Environmental Studies 30 -- The Global Ecosystem
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LECTURES 7 & 8. The Arid and Semi-Arid Biomes. Subtropical Deserts, Temperate Deserts and Steppes.

Introduction. Despite great variety and wide distribution (see **Figure 7.1**), the world's deserts, semi-deserts and grasslands have many adaptations in common. The main adaptive problem is **water conservation**, of course. Semi-arid and arid biomes are very generally defined by climates with a potential evapotranspiration to precipitation ratio of 1 or more (PE ratio). Nevertheless, the water problem can be solved in an amazing number of different ways by plants. Desert vegetation differs a great deal depending not only on the precise amount of rainfall, but also on timing and reliability of the rainy season, soil conditions, groundwater availability, temperature and humidity. Steppes (temperate grasslands) are much more uniform, often exhibiting simple patterns of large-scale zonation.

Animal adaptations to drought are also quite variable. In addition, deserts have such low productivity that energy is a strong limiting factor as well. On the other hand steppes resemble savannas in supporting a very large biomass of herbivores. Thus, for animals the rainforest-savanna and desert-steppe gradients are somewhat similar, as different as they are for plants.

The Arid and Semi-Arid Biomes

There are two climatic gradients that differentiate the water-limited biomes, the degree of drought and temperature. The first is obvious, but the important role of the latter is less well appreciated. By our PE ratio definition, parts of the savanna ecotone between the Tropical Deciduous Forest Biomes and the drier parts of the Mediterranean Biome are semi-arid. The two Biomes we will consider today, Subtropical Deserts and Steppes, fall within this rather arbitrary definition almost entirely. Each of these has a distinctive subtype, that could arguably be classified as a separate biome, the Coastal Fog Deserts of the tropics and the rain-Shadow or Continent Deserts of the temperate zone. After defining these biomes on a climatic basis, we will compare the plant, animal, and human adaptations to them.

A. Typical Subtropical Deserts (Figure 7.2)

Climates under the influence of subtropical high pressure.

1. Mean temperatures above 0°C for all months, but winters noticeably to somewhat frosty.

2. Summers hot to very hot.

3. Very low relative humidity.

4. Seasonal distribution of rainfall quite variable. Some deserts (e.g. American Southwest) get mid-latitude cyclonic storms in winter, and tropical storms ultimately spawned in the ITCZ in the summer. The more equatorward deserts mainly get summer rain from the fringes of the ITCZ only. Deserts on the fringe of the Mediterranean regions have only winter rain.

5. Total rainfall is low though variable from desert to desert. The subsidence (descent) of air in the subtropics (see Lecture 1) inhibits the formation of clouds and precipitation (which require ascending air). This air is also very dry. Under these conditions, the air is said to be "stable." The moistest examples of the Subtropical Deserts occur where continents are small. The driest examples are in the Central Sahara, where rainfall is lacking for many years at a time, because continentality contributes to aridity.

B. **Tropical Fog Deserts (Figure 7.3)**

The extreme maritime deserts under the influence of cold currents, plus the Subtropical Highs.

1. A nearby ocean is usually a guarantee of at least some rain. Whenever the wind blows onshore, even from local breezes, the heating of moist air leads to convective showers. Two prominent exceptions occur in Namibia (Southwest Africa) and in Northern Chile and Peru, where very cold currents occur offshore, In these places, the warm, humid maritime air from the Pacific or Atlantic pass over the currents, and is chilled. Fog condenses and moves ashore, but so much heat and latent heat are removed from such air masses that heating by the sun alone is insufficient to destabilize the moist air and create showers. In addition, these areas are either under or within the edges of the subtropical high. Both areas are "protected" from moist air from the east by the bulk of the continent. The Peruvian Desert, particularly, extends far northward, almost to the equator, and is separated from the maximum- rainfall areas of Amazonia by only a couple of hundred kilometers.

2. Contrast with typical Subtropical Deserts

   a. Temperature extremes, both daily and seasonal are greatly reduced.

   b. Temperatures, even at sea level, are comparatively cool. The climate of Lima is more reminiscent of Los Angeles summer, than of West Africa at the same latitude.

   c. Although rainfall is negligible, humidity is high, with many days of fog. These deserts are generally as lifeless as the central Sahara. In some locations there is enough fog drip for vegetation to occur, usually thin grasslands, in Peru called "lomas," but occasionally small woodlands.

   d. Away from the the coast, these deserts grade into the more typical Subtropical Deserts or the Tropical savannas.

C. **Typical Steppe (Figure 7.4)**

Steppe climates are temperate and generally continental, occurring in the centers of the large continents, North America and Eurasia. As rainfall drops to a PE ratio of 1 far from oceanic influences, forests give way to the grass-dominated Steppe Biome. Small steppe regions also occur in South America (the Pampas of Argentina) and in New Zealand.

1. Temperatures are cold in the winter, with at least some months having means below 0°C. Summers are mild to warm, with a fairly long growing season (120 days).

2. Precipitation occurs throughout the year, with snow in the winters and a summer rainfall maximum. However, late summer rain is generally insufficient to support full photosynthetic activity and the vegetation becomes dormant from drought before the first frosts.

D. **Temperate Desert Steppe (Figure 7.5)**

Temperate zone deserts occur where even greater distance from the ocean or where mountain ranges deepen the continentality of the typical Steppe regions. The rain shadows cast by the mountains reduce rainfall to the point where grasses are replaced by shrubs (often Artemesia sagebrush). The largest extent of Temperate Deserts are the Central Asian Deserts, south and east of the Steppe proper. These deserts are both a great distance from the Atlantic to the west and are in the rain shadow of the Himalayas. Our Great Basin between the Sierra Nevada-Cascades and the Rockies, and the Patagonian desert in the lee of the Southern Andes are the other examples.

1. Temperatures as in the Steppe, but with sharper diurnal fluctuations. Many of these deserts are fairly high, so mean annual and winter temperatures may be low for this reason as well.

2. Rainfall ranging from about 250 mm as it grades into more typical grass dominated steppe, down to well below 100 mm in the extreme examples of central Asia.

Physical Factors in Arid and Semi-Arid Areas

A. Rainfall

As the absolute amount of rainfall decreases, the variability of rainfall increases. In extreme deserts, the near zero annual mean is hardly an informative number at all. Most years have rainfall well below the mean, but a few years have much more than the mean (see **Figure 7.6**).

Plants and animals must adapt to this variability as well as the low average amount of water. Welwichia plants of the Namibia have a simple solution to this problem. Its leathery strap-like leaves lengthen when it rains, and dry back almost to the meristem after a succession of dry years.

B. Soil Conditions

In the desert regions, soil forming processes are very different from wetter regions. The parent material is more important, because weathering is less complete, and leaching by water is almost absent. Physical processes like water transport and wind erosion are more important because of the lack of plant cover.

A close association between climate, soil character and plant cover fails in the desert. As a consequence, desert vegetation is edaphically determined to an unusual degree. Stony deserts favor the development of shrubs whose extensive roots tap water stored at depth. Sandy soils favor annuals and grasses because sandy soils hold most of the sparse rainfall within easy reach of intensive root systems, but minimize evaporation from the surface. Dunes of pure sorted sand hold water, but shifting dunes are lifeless because of the unstable substrate. Often sandy areas are partly stabilized by grasses or shrubs that trap a mound of sand and just manage to grow a little faster than the mound.

On the other hand, semi-arid Steppes develop characteristic chernozem soils as enough water becomes available to cause leaching and permit plants to minimize wind and water erosion. Soil science was developed by Russians like Dokutchaev (1846-1903) from their studies of steppe soil development.

C. Topographic Effects

The small amount of desert water undergoes a surprising amount of horizontal movement, partly because the soils are hard to wet, partly because the vegetation does not moderate rainfall, so a sudden shower may cause much runoff, and partly because coarse desert soils permit free flow of ground water. Small variations in relief often cause very substantial differences in groundwater availability. In extreme deserts the only vegetation may be along drainage channels where water is concentrated during the rare showers. Water collection and water loss areas, hillsides and canyon bottoms, often have very different vegetation (**Figure 7.7**).

D. Salt Balance

A general excess of evaporation over rainfall means that deserts generally export little water from large regions. They are often internal drainages with no river connection to the sea. A low point in the basin collects the available runoff, and it evaporates, leaving its dissolved salts behind. The lower parts of deserts thus often have large areas with salty soils, especially when the already salty ground water can rise to the surface by capillary action. When deserts have water, it is often bad.

E. **Temperature Extremes**

Clear air, low humidity and a lack of open water bodies cause deserts to have extreme diurnal temperature changes. The record is the Central Sahara, at Bir Mighla which once had a 38°C daytime maximum, and a -.5°C minimum in the same day, (30°-100°F). Radiation losses at night and gains during the day make these differences even more extreme than the shelter temperatures suggest.

Both plants and animals, but especially the animals, show elaborate adaptations to these extremes. A good example is the tenebrionid beetle fauna of the Namib. Most of the beetles are black, and use their color to warm up quickly in the morning. After a few hours of activity in the relative cool and humid morning, they burrow into the sand to escape the heat of the day. Some species prolong their activity by various expedients, such as long stilt-like legs to stand above the very hot boundary layer next to the ground.

<u>Plant Adaptive Types</u>

A. **Poikilohydric Plants**

Some ferns, lichens, mosses and even algae survive by simply dehydrating their tissues. Desert algae live under clear or translucent stones, or even <u>in</u> the porous stone in the Antarctic deserts.

B. **Ephemerals**

These plants survive the dry season as seeds, sprouting and growing quickly when water becomes available. Some of them are extremely tiny and can make a crop of seeds in a few weeks from one or two fair rains. When our deserts are carpeted with flowers, it is the ephemerals that make most of the show. In the more extreme deserts, these plants build up a seed store in the ground that may be replenished by growth only a few times a century. Even in the less extreme cases, success varies greatly from year to year.

C. **Bulbs**

Some desert plants use underground storage organs, such as bulbs, instead of seeds to survive the dry period.

D. **Deciduous Shrubs**

Among desert shrubs, seasonal shedding and regrowing leaves is an obvious, but relatively uncommon method for coping with annual drought. But deciduousness is found among evergreen shrubs in times of extreme and prolonged drought.

E. **Sclerophyll and Malakophyll Xerophytic Shrubs**

One of the commonest desert adaptations. Small, waxy evergreen hard (**sclerophyll**) or soft (**malakophyll**) leaves that resist water loss. During the dry season, the stomata close, the plant minimizes transpiration, and merely waits for the rains. An extensive root system penetrates deeply to find a small amount of water to make up losses in the dry season. <u>Larrea</u>, the creosote-bush, of the California and Argentina deserts is an example of sclerophyll. Sagebrush (<u>Artemisia tridentata</u>) and Rabbitbrush (<u>Chrysothaumnus</u>) are typical malakophylls.

These kinds of xerophytes dominate most deserts rather than deciduous shrubs probably because the short duration and unpredictable nature of the rainy season puts a premium on being able to start photosynthesis as soon as water is available. Typical growing seasons are too short to favor the more slowly responding deciduous vegetation, particularly when the plants cannot leaf out in secure anticipation of good rainfall.

F. Succulents

This is the classic desert adaptation, which sometimes obscures the fact that xerophytic shrubs are more common in deserts and that succulents occur elsewhere (as epiphytes in wet tropical forests, for example). Succulents store water in leaves (agave), stems (cactus), or roots (asparagus). They use an extensive, shallow root system to collect water during a rain, and use the stored water to maintain a steady, slow rate of photosynthesis the rest of the time. Leaf area is greatly reduced, or leaves are entirely absent. Many of such plants have crassulacean acid photosynthesis. They open stomata at night, when transpiration is reduced by lower temperatures and higher humidity, and store CO_2 as organic acids. Photosynthesis during the day proceeds with stomata closed. Photosynthesis by this pathway is quite slow, but makes efficient use of available water.

G. Phreatophytes

Plants which reach deep ground water with long roots. Tamarisks, mesquites, and acacias can form little woodlands in the desert by this method.

H. Halophytes

Plants such as pickleweed, Atriplex, and saltgrass which have high salt concentration in the leaves to balance the osmotic potential of salty soils. Adapted to salt and alkali deserts.

I. Oasis plants

Plants that have no special water conservation adaptations, but grow where freshwater is available in abundance. Palms, willows, and cottonwoods are examples.

J. Perennial herbs and grasses

Almost absent in the deserts, these plants become the dominants on the steppes. Perennial grasses, first bunch types in the steppe-desert transition, then turf-forming types in the wetter areas, dominate. Bulbs and a profusion of forbs, the latter often with deeper taproots to compete with the shallow, intensive roots of the grasses, are often sufficiently common to provide beautiful flower displays.

The steppe vegetation is dormant from late summer, when drought overtakes it, until snowmelt in the spring. The grassland vegetation of the steppes is analogous to that on the savannah-desert ecotone in the tropics. Whenever rainfall is sufficient to permit the extensively rooted grasses to intercept and use most of the moisture, the shrubs of the desert disappear. On the desert-steppe ecotone, overgrazing often causes shrub invasions as the grasses are exploited to the point where enough water remains for shrubs to grow. In the Great Basin, grazing favors sagebrush; in the Southwest, the invasion of mesquite. As with the savannah - tropical forest ecotone, the steppe forest ecotone is controlled by fire. When settlers in the early 19th Century suppressed wildfires in the wetter prairies of Wisconsin, Illinois, and Ohio, forest area increased dramatically.

Most lawn and pasture grasses and legumes have been domesticated from steppe ancestors, except the hot climate grasses like Bermuda grass that come from the savanna.

Animal Adaptations

A. Ephemeral Animals

Insects and other arthropods are prominent components of arid and semi-arid faunas, partly because they are adapted to exploit the seasonal and irregular pulses of production, surviving the dry season in some sort of resting state. A few good years in succession may cause dramatic outbreaks, as with grasshoppers (locust plagues).

B. Seed Specialists

Desert plants adapt to climatic uncertainty by diverting a disproportionate amount of production into seeds. Animals that must survive long periods of drought without becoming dormant are often seed collectors and storers. Ants, and rodents like Kangaroo rats, are good examples.

C. Nocturnal Habits

Many hot-desert animals are active only at night to conserve water. Snakes, particularly venomous ones, are particularly successful predators in deserts because of the predominately small prey, such as rodents, that can be hunted with ambush tactics at night. The pit-vipers (rattlesnakes and their allies) are particularly effective at this work, using their heat sensing organs to locate mammalian prey. Scorpions work a similar trick on smaller, cold-blooded prey.

D. Poikilothermy

Reptiles are relatively successful in deserts, much as both reptiles and amphibians are successful in tropical forests. Relatively warm temperatures and sparse food favor the cheaper metabolism of these animals, and reptiles are also well adapted to withstand water loss through their skin. Insectivorous lizards, for example, can live on much less food than a shrew or a bird, do without free water to drink, and are adapted to permit a 30-40% loss of body weight during the poorest season of the year. Even reptilian herbivores persist in the desert -- chuckwallas and tortoises in our S.W. deserts for example. Cold deserts lack the variety of poikilotherms of the hot deserts and have a very low diversity of animals.

E. Big Herbivores

Almost absent in the deserts, the big-game becomes spectacularly dominant on steppes. The Pleistocene fauna of the steppes was fully as diverse as that of the tropical savanna. Despite other differences in climate, the steppes and savannas have many convergent adaptations to semi-aridity on the part of both plants and animals. Sadly, most of the steppe animals went in the Pleistocene extinction, and only relicts like the bison in North America, and cattle and horses in Europe and Asia survived to furnish many important domesticated animals.

The few big herbivores of the desert are either adaptable refugees from the steppes or savannas, or extreme specialists like the camels. Camels are convergent on the reptiles in some ways. Their body temperature fluctuates, they can lose a higher percentage of body water than typical mammals, and store large amounts of fat in their humps in order to survive the dry season.

Ecosystem Function

Primary production in all the arid and semi-arid biomes is nearly a linear function of rainfall (**Figure 7.8**), ranging from zero in the lifeless extreme deserts to very high levels in the tall-grass prairies on the wet fringe of the steppe. Even when growing seasons are short in the steppes, the vegetation is capable of using all the water remaining in the soil. When significant surplus water becomes available below the grass root zone, trees will generally invade.

Soil nutrients are also usually relatively high in these biomes. Low rainfall (and cool temperatures in the steppes) limit leaching and the weathering of soils. The lack of plant cover also favors erosion and wind transport of soil and most arid and semi-arid zone soils are young. Many steppe soils are derived from Loess, windblown debris from the terminal moraines of the continental glaciers of the last ice age, redeposited a few thousand years ago. Even today, loess may move in dust storms during droughts. Young soils rich in bases (e.g. $CaCO_3$) and clays are supplemented in the more productive steppes by a high organic matter content in the soil. Both clays and organic matter bind mineral nutrients and prevent losses by leaching.

As a consequence of good nutrient conditions, net primary production on the wetter steppes can be high -- up to perhaps 10 tons/ha of above ground dry production. Productive forests can double this value. The difference is that in the steppe half or more of the production is available to grazing animals, making secondary production the highest of any terrestrial biome.

The distribution of the biomass is also characteristically different in arid and humid regions. Forests have half or less of their total biomass below ground, whereas arid and semi-arid vegetation has well over 50% of the standing crop in roots and storage organs below ground. In steppes about 90% is in roots and only 10% in shoots.

Human Uses of Arid and Semi-Arid Biomes

A. Hunting and Gathering

Hunting and gathering people penetrated deep into the Subtropical and Temperate Deserts and Steppes and some of the remaining hunters still find refuge there (the San Bushman of the Kalahari). Julian Steward, one of the pioneers of human ecology, did a famous study in the 1930s reconstructing hunting and gathering adaptations to the Great Basin. In the driest areas, people were able to live in the desert only by spending most of the year seeking out plant resources as individual families, gathering together for rabbit hunts and other communal activities only during the winter. In better areas, like the Owens Valley where small rivers from the Sierra increased productivity, larger bands of 30 people or so were able to stay together throughout the year.

B. Livestock Raising

The classical human use for the Steppe was livestock grazing. We have mentioned pastoral nomads and ranching before. Very much livestock still comes from the Steppes -- although now closely confined pastures and dry-lot feeding are the rule. Grazing is also the primary use of the desert Steppe and the wetter parts of the Subtropical Deserts themselves. Even very dry deserts support some grazing in selected localities or in especially wet years. Herdsmen frequently develop elaborate systems of **transhumance** to exploit the more arid pasturelands. In the level desert, this may involve moving animals about over a wide area in search of the ephemeral vegetation produced by isolated, unpredictable rains. The Bedouin camel and sheep herders use this strategy in the Sinai and Arabian Deserts. Very often transhumance involves a more regular migration between lowlands and highlands. The desert vegetation is exploited early in the season, and the animals are driven to the mountains to exploit bits of summer pasture there. In some places, this seasonal round may involve trips of hundreds of miles. A form of transhumanent herding is quite common in the Great Basin. Cattle are pastured on irrigated meadows or given hay in the winter, grazed in the lowland sage communities in the spring and driven or trucked to the mountain pastures in midsummer.

Overgrazing is a severe problem in the more arid parts of the deserts and steppes. Cattle grazing often encourages brush encroachment, and herding goats with cattle or sheep may result in denudation. Some ecologists believe that denudation has a positive feedback aspect; denuded areas have higher albedo (reflection) and less transpiration. Thus the air may be robbed of the heat and latent heat necessary to drive thunderstorms, and the lack of rain may intensify. **Desertification** is a very serious problem on the edges of the Sahara (e.g. the Sahel) and Arabian deserts, although human effects are badly confounded with natural climatic fluctuations.

C. Farming

The prevalence of high quality soils in the Deserts and Steppes have attracted farming, despite the problems.

In deserts, the obvious problem is water, solved first in the Tigris-Euphrates area about 5,000 years ago by the development of irrigation. Irrigation has two classic problems, one social and one ecological. The social problem is that complex irrigation works require elaborate organization, and the state functionaries have extreme power over the peasants through their management of the irrigation works. Some of the world's most unattractive despotisms result. The ruins of the ancient civilizations are impressive, but we shouldn't forget that their grandeur was at the expense of their common citizens.

The ecological problem is soil salinization. The provision of water to desert soils brings dissolved salts, and high rates of evapotranspiration. A favorable salt balance in the root zone is difficult to maintain in the long run without expensive drainage works and provision of extra water to leach away the salt. Large areas of Mesopotamia disappeared from cultivation in antiquity due to this problem. Our own southern San Joaquin Valley is in the throes of a very serious salt balance problem that may remove a million acres from production in the next few decades.

The drier steppes also have sufficiently low rainfall to make agriculture difficult. In addition, the tough, strong-rooted grasses of the steppes make cultivation very difficult. The problems of agriculture on the steppes was solved only in the last few hundred years. Heavy draft horses and coultered, moldboard plows were eventually used to cut and turn the sod of the steppes. Once developed, the steppes are extraordinarily productive. The U.S. and the former Soviet Union both derive the bulk of their staple grains from the steppes. Rainfall agriculture can be pushed into the drier part of the steppes (e.g. West of the 100th meridian in the U.S.) either by irrigation or by summer fallowing. Summer fallowing involves cropping a field in alternative years. During the off year, the field is cultivated so that weeds do not use the rain of that year. A major part of the fallow year's rain can thus be stored in the soil for the subsequent crop year.

Steppe agriculture is far from trouble free. Uncertain rainfall is a serious problem, as with the Dust Bowl years in the midwest in the 1930s. The problem is much worse on the Eurasian Steppes, resulting in severe fluctuations in the former Soviet Union's and China's grain supply. The complex geopolitics of the world grain trade are in large measure tied to the peculiarities of steppe climates.

Land degradation is also a serious problem. Loess soils, especially, are very prone to erosion. The breaking of the tight grass root system has greatly accelerated erosion losses, and the sustainability of Steppe agriculture is in some doubt. The problem is especially severe in more arid margins of the steppes, where dust storm losses occur during droughts. In times of agricultural surpluses, the U.S. was able to retire much of the more marginal lands. Onto marginal and sensitive soils, high grain prices result in expanding cultivation other times. One of the major tests of the competence of modern civilization is whether we can maintain the great grain belts of the steppes in the face of these problems.

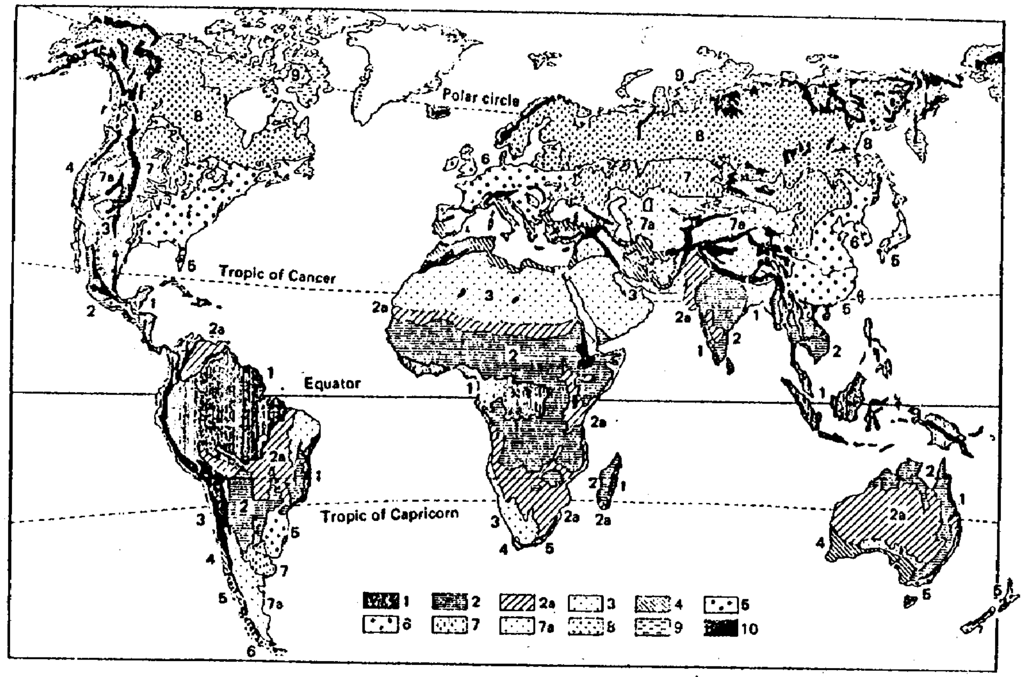


Fig. 13. Vegetational zones (much simplified, without edaphically or anthropogenically influenced vegetational regions). I. Tropical and subtropical zones: 1 Evergreen, rainforests of the lowlands and mountain-sides (cloud forests), 2 semi-evergreen and deciduous forests, 2 a dry woodlands, natural savannas or grassland, 3 hot semi-deserts and deserts, polewards up to latitude of 35° (see also 7 a). II. Temperate and Arctic zones: 4 Sclerophyllous woodlands with winter rain, 5 moist warm temperature woodlands, 6 deciduous (nemoral) forests, 7 steppes of the temperate zone, 7 a semi-deserts and deserts with cold winters, 8 boreal coniferous zone, 9 tundra, 10 mountains.

Figure 7.1

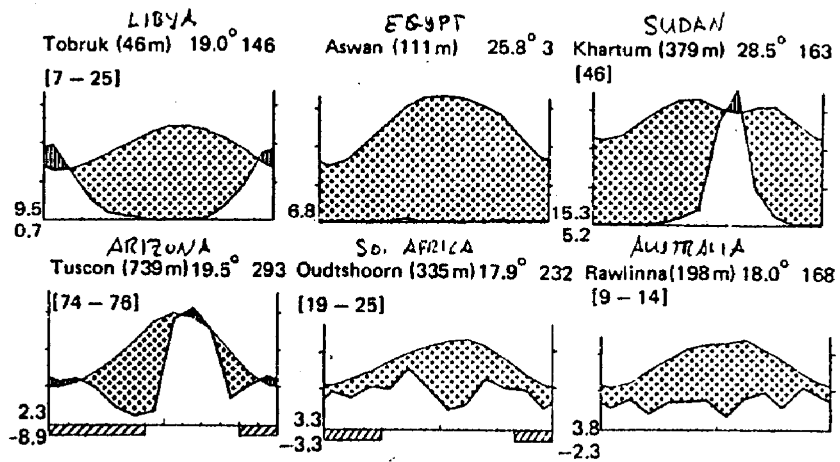


Fig. 41. Climatic diagrams of desert stations. Above, from North Africa with winter rain, no rain and summer rain; below, with two rainy seasons (Sonoran desert and Karroo) and some rain at all seasons (Rawlinna, Australia).

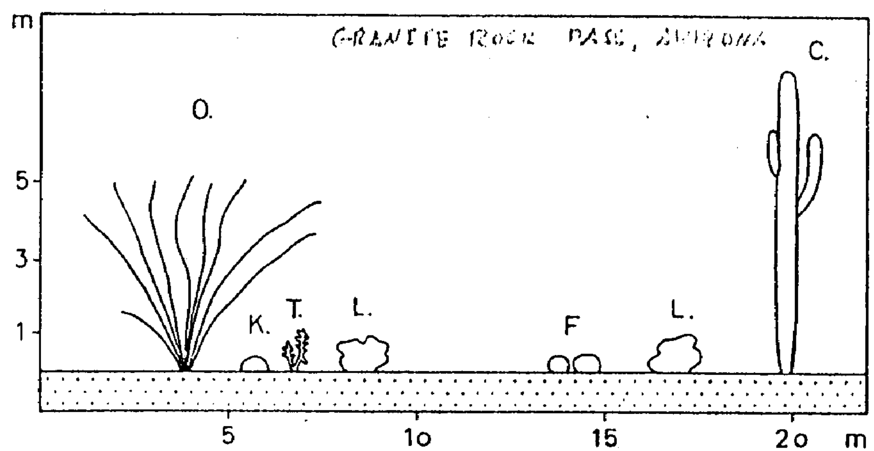


Abb. 135: Profildiagramm im Übergangs-Bereich zwischen Sahuaro-Säulenkakteen-Gesellschaften und Creosotbusch-Wüsten in Südwest-Arizona am Granit Rock Pass. **O** = Ocotillo (*Fouquieria splendens*). **C** = Sahuaro-Kaktus (*Carnegiea gigantea*). **K** = *Krameria grayi*. **T** = *Opuntia bigelovii*. **L** = *Larrea tridentata*. **F** = *Franseria dumosa*. Or.

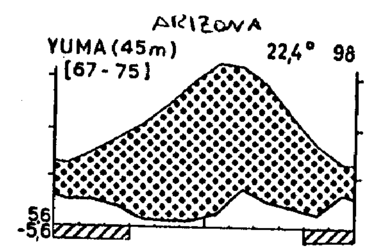


Figure 7.2 S̈ʼʼTROPICAL DESERT

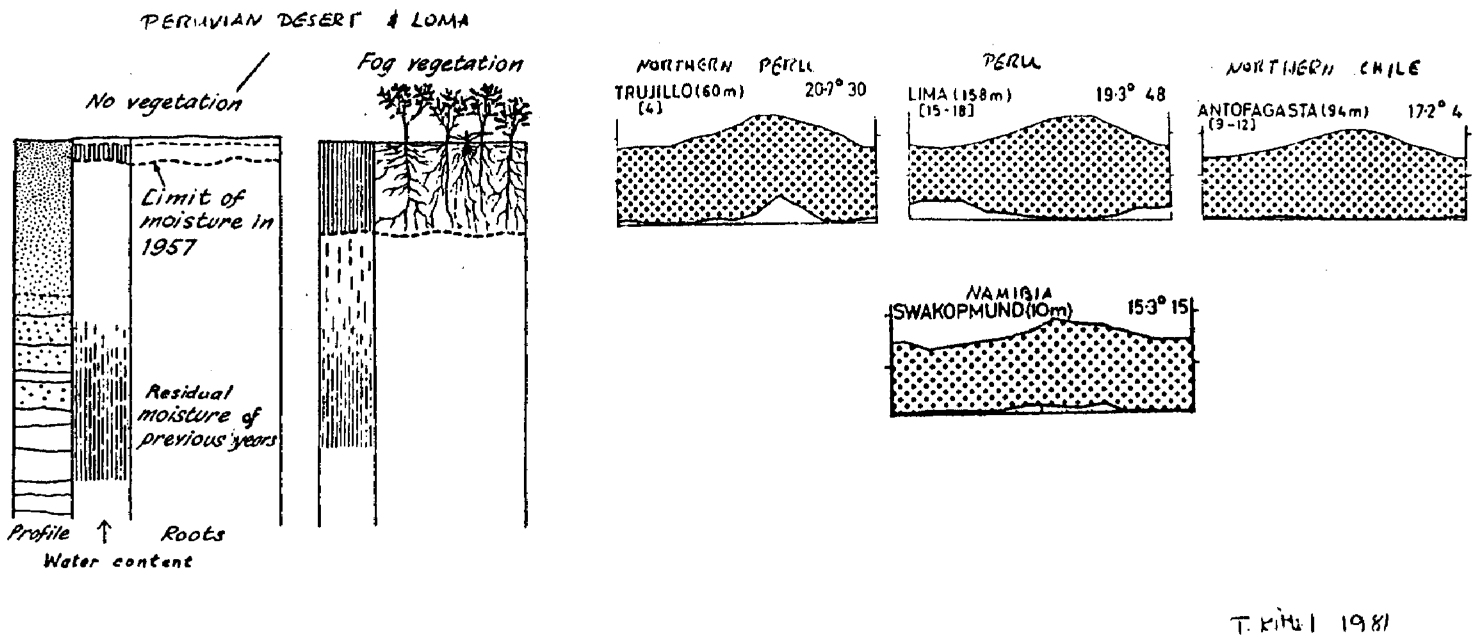


Figure 7.3 TROPICAL, COLD CURRENT DESERTS

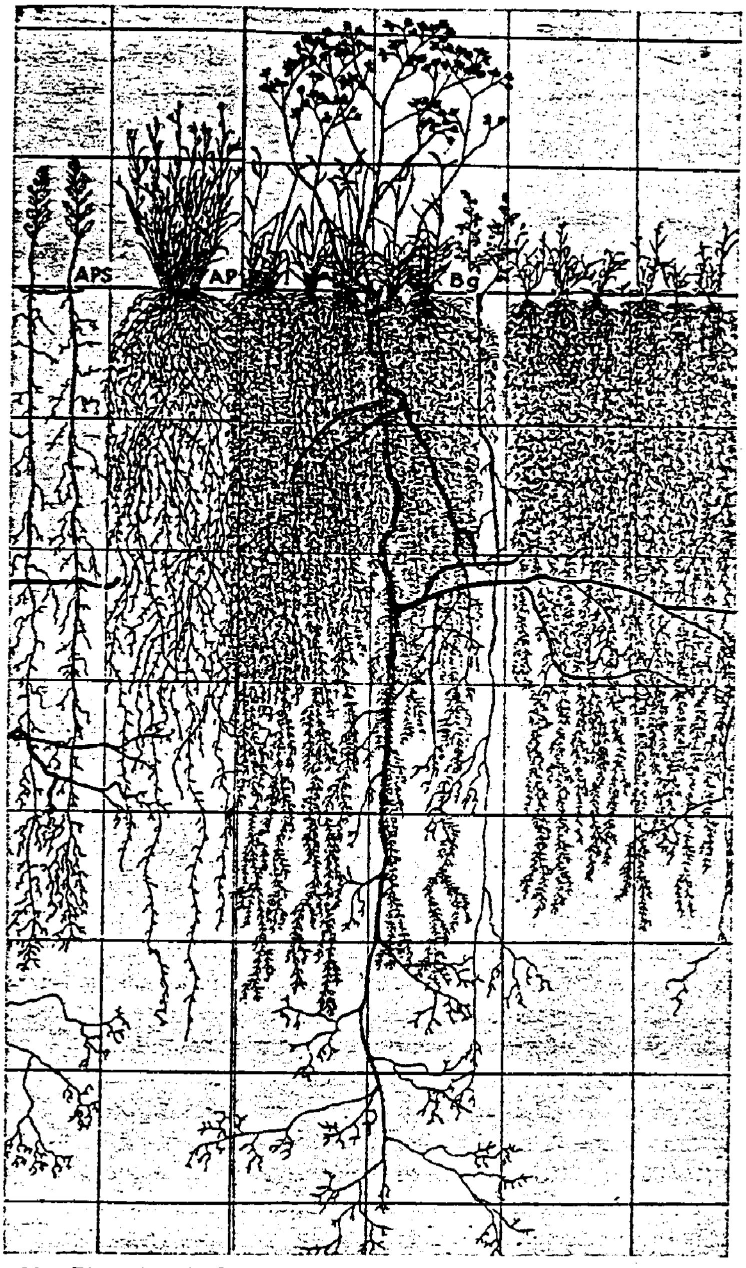


FIG. 26.—Bisect in mixed prairie at Hays in west-central Kansas. Each square is 1 foot in length. Buffalo grass on the right; *Bg*, blue grama grass; *Ap*, wire grass (*Aristida purpurea*); and *Aps*, western ragweed. The large legume in the center is *Psoralea tenuiflora*. (*After F W. Albertson.*)

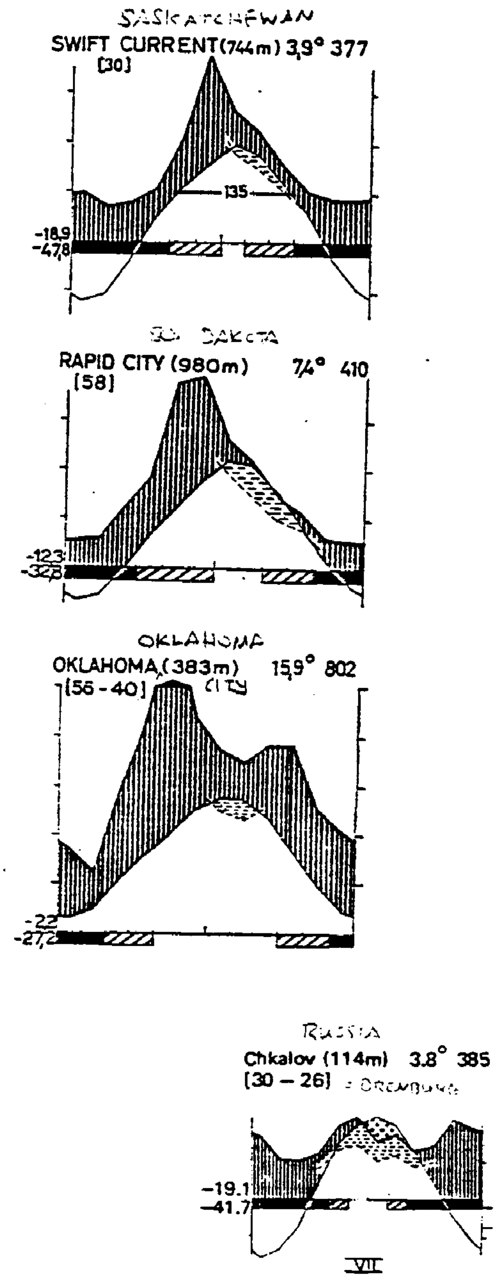
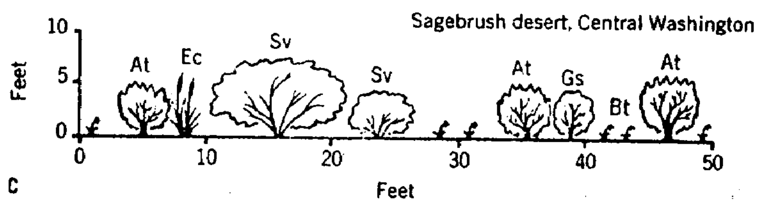


Figure 7.4 STEPPE



C. Cold desert: At, *Artemisia tridentata* (sagebrush); Bt, *Bromus tectorum* (cheatgrass); Ec, *Elymus cinereus* (giant wild-rye); Gs, *Grayia spinosa* (hopsage); Sv, *Sarcobatus vermiculatus* (greasewood).

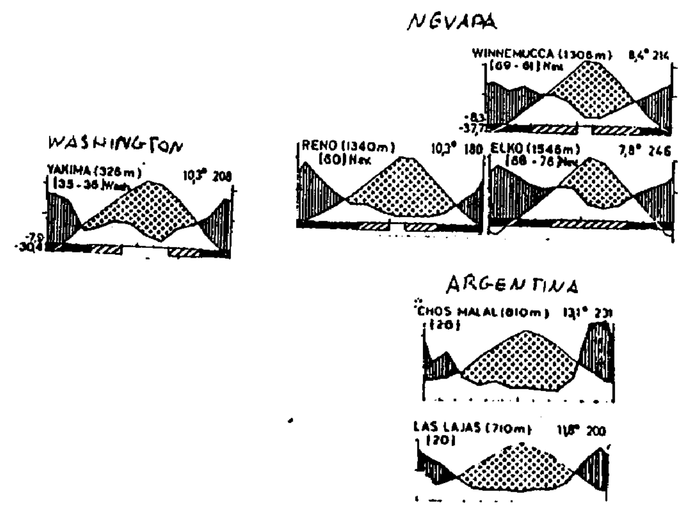


Figure 7.5 TEMPERATE DESERT

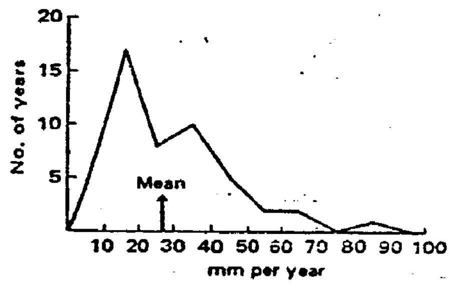


Fig. 45
Curve showing variability in annual precipitation near Cairo, between 1906 and 1953. (From Walter, 1973.)

Figure 7.6

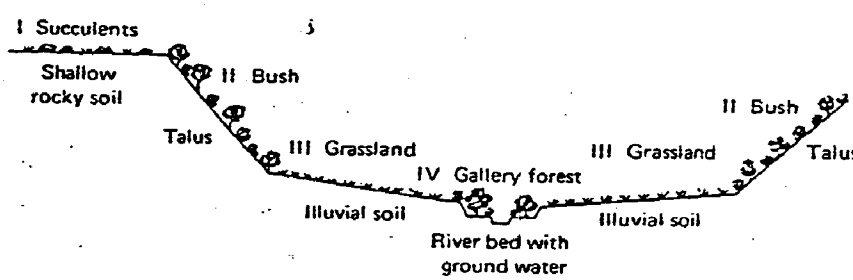


Fig. 45. Vegetation profile of a valley of the Upper Karroo near Fauresmith (South Africa). Distribution of the plant cover determined by differences in soil. Bush with *Oleo, Rhus* and *Euclea.*

Figure 7.7

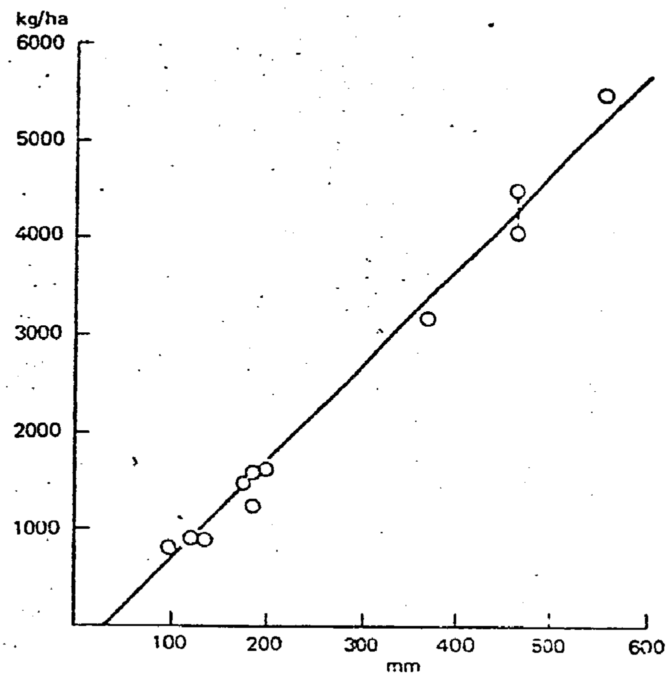


Fig. 36. Production (aboveground dry mass in kg/ha) of the grassland of S. W. Africa in relation to annual rainfall in mm.

Figure 7.8

Lectures 7 and 8: Discussion questions

1. In very arid areas, irrigation agriculture is plagued by salt balance problems and falling water tables. The semi-arid rainfall agricultural zones of the steppes are subject to severe soil erosion; the high quality loess soils are especially subject to both wind and water erosion. The dilemma is this: The short-term exploitation of these areas is highly profitable, and the costs of solutions to these slowly developing problems are very high. What should our policy for these areas be? Economists argue that if a benefit-cost analysis for the problem indicates that solutions are more expensive than benefits, we should just treat arid zones as non-renewable resources like minerals or oil. Conservationists of various pursuations argue that degrading potentially renewable resources for short-term profits is bad policy in the long run. How would you characterize the main policy isssues? What general principles would you favor for situations like this? How would you answer opposing arguments?

2. The competition between trees, shrubs and grasses leads to complex patterns of growth forms in arid and semi-arid areas. Why is the precise PET ratio and the details of soil texture so important in these biomes?