ENVIRONMENTAL STUDIES 30 -- THE GLOBAL ECOSYSTEM

P.J. Richerson

LECTURE 14: Mountain "Biomes"

Introduction

The patterns of vegetation on mountains mimic many features of the latitudinal distribution of low elevation biomes. The adiabatic cooling of rising air causes temperatures to fall up mountain slopes so that at high enough elevation even tropical mountains have permanent snow (at around 4500-5000 m near the equator). Sometimes the communities of mountain slopes very strongly resemble biomes at higher latitudes. In North America this resemblance was emphasized before the turn of the century by C. Hart Merriam who bestowed mountain life zones with names like "Canadian," "Hudsonian" and "Boreal." However, the altitude-latitude analogy can very easily be overdone. Merriam's scheme has largely fallen into disuse in recent years as ecologists and plants geographers have recognized its over-simplification. The problem is that mean annual temperature alone is completely insufficient to characterize the environment of plants and animals but it is the only parameter for which the altitude and latitude patterns are very similar. In every other way, mountain slopes either have environmental relationships to nearby low altitude areas, or have special characteristics of their own.

High-Altitude Environmental Conditions

I. Seasonality in Temperatures

Figure 14.1 shows some typical montane climate diagrams corresponding to the main biomes. Even when the mean temperature of a high altitude environment corresponds to a location many degrees of latitude poleward, patterns of temperature seasonality respond primarily to latitude. The same is true of light conditions. Tropical mountains have minimal seasonal fluctuations of temperature, and temperate latitudes moderate ones. Rainfall seasonality is also generally similar to the lowlands. On tropical mountains, the alpine environment is very different from the Tundra. Rather than the long cold, snowy winter and a brief, relatively warm summer of the Tundra, the tropical alpine is always very cold but seldom snowy. The snowline on such mountains is essentially static, fluctuating little through the year.

II. Light Intensity

Total light intensity increases up mountain slopes and the UV component becomes especially pronounced. (Atmospheric extinction of light decreases with altitude.) Except in the important misty belts, plants suffer correspondingly high radiation loads, often greatly in excess of those required for photosynthesis.

III. Evaporation

Biogeographers have been seriously misled by thinking of potential evapotranspiration as only a function of temperature. Lower atmospheric pressure in fact greatly increases evaporation rates. In addition, high radiation loads on leaves heat them considerably more above ambient temperatures, than at lower elevations. Thus potential evaportranspiration on mountains is surprisingly high.

The widely used classification system of Holdridge is deficient in this way. At the temperatures prevailing in the tropical Andes at about 4000 m, the Holdridge system estimates a potential evapotranspiration of round 400 mm. The measured values are something like 1500 mm. Where Holdridge predicts "moist woodlands" a semi-arid, steppe-like vegetation prevails. Unfortunately, the Peruvian Government chose the Holdridge system to make an ecological classification of the country. The resulting maps are very nicely done, but almost worthless!

IV. Rainfall

Mountains have very complex rainfall patterns. If there is a prevailing wind direction for moist air, the windward side of the mountain will be quite wet, and the lee rather dry. The Himalayas are a good example. The southern side, exposed to the warm moist air of the summer monsoon are extremely humid, containing stations that report world record (more than 10,000 mm) and near world record precipitation. On the north side are the Central Asiatic Steppe-Deserts with many stations reporting under 100 mm of rain.

The other effect is the tendency on the windward side of precipitation to first increase and then decrease up mountain slopes. As a moist air mass is lifted up the slope of a mountain, it cools adiabatically. The cool air can hold less moisture, clouds form, and it rains or snows. If it is already raining in the lowlands, the uplift by the mountains increases the rate at which moisture is extracted from the air. The term orographic precipitation is applied to this extra rain. However, as the air continues to cool, the amount of remaining moisture drops. Further cooling produces less and less precipitation. In the Sierras the precipitation maximum is at about 5,000-6,000 feet.

As the air mass passes the crest, it begins to warm as it descends. This adiabatic warming increases its ability to hold water vapor, but with no large moisture source the air becomes very dry. Additional orographic rain may fall on the higher mountains further down-wind.

In California winter storms persist longer in the mountains, and weak storms at sea level often produce significant precipitation at higher elevations. Often, it will rain at some elevations in the mountains when the air is insufficiently humid to produce a storm at sea level. Also the Sierras often have a little thunder shower weather in the summer when the lowlands are dry. **Figure 14.2a (from slide in lecture)-b shows rainfall patterns for California as an example.**

V. Soils

Soils forming processes are strongly dependent on temperature and rainfall. The cool, wet soils at medium elevation are often strongly podsolized, even when the lowlands are lateritic.

Examples of "Orobiomes"

I. Tropical Andean Orobiomes

The mountain vegetation belts of the Andes are good examples of elevation gradients in the tropics. Similar features occur on the tropical mountains of Africa (Kilimanjaro, the Ruwenzoris, Mt. Kenya) and in South East Asia (e.g. The Bismark Range in New Guinea). From east to west (wet to dry) we have the following main belts (Figure 14.3a-c shows a series of diagrams for different tropical mountains).

A. Lowland Rain Forest, previously discussed. In Latin America, this zone is called Selva Baja, (low forest), or Tierra Caliente (hot country).

B. Montane Evergreen Forest, Selva Alta (high forest), or Tierra Templada (temperate country): This forest begins at about 1000 m elevation. The vegetation is not strikingly different from the lowland forest, the climate is a bit cooler, but still frost free, and rainier than Selva Baja. If anything, the forest cover is more continuous than in the lowlands because good drainage on the slopes prevents the formation of open swampy communities or seasonally flooded grasslands. The increased rainfall also favors a greater abundance of lianas and epiphytes than in the lowland forest.

C. Cloud Forest, Tierra Fria (cold country) or Ceja de la Montaña (eyebrow of the mountain): Cloud forests form at 2000-2500 m and extend upwards 500-1000 m. This is the zone of maximum rainfall; it is cloudy or foggy most of the time in this region. Relative humidity is always high so epiphytes and lianas become still more important. However, now many of the epiphytes are ferns instead of the warmth-loving Bromeliads and orchids. This is also the zone of tree ferns and bamboo thickets on some mountains.

Between about 3500 and 4000 meters the Ceja Forest is gradually reduced to a scrub, rainfall begins to decrease, and the zone of frost is reached. The vegetation here is all of lowland tropical ancestry and is sensitive to both drought and frost. For some reason, perhaps historical, perhaps ecological, cool temperate species do not penetrate into the tropical mountains. There is no conifer belt close to the equator. The control of the treelines in the tropics is poorly understood. Almost as soon as frosts begin, there is a cycle of nightly frosts and daily thaw. The tropics lack much seasonality, so a low annual mean temperature means low temperatures every day, not a cold winter-warm summer cycle as in the temperate zones. It is not clear whether temperate zone conifers could easily adapt to such a climate, and tropical species certainly cannot. However, about the same elevation that frost becomes important, PE ratios rise to about 1 because of the declining rainfall and high evaporation. Just exactly how frost and drought interact to control the vegetation is a problem that awaits further research.

An important variant of Tierra Fria occurs in the mid-elevation interior valleys of the Andes, called the Quechua zone in Peru. These valleys are in the rain shadow of the eastern cordilliera (mountain chain) of the Andes. Here, rainfall is much less than in the eastern Cloud Forest, but the climate is still moist enough for rainfall agriculture. The heartland of the Inca Empire was in the zone, and previous smaller states reach back for thousands of years. Crops include potatoes, quinoa, maize and other native domesticates and European introductions. Eight or ten million Bolivians, Peruvians and Ecuadorians make their living as peasant farmers in this zone today. This zone has been heavily exploited for several millennia, and its natural vegetation is in some doubt. Presumably it was covered with a low, somewhat sclerophyllous woodland, to judge from the remnant vegetation.

D. Paramo and Puna, Tierra Helada (frozen country): Above the treeline, the Andes have two types of communities. The more moist areas are called Paramo and the drier ones Puna. The Puna is most important in the Altiplano, the large, high plain between the eastern and western subranges of the Andes. Lake Titicaca is near the northern end of the Altiplano. Paramos are distributed on the Eastern Cordillera, facing the moist winds from Amazonia, or are found clear across the more northerly high altitude belt where the mountains are narrower and the climate generally more humid. Paramos are continuously misty, but probably the vegetation suffers frequent drought stress from too little rainfall. The important plants include large bunch grasses (tussock grasses), and tree-like composites (sunflower family). In the Andes these are in the genus Espeletia. African and southeast Asian mountains have convergent forms from different genera of composites and other families. Candle plants are also common in Paramo; several genera of plants have converged on this adaptation as well in different tropical mountains.

The Puna zone is dominated by large, stiff-leafed bunch grasses, with other annual and turf-forming grasses in between. The vegetation is Steppe-like in appearance now, but probably had more small trees and shrubs in the past. The people who farm the Quechua zone graze sheep, llamas and alpacas very extensively in this zone, and severely deplete the woody species for fuels.

The snowline occurs in the Andes between about 4800 and 5300 m. The snowline is actually a little lower and closer to the equator in Ecuador and northern Peru than further south or north. Since the snowline is quite abrupt, no plants adapted to winter snow cover occur. This is a major difference between the alpine of the tropics and temperate zones.

E. High, Moist Deserts: These occur between about 2000 and 3000 m on the western side of the Andes. Also small bits of similar vegetation occur in the low elevations of rain-shadowed valleys on the east side. (The Amazon-tributary valleys of the east slope run northward before turning east into the lowlands. Hence they often have a tall mountain range between them and the lowland forest.) These deserts receive 200-300 mm of precipitation and resemble the wetter areas in the subtropical desert. The dominant vegetation here is succulent or shrubby. On the west, irrigated agriculture has long been practiced along the small rivers draining into the Pacific. Further north in Ecuador, this vegetation is replaced by a more typical tropical deciduous forest, but in Peru the fog desert to the seaward leaves theses elevations in a strong rain shadow.

F. Fog Desert, the low elevation biome, reaches to about 1000 m. It was discussed as a variant of the subtropical desert biome.

II. The California variant of the Mediterranean "Orobiome"

This set of mountain communities shows a much greater resemblance to the latitudinal gradient. At least the general form of the "life zones" resembles the lowland biomes. Floristically, however, the conifer and alpine belts have few species in common with their northerly relatives, and other differences will be apparent as we examine each community. The generalizations are that California's mountain communities are generally warmer and far drier, especially in the summer, than similar communities in the Boreal Forest (Taiga) or Tundra. Growing seasons are generally longer in these mountains and until the highest elevations are reached, the forest is composed of much larger trees than the Taiga. Floristically, the Taiga lacks a north-south zonation of species. The major species in California mountains by contrast have sharply different altitudinal ranges and community composition changes much more than in the analogous Taiga latitude gradient.

A. Lowland Sclerophyll Communities

This complex of woodland and chaparral was discussed in Lecture 9. Although it has a component of particularly drought adapted conifer like Knobcone and Digger Pines and various cypresses, these are seldom dominant. These communities extend up to about 1000 m elevation on drier exposures and soils.

B. Yellow Pine Belt

This belt begins in sheltered locations on west slopes of the Sierras at about 600 m (2000 ft.) and extends up to about 1800 m (6000 ft.). It is strongly dominated by Ponderosa Pine (a yellow pine) with Incense Cedar, Sugar Pine, and Douglas Fir. The east slopes have a similar community but at higher elevations 1800-2200 m (7000 ft.). However, the eastern forest has a different yellow pine, Jeffery Pine. Most of the coniferous forest and alpine communities are represented by analogs on both slopes but at higher elevation on the east. The typical elevations of the belts also change from north to south. The belts begin about 500 m higher in the southern end of the range than in the north. Moreover, similar communities also occur at higher elevations in the Coast Ranges. Refer to **Figure 14.4** for a general illustration.

The yellow pines are able to tolerate the heat and drought of lower elevations in this Mediterranean zone, and may be found in small groups or as individuals in the upper parts of the sclerophyll communities. In the Yellow Pine Belt proper, wetter, cooler locations have Douglas Fir, while drier sites are predominately Ponderosa. At the upper margin of this belt, White Fir plays an important role.

The ample growing season and high precipitation of this zone makes it a major area of lumbering. Aside from the North Coast Forest (Redwood and other conifers), belonging as much to the Temperate Evergreen Forest as to the Mediterranean, little lumbering is done outside this belt.

For some reason, deciduous trees seldom dominate any communities in the California mountains (the Alps differ in this respect). The Yellow Pine Belt has a fairly important deciduous subdominant Black Oak, though. Presumably, the summer drought is generally favorable for the evergreen habitat due to its drought resistance. At any rate, the Southern Alps have much more summer rain than the Sierras.

C. Lodgepole Pine - Red Fir Belt

This belt occupies an altitude range of about 1800-2250 m. The typical forests in this zone are monospecific stands of Red Fir (on moist, but well drained sites) or Lodgepoles on either dry or poorly drained sites. (Lodgepoles are tough but are outcompeted by Red Fir on intermediate sites.) This belt is perhaps the most Taiga-like of the Sierra Mountain Belts. On good soils drought stress is mild to absent in the summer, and like the Taiga, the pine is the species adapted to edaphic drought (thin or very well drained soils). Still, the growing season is longer (Red Firs are big trees compared to the Taiga, although Lodgepoles are getting down there).

It is not wet enough for bogs to form in the Sierra very often. Mostly, the wet meadows of California are the filled-in remanents of old glacial lakes. Trees will gradually invade most of these (barring another ice age first), rather than the bogs spreading against the trees.

D. Subalpine Belt

This belt ranges from about 2250-3100 m (7,000-10,000 ft.) on the west slopes. It is quite a bit drier than the preceding zone, as it extends above the rainfall maximum. The dominant trees are Whitebark Pine and Western Juniper. On more moist sites, one finds Mountain Hemlock, a Taiga-like species, but mostly this belt is much too arid to resemble Taiga. Commonly, the forest here is quite open and the trees short.

Treeline is a function of three factors: cold temperatures, wind exposure, and drought. Soils often play a role in water stress as well. In the Sierras it is often difficult to tell if treeline is determined climatically or because the steep slopes retain so little fine soil among the boulders to support trees. Noticing isolated trees quite a way up the slope on slightly more favorable soils is an indication. Wind damage is most noticeable on trees with flagging (limbs alive only on the lee side of the trunk). Where snow accumulates, the last trees may be dwarf (Krummholtz) protected from the wind and cold under the snow. Any projecting branches are pruned back by a combination of wind, cold, and the resulting desiccation.

E. Alpine Belt

The Alpine Belt, from about 3100 m to permanent snow or bare rock, has significant resemblances to the Tundra. Small shrubs, grasses, and sedges are common dominants in both and there are some floristic similarities. Ten percent of California alpine species are shared with the Arctic Tundra. (The percentage is much greater in the Rocky Mountains with higher summer rainfall.) The upright lichens are entirely missing.

The main difference between these systems is moisture. The California Alpine Belt is quite arid, warmer and drier than the Tundra, and the plants often fade after the snowmelt water is gone. A far larger portion of the flora is annual than is common in the Tundra.

F. The Steppe Desert

Descending the eastern slope of the Sierra, one counts backwards down the belts of the west until sagebrush is reached at about 1900 m. Sclerophyll woodlands are absent. The Steppe Desert communities reach higher elevations on dry slopes and fingers of the forest, usually Jeffery Pine, reach down the canyons and out on the flats in more moist situations, not unlike the inter-fingering of the Yellow Pine and sclerophyll belts on the West.

Fig. 13. Examples from mountain stations in the various orobiomes: OB I, Páramos de Mucuchies in Venezuela; OB II, Antonio de Los Cobres in the Peruvian puna, OB III, Calama in the North Chilean desert puna; OB IV, Cedres in Lebanon; OB V, Hotham Heights in the Snowy Mountains of Australia; OB VI, Zugspitze in the northern Alps; OB VII, Pikes Peak in the Rocky Mountains above the Great Plains of North America; OB VIII, Aishihik in southern Alaska; OB IX, Wostok on the ice cap of the Antarctic.

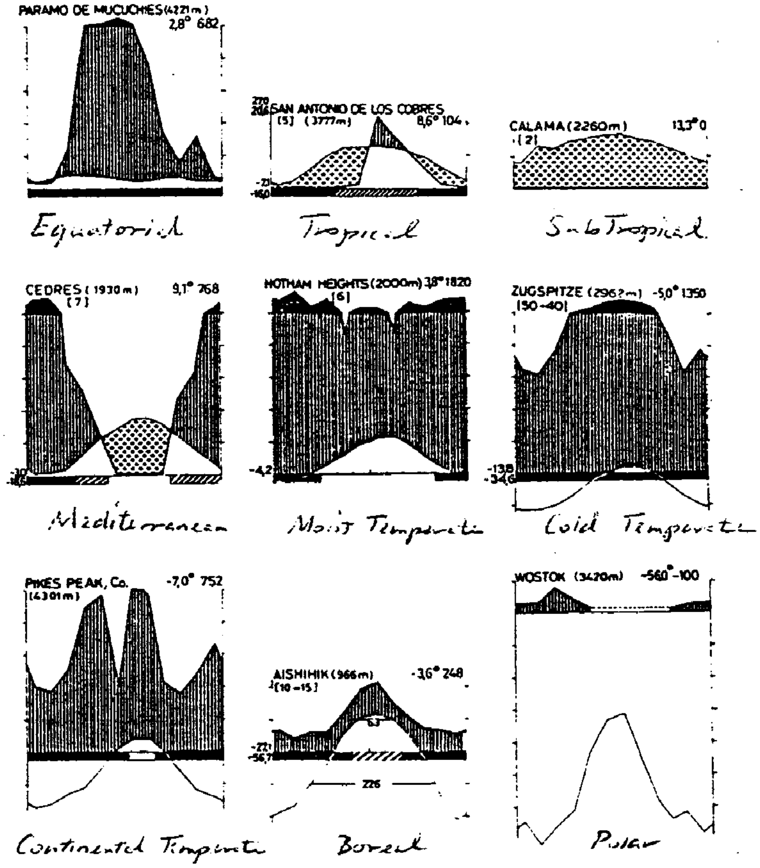

Figure 14.1

Figure 14.2a -- Total Annual Precipitation, inches

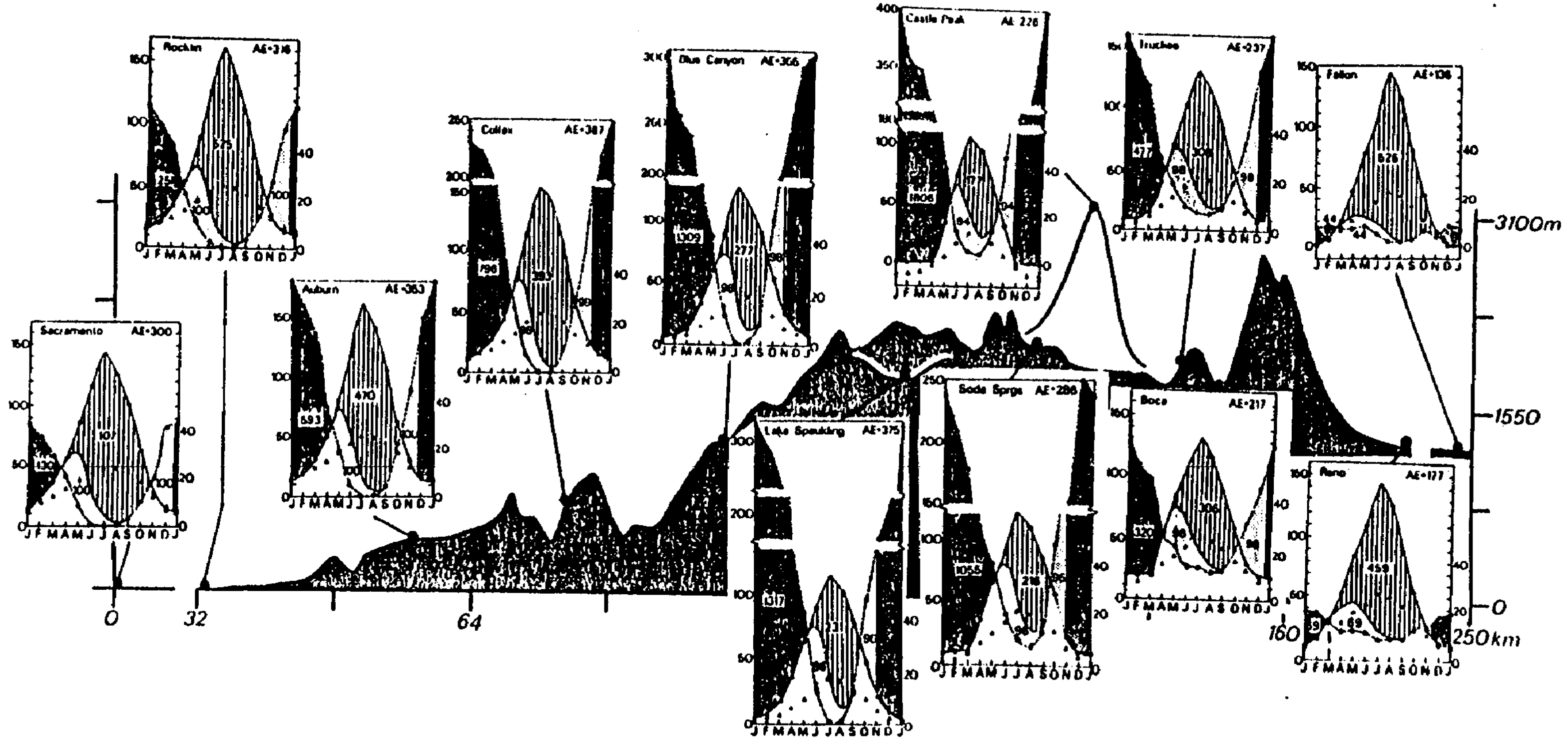

Figure 2-11. A transect over the Sierra Nevada from Sacramento (38.5°N), over Donner Summit (39.3°N), to Reno and Fallon, Nevada (39.5°N), roughly3 along the line of the original Union Pacific Railroad, showing water balances. For legend see Fig. 2-4. Vertical exaggeration 14.5×.

Figure 14.2b