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Chapter 6

Climate and Terrain

Our knowledge of the physical requirements of cultivated plants is far advanced in contrast to that of the native and introduced species used in range plantings. Cultivated plants are usually grown as single varieties of a species under specific controlled conditions to ensure maximum yields. Native and introduced range plants often grow in species mixtures on sites that are more variable than agricultural croplands. Our knowledge of the specific requirements of individual species or varieties may not always apply with respect to interspecific competition or to the widely varying wildlands now being reclaimed or rehabilitated. Data obtained by growing native and introduced species in pure stands are only partially applicable to stand mixtures because the requirements for a species in a pure stand often differ from its needs when competing with other plant species. At present, we understand little of the effects of competition, let alone the complex interaction of climate, soil, and terrain upon which our native plant species grow (Hansen and Churchill 1961).

Any site under consideration for rehabilitation or restoration will have its own peculiar combination of environmental conditions that interact to form a distinctive environment, and thus a unique plant community. Ideally, the use and management of any resource should be based on extensive knowledge and understanding of that resource and its environment. Knowledge of the nature of the potential plant community to be rehabilitated (table 1) is a prerequisite to an evaluation of a site condition (Passey and Hugie 1962a). Site potential cannot be determined unless one becomes familiar with the complexity of its environmental parameters.

It is not the purpose of this short review to thoroughly detail all the possible responses that plants exhibit with respect to their environment. Rather, this review is to help make a person, in a general way, more familiar with how complex environmental factors can become and what their possible effects on a plant can be. Billings (1952) felt that the complexity of the interrelationships between the plant and its environment and between the various factors of the environment in themselves was almost enough to discourage any attempt at a complete analysis and understanding. To make it even more complex, there is, in many cases, an apparent compensation of one environmental factor for another. This will often occur near the boundaries of a species' range where it allows individuals of a species to occur in areas that do not appear to be normal habitat (Billings 1952). Since the environmental complex is so complicated, it has been customary to break up the environment into arbitrary factors and then study the effect of each factor on the seeded and endemic species. This approach is being used in my analysis herein.

Table 1—Climatic zones, showing major vegetational types and average annual precipitation in inches.

Climatic zone	Vegetational zone and associated shrubs and herbs	Average annual precipitation
		Inches
Lower Sonoran	Southern desert shrub: Blackbrush, creosotebush, Joshua tree, red brome, galleta grass	10
Upper Sonoran	Juniper and pinyon pine: Green ephedra, big sagebrush, antelope bitterbrush, bluebunch wheatgrass, Indian ricegrass	13
	Northern desert shrub: Big sagebrush, rubber rabbitbrush, Nevada ephedra, bluebunch wheatgrass, Indian ricegrass	10
	Salt-desert shrub: Black greasewood, shadscale, Gardner saltbush, bottlebrush squirreltail, alkali sacaton	9
	Salt-desert grassland: Inland saltgrass, alkali sacaton, Nuttall alkaligrass, creeping wildrye	9
Transition	Mountain brush-ponderosa pine: Gambel oak, bigtooth maple, black chokecherry, serviceberry	16
Canadian	Aspen-fir (canopy and opening): Mountain snowberry, slender wheatgrass, mountain brome, sticky geranium	25
Hudsonian	Subalpine herbland or spruce-fir: Red elderberry, western yarrow, letterman needlegrass, mountain brome	34
Alpine	Alpine herbland (above timberline): Cushion eriogonum, Scribner wheatgrass, red elderberry	40

Climate

Basically, climatic zones were first identified from studies of the distribution of vegetation. Various climatic values were then selected from within these vegetative types to determine if there were significant relationships between any of these climatic values and the represented plant community (Thornthwaite 1948). Daubenmire (1956) reviewed four of the most popular climatic classification schemes (and as proposed by Thornthwaite [1931, 1948]) and concluded that none of the four classifications proved adequate to define what appeared to be climatically determined vegetation zones located in eastern Washington and northern Idaho. He found that each vegetative type (or climatic zone) differed from its neighbors in the degree of summer drought, except at the wet end of the climatic gradient where lower summer temperatures became more influential. Therefore, it is generally thought that, within climatic regions or zones, quantity and seasonal availability of soil moisture, especially in the summer, are major limiting factors for the geographic distribution of plant species (Blaisdell 1958; Daubenmire 1974; Hansen and Churchill 1961; Krebs 1972; Oosting 1956). Soil moisture availability for plant growth is modified by changes in elevation, latitude, slope, or soil type. Thus, certain vegetational zones occur at higher elevations on south slopes or lower elevations on north slopes. These vegetational zones also have higher elevational limits on smaller mountains because they tend to intercept less moisture than the larger mountain masses (West and others 1975). Most dry or desert environments share two characteristics with regard to precipitation: it usually falls in one or two short seasons, and the amount received is unpredictable from year to year (Solbrig and Orians 1977).

Temperature

Temperature is one of the major factors limiting the distribution of plants (Krebs 1972). Mean annual temperatures are almost useless for ecological interpretations, for they do not indicate seasonal variation and duration. It has been shown that mean maximum and minimum values best describe the effects of temperature on plants (Oosting 1956). Temperature effects are modified by complex interactions among elevation, slope, position on the slope, aspect, and precipitation. Plant injuries from temperature changes are most often the result of freezing. Some species of browse seedlings are especially susceptible to frost damage. For example, this should be of concern if bitterbrush is to be planted and late frosts are common to the area being planted. Temperature variation (extremes) also greatly influence which species can best survive on a given site. For example, on some dry desert ranges, soil surface temperatures during the summer can range from 140 °F (60 °C) in the day to 40 °F (4.4 °C) at night. We have found that plant selections can be more easily moved from cool to warm environments than from warm to cool environments. To further illustrate the important effect that temperature has on some groups of plants, Hartley (1950) analyzed the distribution of the grasses of the world and concluded that temperature was much more important than rainfall in limiting species distribution. He also suggested that winter temperatures were especially critical.

Precipitation

Water alone, or in association with temperature, is probably the most important physical factor affecting the distribution of plants and plant communities (Krebs 1972) (table 1). Differences in rainfall patterns, whether in seasonal distribution or annual total, are reflected by differences in the naturally occurring plant populations (Daubenmire 1956). The season of precipitation, and the form in which precipitation is received, are important characteristics to consider when planning a wildland restoration or rehabilitation project. The vegetation in areas having significantly different precipitation patterns can be expected to have only a few species in common (Daubenmire 1974; Weaver and Clements 1938). In the Intermountain Region, many areas receive most of the annual precipitation as snow during the winter. Other areas receive the bulk of their moisture as rain in the warm season. In still other areas, precipitation is evenly distributed between these two periods. Plants selected for seeding should have a life cycle compatible with the precipitation pattern of the planting area. Most of the annual precipitation in cold deserts is received when temperatures are too cold to permit growth (Fetcher and Trlica 1980). Therefore, winter precipitation is believed to be most important for plant growth the following year (Wein and West 1971). There, adapted species must be able to complete their life cycle before the winter moisture is depleted or enter into a dormant state that is tolerant of severe drought. Stevens and others (1974) have shown that May precipitation has a greater significant effect on forage production than does precipitation in any other months. When most of the precipitation comes during the spring and summer, evaporative losses can be larger. If the precipitation arrives in light, scattered storms, little may remain available for plant growth. When rain falls in high intensity downpours, heavy runoff may result and leave little to wet the soil (Weaver and Clements 1938).

Many researchers have shown that the amount of precipitation has a direct effect on plant production regardless of whether the community is dominated by grasses, forbs, shrubs, or complex mixtures of these life forms (Blaisdell 1958; Currie and Peterson 1966; Jordan 1983; Kindschy 1982; Martin and Cable 1974; Sneva 1977; Stevens and others 1974; Wein and West 1971). Annual herbage production in arid rangelands can vary by several hundred percent as a result of variation in precipitation (Hannay and Lacy 1931).

An introduced species that is long-lived and easy to establish may not have a problem matching its life cycle to the season in which precipitation is received. Plummer and others (1968) determined that the average annual precipitation must be at least 9 inches (228 mm) before artificial seedings can be expected to be successful.

Soils

Under a given climatic regime, edaphic factors can strongly influence the kind and amount of vegetation produced (Gates and others 1956; Martin and Cable 1974; Passey and Hugie 1962a). To illustrate the importance of soil in plant development, a series of plants were moved to common gardens, where individuals of several species were grown on each soil type. It was determined that the differences in soil could affect plants in the following ways: germination success; growth, size; erectness of plants; plant vigor; stem woodiness; root depth; amount of pubescence; susceptibility to drought, frost and parasites; number of flowers; and date of flower appearance (Marsden-Jones and Turrill 1945). One could consult other literature and probably extend the list indefinitely. The concept to emphasize is that soil conditions can and do affect many aspects of plant development.

Most rangeland soils are normally low in nitrogen, phosphorus, and sulfur (Eckert and others 1961a; Evans and Neal 1982; Wagle and Vlamis 1961). Wagle and Vlamis (1961) found that because bitterbrush was able to fix nitrogen, soils low in nitrogen did not appear to impair that plant's performance, but soils low in phosphorus and sulfur did. Therefore, properly inoculated species capable of fixing nitrogen should not need N-fertilizer in soils deficient in nitrogen. Such species could also be of benefit to associated species that do not fix nitrogen. Mineral uptake can be expected to be affected not only by the chemical nature of the soil, but by temperature, soil moisture, light, and soil texture as well (Ames and Kitsuta 1933).

Under conditions of similar management and precipitation, fine textured soils characteristically support more perennial grasses and fewer shrubs than do coarse soils (Martin and Cable 1974). Wyckoff (1973) found that the primary factor limiting plant species diversity in a desert grassland appeared to be soil texture. He said the loamy soils consistently supported more species than adjacent sandy soils because of the probable increase in microenvironment diversity associated with the heavier soils. However, soils with either too high silt or clay content, or both, retard growth by increasing the extent and degree of branching of roots (Weaver 1919).

With regard to soil texture and related soil moisture availability for plant growth, sandy soils have the most favorable regime in arid regions. For a given amount of added free water, they are wetted more deeply, release more of the absorbed water to plant roots, lose less moisture to evaporation, and have less surface runoff. Therefore, 80 percent of moisture infiltrating sand is available for transpiration of plants (Daubenmire 1974).

High amounts of soluble salt in the soil reduce water uptake and may inhibit uptake of magnesium (Mg), potassium (K), and phosphorus (P). Nitrogen deficiency symptoms may also appear (Kleinkopf and others 1975). Gates and others (1956) found that the major significant difference between some Great Basin plant community types was the amount of salt in the soil. Plummer and others (1968) determined that soils with more than 1 percent soluble salts are usually not suitable for revegetation efforts.

The effective depth of the soil may be shallow, or somewhat restricted by the presence of a hardpan. Hardpan can form from clay, calcium carbonate, calcium sulfate, oxides of iron, aluminum, or silicon. Hardpans are common in soils of the drier areas of the Intermountain area (Daubenmire 1974). Because hardpans are essentially impervious to roots, they often determine the effective soil depth and types of plants that grow in a particular habitat. The growth rate of trees tend to vary directly with the depth of loose soil above a hardpan layer (Coile 1952).

Terrain

Elevation will have a direct effect on temperature by lowering it approximately 3 °F (1.1 °C) for each 1,000 ft (305 m) rise in elevation (Oosting 1956). Elevation also has a direct effect on precipitation received. Lull and Ellison (1950) determined that in central Utah, one should expect to receive an additional nearly 5 inches (127 mm) of precipitation for each 1,000 ft (305 m) rise in elevation.

When precipitation is received, slope, smoothness of slope, position on slope, vegetation, and soils interact to control the amount of runoff and water infiltration, which in turn affect plant growth and survival. Slope aspect and steepness also affect solar radiation received and thus the temperature at and near the ground surface (Farnes and Romme 1993).

Slope and exposure also influence amount and type of soil accumulated. Southern slopes usually have coarser soils with lower water-holding capacity than the finer textured northern slope soils (Krebs 1972). For example, in two or more areas, essentially the same in soil, cover, and precipitation, differences in soil water content were directly determined by differences in slope (Krebs 1972; Oosting 1956). Consequently, topography affects vegetation indirectly by modifying other factors of the environment (Oosting 1956). Different combinations of slope and exposure have great effects on the temperature of arid soils.

The mountains will modify precipitation patterns, airflow, and wind exposure. Local topography, with its different slopes, bluffs, ridges (with different exposures), lowland drainage lines, and depressions produce different combinations of light, temperature, and moisture that combine to produce local divergence of plant life forms and species in the Intermountain West.

Most wildland rehabilitation or improvement projects have been undertaken on fairly flat terrain, or on slopes of less than 30 percent. In recent years, steeper, rocky slopes are being rehabilitated. Topographic variation complicates the formulation of seeding mixtures and the prediction of composition of the new plant cover.

Discussion

Many researchers have concluded that plant distribution is primarily controlled by varying combinations of climatic factors and secondarily by edaphic factors (Billings 1951; Gates and others 1956; Mason 1936; Shantz 1938). Mason's (1936) conclusion that single factors or combinations of several factors could restrict the range of a species must be considered by revegetation scientists.

The effects of habitat on the plant, and of the plant on the habitat, are mutually complementary and often very complex (Weaver and Clements 1938). A plant is at once affected by the amount of heat, light, moisture, and nutrients available to it. Its life processes must go on under numerous and fluctuating variations in the environment. Plants selected for revegetation must be adapted to an ever-changing, wide range of environmental conditions. Because numerous factors operate on an organism simultaneously, each life function is a multiconditional process (Daubenmire 1974). With identical combinations of environmental conditions repeated only at rare and irregular intervals (Livingston 1934), a plant must have broad tolerance limits to be consistently competitive. The intensity of most environmental factors varies with the hour, day, and season; the rate of change, duration, and intensity of extreme values are all ecologically important aspects of the environment.

Competition undoubtedly is greatest between seedlings because of the restricted environment near the soil surface. Seedlings are especially vulnerable to the vagaries of environment. This is why many wildland plants have evolved the characteristic of seed dormancy. Successful growth of container grown plants is not a safe guide to success of seeding of these species on the same site.

Normally, successful plant establishment in an area depends on recognition of factors (climate, soil, and terrain) critical for seedling establishment. Proper composition of the species mixture sown will also affect the success of revegetation at any site.

How can one determine if the environmental conditions are adequate for the species in question? With an increase in altitude, there is an increase in precipitation and a decrease in temperature that is reflected in the natural altitudinal zonation of native vegetation. There are also zones of vegetation that reflect differential response to increasing concentrations of soil salts as one goes from higher to lower elevations. These two factors interact (elevation and salinity) and generally parallel each other as one descends into any one of the many closed basins within the Great Basin. Branson and others (1967) also noted that in addition to increased aridity and salinity with the descent into each basin, soil-particle sizes tend to become smaller as one approaches the playas. Fine textured soil can be expected to produce more severe soil moisture stresses (Branson and others 1967, 1976).

It is generally understood and has been demonstrated (Billings 1949; Fautin 1946) that shadscale is usually indicative of climatically dry, as well as physiologically dry soils. Billings (1949) showed the relationship between the presence of big sagebrush and higher available soil moisture. His data indicated that from central Nevada to eastern California, the mean annual precipitation for the shadscale zone was only about 5 inches (127 mm), while the mean annual precipitation for the sagebrush zones in northern and western Nevada was about 9 inches (229 mm) or more.

Conclusions

How can one put all these interacting factors into some kind of logical approach to help determine whether a site may warrant rehabilitation efforts? First, and most important, the amount and timing of precipitation in association with the occurrence of indicator species are important guides to species that may be successfully planted.

The presence of juniper and pinyon indicates the availability of adequate moisture for most of the commonly seeded species. Juniper-pinyon woodland normally occurs from 4,500 to 5,000 ft (1,400 to 1,500 m) to 7,000 to 7,500 ft (2,100 to 2,300 m) elevation (Springfield 1976; Woodbury 1947). The extreme range can be as low as 2,500 to 3,200 ft (760 to 980 m) (Franklin and Dyrness 1969; Johnsen 1962; Woodbury 1947), and the upper limit approaches 10,000 ft (3,000 m) (Lanner 1975; St. Andre and others 1965). There is a general tendency of junipers to extend below the pinyon component (Lanner 1975). The lower elevational limits appear about where the precipitation reaches the 10 inch (254 mm) point (Woodbury 1947). Generally, the annual precipitation is about 12 to 13 inches (305 to 330 mm) (Phillips 1977; Plummer and others 1968). The annual mean can range from about 8 to 10 inches (203 to 254 mm) (Dealy and others 1978; Phillips 1977; West and others 1975) to 20 inches (518 mm) (Dealy and others 1978; West and others 1975). The best developed woodlands occurs between 12 and 18 inches (305 to 457 mm) of precipitation (West and others 1975). Sagebrush not only occurs at elevations that juniper-pinyon occurs, but usually at higher and lower elevations beyond its normal limits (Woodbury 1947).

As the relative importance of pinyon increases, precipitation can usually be assumed to increase. Conversely, as the importance of pinyon decreases on undisturbed sites, the amount of precipitation can also be assumed to decrease.

The presence of appreciable numbers of shrubs that normally occur in the mountain brush zone (this could include Gambel oak, true mountain mahogany, and mountain snowberry) usually indicates favorable moisture conditions for most seeded species. Above or within the mountain brush zone, moisture is not usually a problem. At higher elevations the primary problem is selection of species tolerant of the cooler temperatures.

As one approaches the lower bounds of the juniper woodland association, potential available moisture can be predicted from the associated subspecies of big sagebrush. Winward (1983) showed that the subspecies of big sagebrush can be used to indicate the degree of droughtiness of a site. Wyoming big sagebrush is the most xeric of the group, followed by basin big sagebrush, and then mountain big sagebrush. The presence of Wyoming big sagebrush also indicates that the soils are relatively shallow and well drained with conditions that are generally warmer than those experienced by the other two subspecies. When black sagebrush and Wyoming big sagebrush are found in the same area, it indicates a more shallow or restricted soil than would normally occur in the Wyoming big sagebrush type only (Hironaka and others 1983). Basin big sagebrush generally grows on deeper soils that are well drained. If it is found growing adjacent to stands of Wyoming big sagebrush, it will occupy the more mesic sites. Mountain big sagebrush is found throughout the upper foothill and mountain areas. Some populations will grow on the lower foothill and bench areas where soil moisture is available for most of the summer. It is not uncommon to find 40 or more plant species associated with mountain big sagebrush. Where sagebrush is displaced by dwarfed salt-desert shrubs, either shadscale or Gardner saltbush, the site will probably be too dry to justify rehabilitation measures. Where available moisture is near the minimum limit, species that can be seeded successfully are limited. At such sites, one should be cautious with selections of species, site preparation, and seeding equipment.