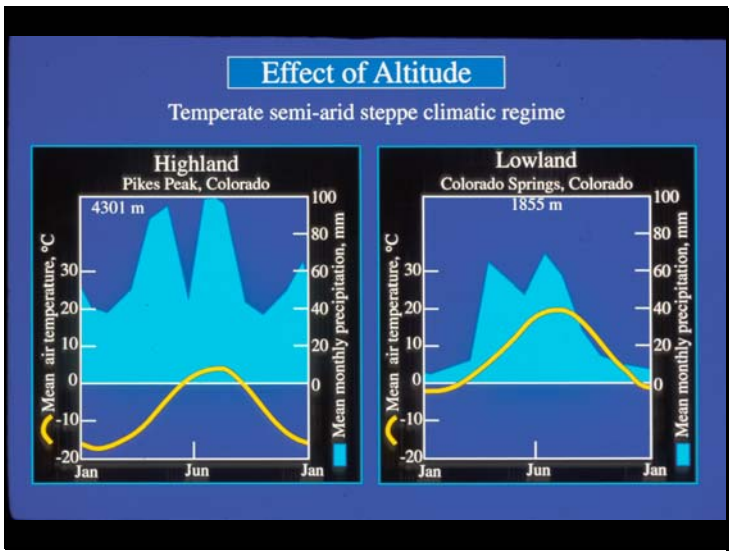

4. *Boundaries should capture the effect of mountains on climate*. The arrangement of the ecological climate zones depends largely on latitude and continental positions. This pattern, however, is overlain by mountain ranges, which cut across latitudinally oriented climate zones to create there own ecosystems. Altitude creates characteristic ecological zones what are variations of the lowland climate. The mountain ranges of Colorado, for example, experience seasonal energy input and moisture regime consisting of relatively dry winter and rainy summer typical of their neighboring lowlands.

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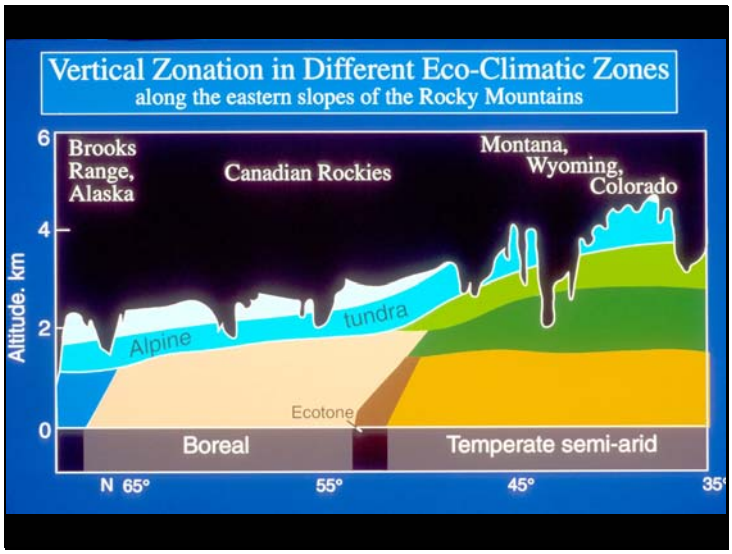

5. *A uniform pattern of mountain zonation is repeated over a climatic zone, which is the basis element in regionalizing mountainous territories*. When a mountain extends over two of more climatic zones, it produces different vertical zonation patterns.

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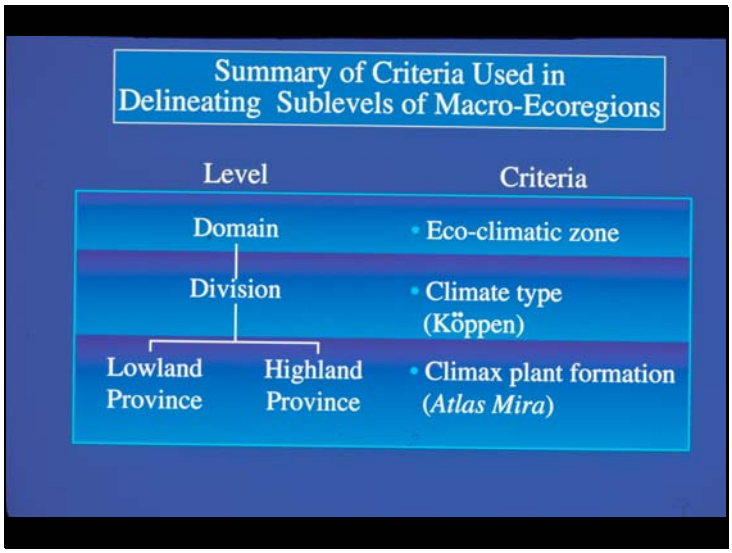

In summary, principal regional divisions (*domains* and *divisions*) are based on eco-climatic zones. Zones are subdivided on basis of macro features of vegetation (more refined climate). Highlands are distinguished according to the character of the vertical zonation pattern.

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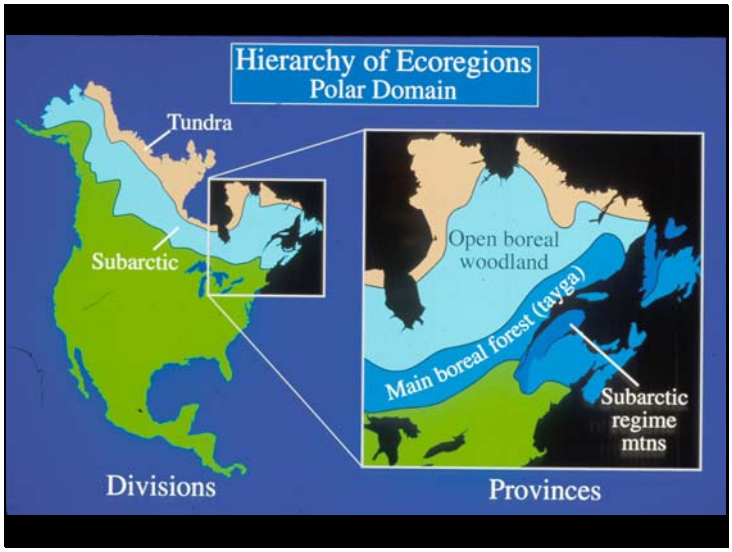

This illustrates the use of these criteria.

Slide 17

6. *Ecoregional boundaries should delineate groups of upland sites with similar characteristics*. Sites to be considered in ecoregional delineation should be reasonably uniform sets of uplands with well-drained surface, moderate surface-slope, and well-developed soils. In this manner the effects of landform differences are screened out, leaving the biologically effective climate as the main variable between ecoregions.

Slide 18

7. *The mosaic of ecosystems found in major transitional zones (ecotones) should be delineated as separate ecoregions*. A good example is the forest-tundra subtype of circumpolar regions in the northern hemisphere, a mixture of tundra on the drier ridges and woodlands in the valleys. This area is a classic example of an ecotone where two major zones, the tundra and the boreal, interpenetrate and blend into each other.

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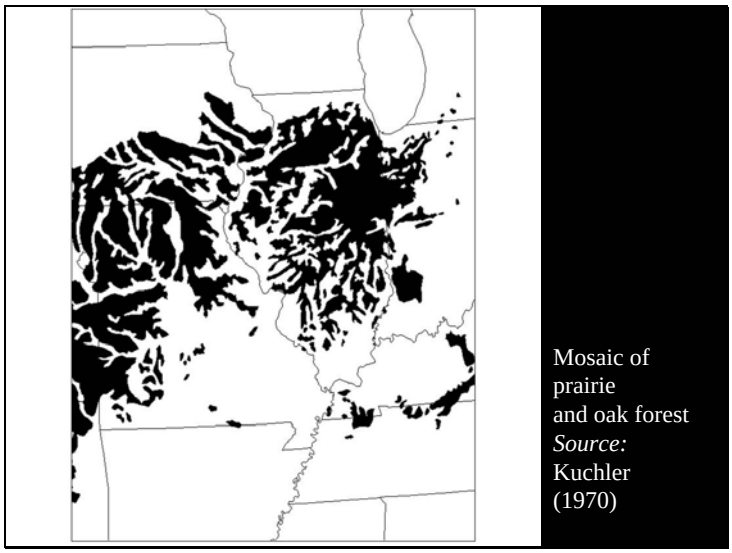

Mosaic of prairie and oak forest *Source:* Kuchler (1970)

Another example of these types of ecotonal regions are the prairie parklands. These are areas in which two types of plant formations grow side-by-side under the same macroclimatic conditions.

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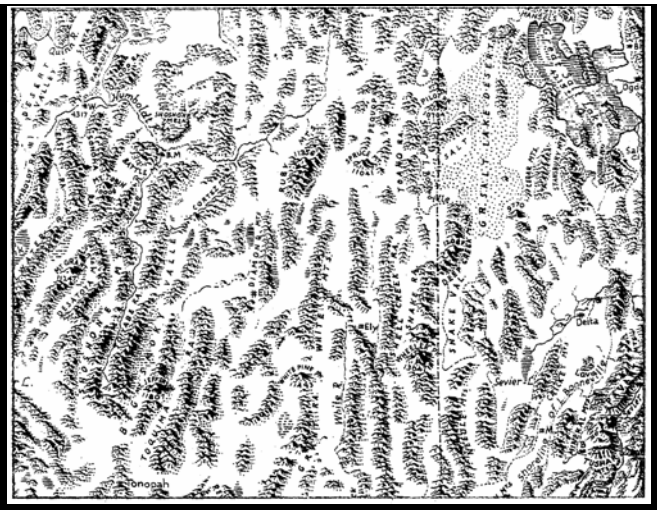

Basin and ranges. *Source:* Raisz (1939)

8. *Context is often as important as content in mapping ecological regions*. Individual lowland basins in the Great Basin of Nevada that are surrounded by widely spaced mountain ranges should be considered part of a single ecological unit that consists of both the mountains and the basins.

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R. Forman photo

Another example is where mountains meet plains. In these cases the orographic and vegetation boundaries do not coincide. For example, the vegetation of the plains commonly does not stop at the foot of the mountains but extends up the lower slopes and valleys that drain the mountain. In this case, the orographic boundary is the one that is used to separate the ecoregions—the vegetation of the plains that occurs on the mountain slope is considered part of the sequence of elevation.

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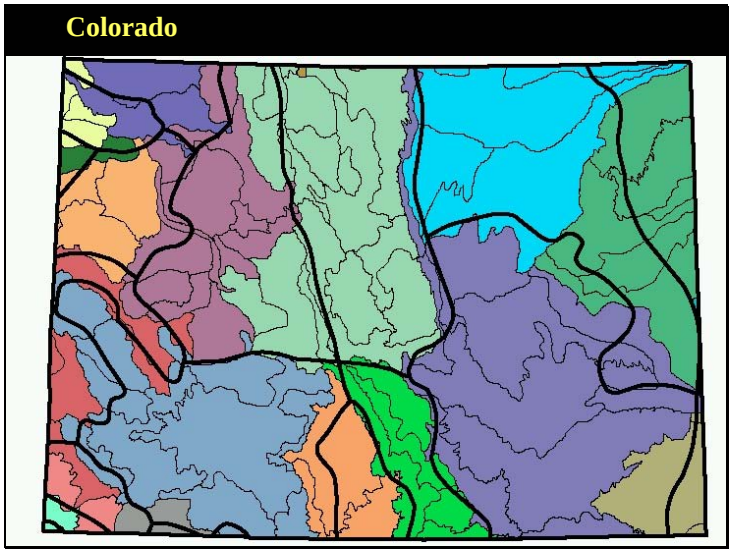

9. *Because subsystems can be understood only within the context of the whole, a classification of ecoregions begins with the largest units and successively subdivides them*. Problems occur when ecosystem maps derived from different scales are overlaid in an attempt to identify subsystems. To overlay, for example, the highly generalized boundaries of ecosystems plotted on a regional or global scale onto a pattern of

ecosystems plotted in detail almost invariably results in considerable lack of correspondence in boundaries.

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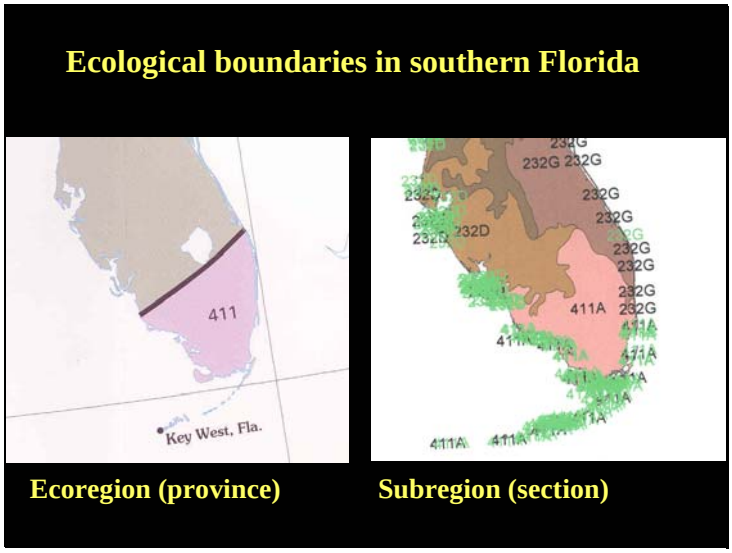

Ecoregion boundaries are relatively smooth because they are controlled by the macroclimate that *lies above the modifying effects of the earth's surface*. In contrast subregion boundaries within the ecoregion can be quite irregular because they are controlled by the irregularities of the surface. <u>This is why higher level systems cannot be mapped (or refined) by aggregating lower level systems.</u>

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10. *The factors used to recognize ecoregions should be relatively stable.* These factors tend to screen out the effects of disturbance, such as fire and timber harvesting, and plant succession. Otherwise the ecoregion boundaries would be constantly changing.

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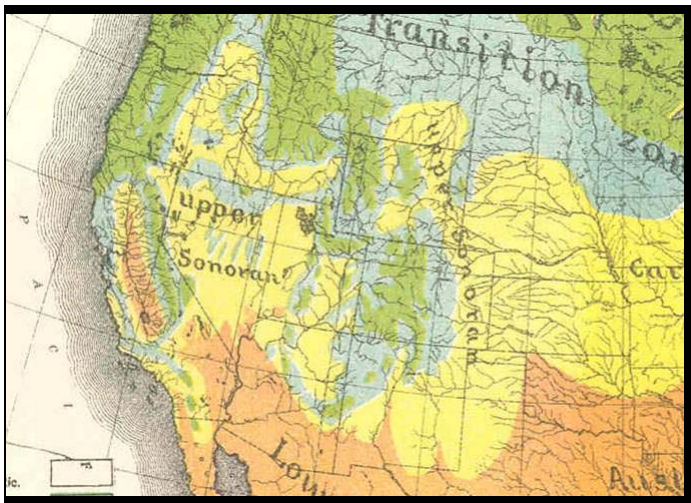

Life Zones. *Source:* Merriam (1893)

11. *Boundaries should circumscribe large, contiguous areas*. The concept of "ecoregion" differs from that of 'biome," for a biome is coincident with its climaxes. Every area having the same climax, however far detached from the main area of that climax, seems to belong to the same biome.

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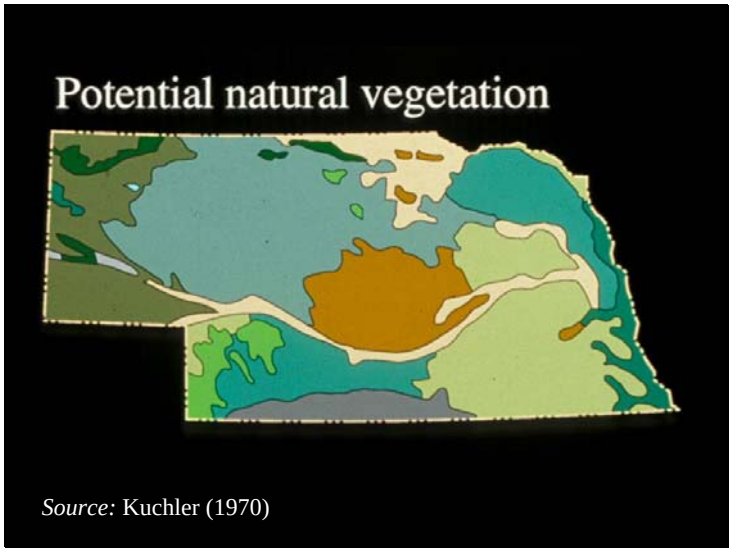

Source: Kuchler (1970)

12. *Potential vegetation, in contrast to actual, or real, vegetation, is useful in capturing ecological regions*. In some areas, problems resulting from disturbance and the

occurrence of an intricate pattern of secondary successional stages make regional boundary placement particularly difficult because the patterns of existing vegetation do not correspond well with the patterns of ecoregions. Those problems can be overcome by considering the pattern displayed on maps of potential natural vegetation.

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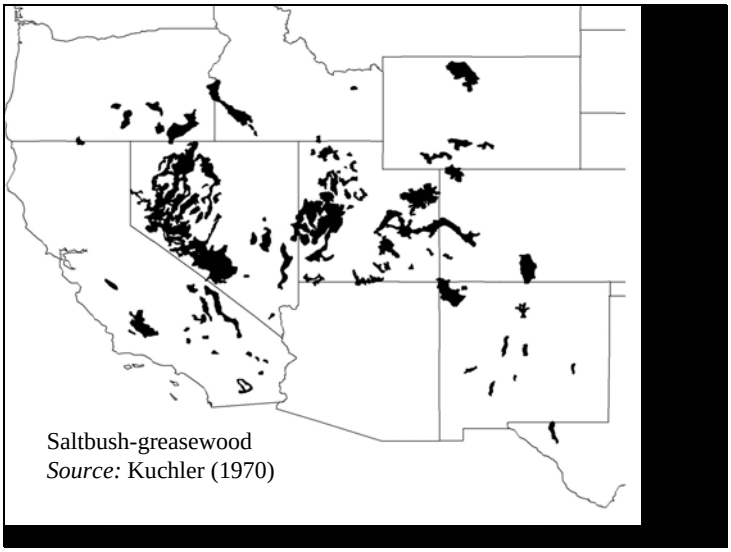

In some areas problems resulting from disturbance and the occurrence of intricate pattern of secondary successional stages make regional boundary placement particularly difficult. These can be overcome by considering the pattern displayed on maps of potential vegetation, such as those by Kuchler, is certain amendments are made. Some of Kuchler's mapping units show the presence of large areas of azonal soils, such as sand-plains and salt deposits. In these cases, a map of ecosystem regions would ignore such areas and relegate edaphically controlled ecosystems to a lower level of classification and more detailed maps.

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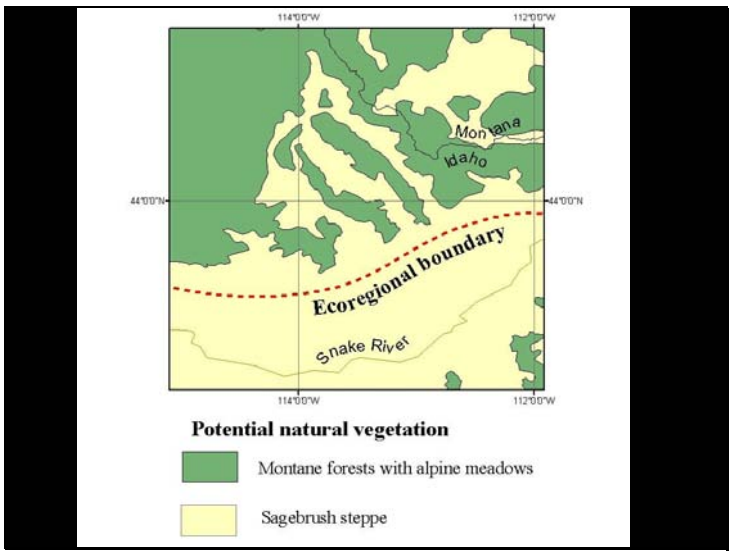

The ecoregion boundaries cannot be compiled from the boundaries of individual ecosystems since the latter are not always easily assigned to either of their neighboring ecoregions; certain types of ecosystem are common to both ecoregions.

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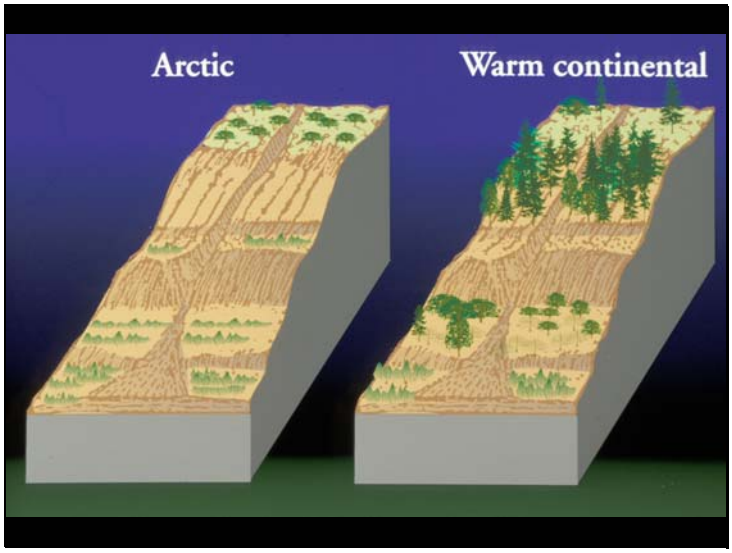

13. *An understanding of the relationships between succession on identical landform positions in different climates is useful for establishing meaningful ecological regions.* Slopes of similar characteristics will be found in various ecoregions and will support different ecosystems because of the different climates (Leser and Nagel 1998). For example, a certain slope in the arctic will support low-growing shrubs and forbs, whereas an identical slope in warm continental ecoregion will have dense broadleaf deciduous and needle-leaf forests.

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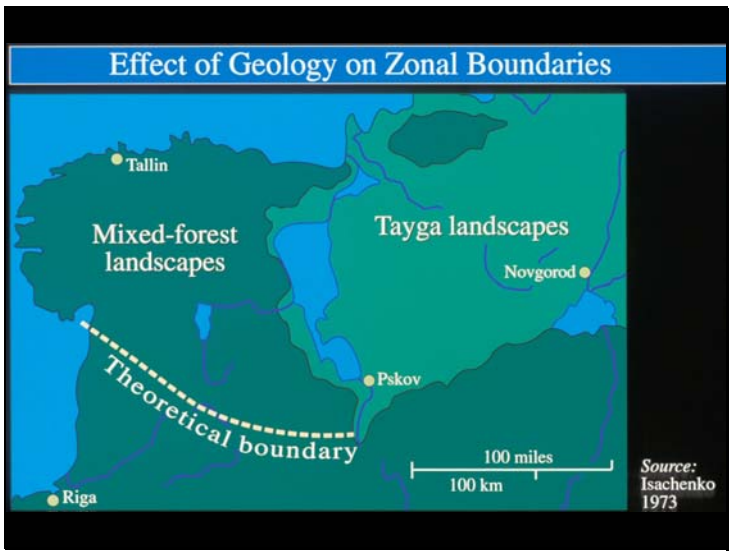

14. *Geologic factors may modify zonal boundaries*. In the Baltic region, owing to the widespread distribution of carbonate rocks, the northern boundary of the mixed-forest zone is displaced far to the north so that its actual position varies with the theoretical position.

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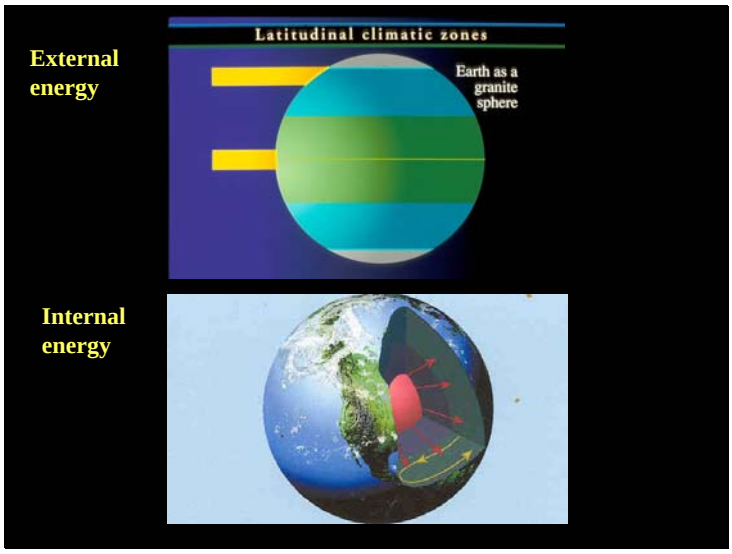

15. *Establishing a specific hierarchy of ecoregional boundaries should be based on understanding the formative processes that operate to differentiate ecoregions at various scales*. Two primary sources of energy and their resultant processes differentiate the Earth's surface into ecosystems; one is external, provided by the sun. At the global level, ecosystem patterns are controlled, or caused, by variation macroclimate related to variation in solar radiation with latitude. The other is the heat generated within the Earth itself. It drives mantle convection and produces plate tectonics, causing mountain building. Mountains modify the climatic pattern that would otherwise develop on a flat

continent. At the local level topography causes variations in the amount of solar radiation received and in soil moisture regimes both of which affect vegetation.

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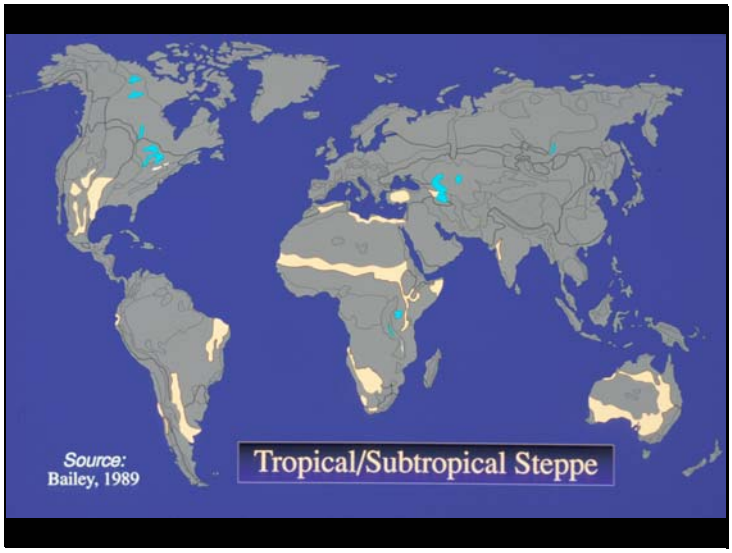

16. *Criteria for setting ecoregion boundaries should be explicit in how regions are identified on the basis of comparable likenesses and differences*. Similar ecoregions are found in similar latitudinal and continental locations. Because of this predictability, we can transfer information from region to region. In contrast, "place name regions," such as the Great Plains of North America makes scrutinizing or confirming the regions difficult; and subsequently, results are difficult to communicate.

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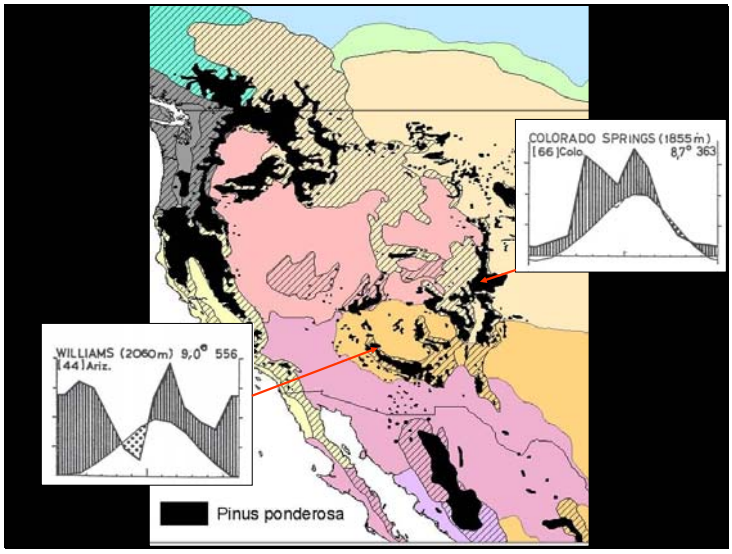

17. *The limits of geographic ranges of species and races of plants and animals are not fully satisfactory criteria for determining the boundaries of ecoregions.* The same type of forest can occur in different ecoregions. It has no regional alliance. For example, ponderosa pine forest occurs in the northern Rockies and the southwest. This does not imply that the climate, topography, soil and fire regimes are necessarily the same. (Note climate diagram for Williams, AZ has a late spring drought shown by dot pattern. Colorado Springs is moist throughout the year.) Many times compensating factors (e.g., high ground water table) will allow the same species to be present in two different ecoregions, but for different reasons.

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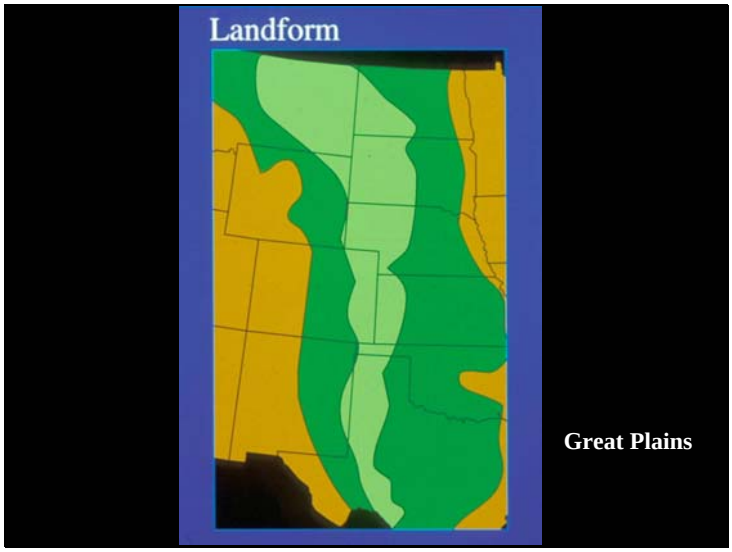

18. *Ecoregions should have greater ecological relevance than large physiographic land units, or landform regions.* These units are based on structural geology and landform attributes, notable relief and degree of dissection. Many times the boundaries cut across energy zones and their associated ecosystems. For example, the northern Great Plains in the Dakotas will have a considerably different climate than the southern plains in Texas.

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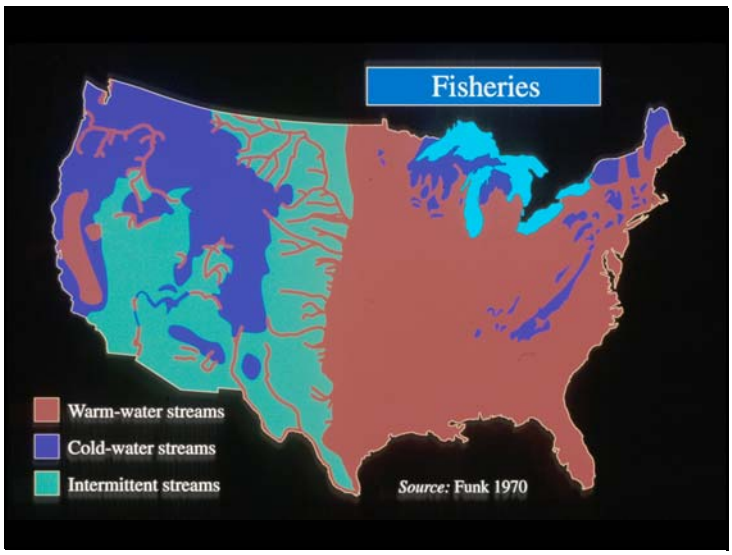

19. *Ecoregion boundaries should have greater ecological relevance than watersheds.* Watersheds are based solely on which direction the water flows. Rivers often run through areas of diverse topography that include many types of ecosystems. The Platte River watershed in Colorado, for example, begins in the humid, high basins of the Rocky Mountains and flows into the semi-arid Great Plains. Depending on the ecoregion their watersheds are embedded, streams flowing into the Platte have very different thermal characteristics, gradients, aeration, and resultant biota. Ecoregions, therefore, make it possible to identify areas within watersheds with similar aquatic environments.

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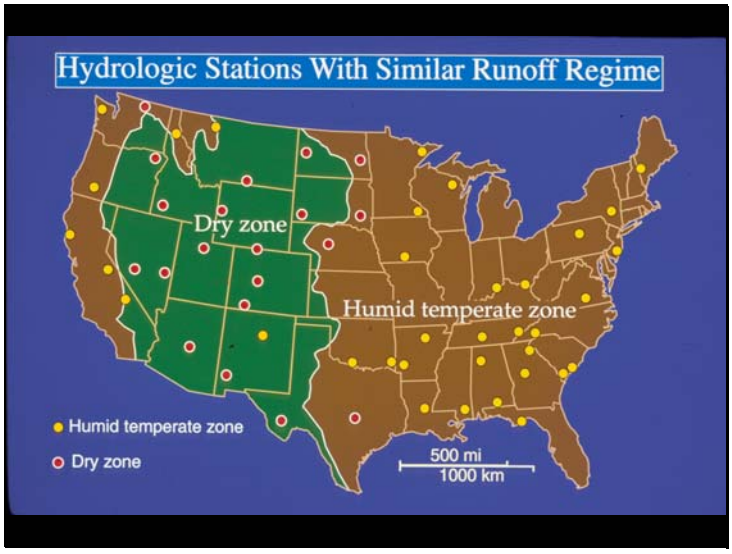

20. *The boundaries of ecoregions emerge from the study of spatial coincidences, patterning, and relationships of climate, vegetation, soil, and landform.* This is preferred to the superimposing of thematic maps by gis because unit boundaries rarely conform to one another. This is also quite different from the numerical taxonomic methods that use

cluster analysis. Boundaries cannot be derived mathematically without understanding ecosystem pattern and process. Often, the best use of such methods is after the fact, validating and refining land units when they have been mapped out by application of ecological theory. For example, I used discriminant analysis to test whether two ecoregions were different hydrologically.

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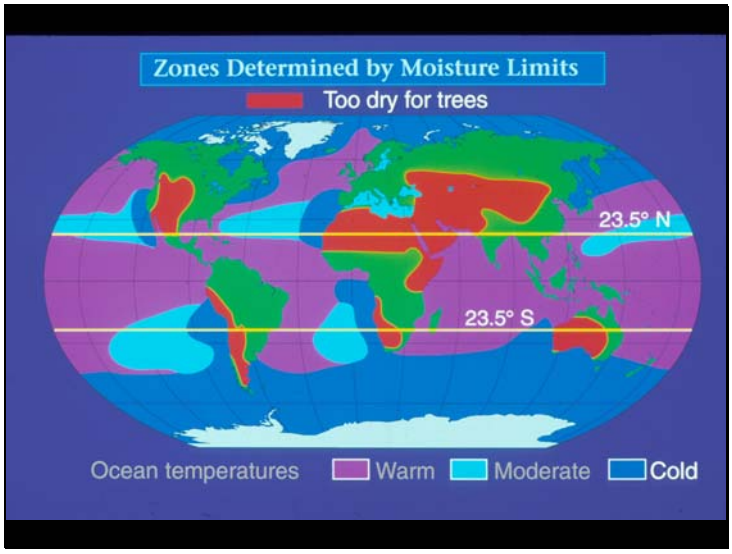

Finally, there is a limitation to all this. Understanding continental systems requires a grasp of the enormous influence that ocean systems exert on terrestrial climatic patterns, and thus the character and distribution of continental ecoregions. For example, there is more precipitation over the margins of continents bathed by warm water. The fact that we have warm-water currents along the East Coast of the U.S. explains why the mid-latitude deserts of the Southwest do not extend completely across North America.

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For More Information:
Bailey, R.G. 2005. Identifying ecoregion boundaries. *Environmental Management* 34, Suppl. 1: S14-S26

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