Thinking of Biology

Pattern and process in early studies of Arizona's San Francisco Peaks

Parmenides and Heraclitus; stasis and flux; pattern and process. Some people look at nature and see mainly regularity; others see mainly change. Different people can emphasize different aspects of the same phenomenon, perhaps because they have different temperaments or different objectives. Sometimes this divergence results in conflicts and controversies among supporters of truly incompatible interpretations. Other cases juxtapose apparently quite different but actually complementary perspectives. Study of the San Francisco Peaks in Arizona in the 1890s provides one such example of complementarity, though it might on the surface seem to be a case of conflict. The case shows that different emphases may make phenomena look more different than they really are.

The San Francisco Peaks dominate the landscape in northern Arizona. The highest point in the state, at 12,670 feet above sea level, the peaks are the remains of a volcano. Current estimates suggest that what now appear as five different peaks (Humphreys, Agassiz, Fremont, Aubineau, and Doyle) once rose together as one peak to a majestic altitude of more than 15,000 feet. The peaks have been often called San Francisco Mountain. The mountain currently rises more than 5000 feet above the surrounding plateau and is visible for long distances. Home to the Hopi's Kachinas and one of the four corners of the Hopi and Navajo universes, the peaks were designated by the US government under President Ronald Reagan as the Kachina National Wilderness Area.

A cool, relatively wet area surrounded by arid terrain, the peaks have long attracted attention of US explorers and travelers. Naturalist Louis Agassiz, for example, visited the mountain when he made fossil studies for the railroad survey in the area in 1867–1868 (Cline 1976). By the late 1880s, as the United States was displaying an enthusiasm at the national, state, and local levels for surveying lands throughout the country, this area of Arizona proved particularly attractive as a land of dramatic contrasts.

The relatively cool and wet peaks provided a hospitable haven for humans as well as animals and plants, yet the nearby deserts offered little to support most life forms. In his report of a trip through the surrounding desert in late July 1889 in connection with surveying life around the mountain, Lieutenant Joseph C. Ives noted

> The scene was one of utter desolation. Not a tree nor a shrub broke its monotony. The edges of the mesas were flaming red, and the sand threw back the sun's rays in a yellow glare. Every object looked hot and dry and dreary. The animals began to give out. We knew that it was desperate to keep on, but felt unwilling to return, and forced the jaded brutes to wade through the powdery impalpable dust for fifteen miles. The country, if possible, grew worse. There was not a spear of grass, and from the porousness of the soil and rocks it was impossible that there should be a drop of water.
> —quoted in Merriam 1890, p. 15.

Yet these explorers realized that this was a region of extremes. A long drought in the desert could be followed by violent thunderstorms, "which shake the very foundations of the earth in their fury, shattering the tall pines with the lightning," and devastating floods "sending mighty torrents down the hillsides to plow deep gorges in the desert" (Merriam 1890). Furthermore, by late summer the mountain tops could be whitened with snow, while rain and hail fell in one area and another remained completely dry.

The ecological contrast between the high mountain and lower desert is what continues to make this area particularly intriguing. It is not surprising, therefore, that the USDA agreed to support several studies of the area in the last decade of the nineteenth century. In 1890, Clinton Hart Merriam's study reported that "Recent explorations in the west, conducted by the Division of Ornithology and Mammalogy of this Department, led to the belief that many facts of scientific interest and economic importance would be brought to light by a biological survey of a region comprehending a diversity of physical and climatic conditions, particularly if a high mountain were selected, where, as is well known, different climates and zones of animal and vegetable life succeed one another from base to summit" (p. 1). The San Francisco Mountain was especially promising because of its "southern position, isolation, great altitude, and proximity to an arid desert" (Merriam 1890).

According to historian Kier Sterling, Merriam had persuaded his USDA employers that the Arizona diversity could provide a microcosmic study of larger issues of biogeographical distribution (Sterling 1977). Merriam headed the Bureau of Biological Survey at the USDA from 1886, following several years with the agency surveying migration and distribution patterns in first birds and then mammals. By 1889, he had abandoned the medical practice made possible by his 1879 M.D. degree from Columbia (College of Physicians and Surgeons). Instead

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he followed his childhood love of natural history and put to use his youthful experience with the Hayden Survey to Idaho, Wyoming, and Utah.

Merriam headed west in 1889 to produce the third volume of the USDA's Division of Ornithology and Mammology's *North American Fauna* series based on his survey, catalog, and generalizations about Arizona's San Francisco Mountain. The findings emphasized the patterns of animal distribution that he saw and led to what Merriam called his life-zones interpretation of biogeographical distribution.

Roughly a decade later, in 1898, the USDA again called for study of the mountain, this time with a closer eye to potential agricultural value. To this end, physiological ecologist Daniel Trembly MacDougal stressed processes and change; he looked at temperature inversions and their effects on plant distribution. While Merriam emphasized the pattern, MacDougal stressed the processes that he saw. The two investigators focused on different time scales and different phenomena, so that their results looked more divergent than their underlying assumptions would suggest. Together their studies provided important new interpretations of why particular plants and animals live where they do.

Merriam's life zones

Merriam was 34 in 1889 when he took the train to Flagstaff and set up camp at the northern base of the mountain at Little Spring. At that site, Merriam's group (assisted by the three Riordan brothers of Flagstaff and including Merriam's wife, Virginia Gosnell Merriam; special agent and collector Vernon Bailey; botanist F. H. Knowlton; and biologist Leonhard Stejneger, who summarized the reptiles and batrachians for the volume) settled amid aspens and pines at approximately 8250 feet for two months while exploring the mountain and surroundings. Merriam's wife evidently helped civilize the camp as she sometimes cooked, made her husband shave, and otherwise was "pleasant" (Sterling 1977).

The group was hampered by what Merriam saw as woefully insufficient funding. With only a little more than $600 for everything including transportation, they had to make do with one man as "cook and general camp-hand" and with inadequate animal help, "which circumstances caused many annoying delays" (Merriam 1890).

Besides collecting and identifying specimens, Merriam questioned existing standard views about biogeographical distribution. The San Francisco Peaks became for Merriam a microcosm for the entire United States, with the north-south distribution exhibited vertically by altitude instead of by latitude. In particular, he challenged the dominant view that the United States exhibited three basic life areas: the Eastern, Central, and Western (including the Sonoran) Provinces. Instead, as he and his crew scouted the region on horseback, they gathered increasing conviction that there are two primary life zones in the United States—the northern (boreal) and southern (subtropical). As Merriam put it, he was "astonished to be forced into the belief that no such province [as the central one] exists" (Merriam 1890).

His studies revealed to Merriam a further breakdown into four boreal and three subtropical zones, making up seven minor zones. Building on existing distinctions, these included: alpine (above 11,500 feet), timberline or subalpine (10,500–11,500 feet), Hudsonian or spruce (9200–10,500 feet), Canadian or balsam fir (8200–9200 feet), neutral or pine (7000–8200 feet), piñon (6000–7000 feet), and desert (4000–6000 feet). These zones were represented by different plants as well as animals. He presented these zones in a classic diagram of the mountain, parallel in style to diagrams of the geological strata of the nearby Grand Canyon (Figures 1 and 2).

Merriam did not pretend to have discovered the zones entirely himself, nor did he claim originality even in identifying them as he did. His claim to novelty was that temperature largely determined distributions of plants and the animals dependent on them. In particular, the temperature during the reproductive seasons is decisive, allowing distribution northward at lower elevations or southward at higher elevations because the same temperatures can be achieved. Southern and southwestern exposures also allow warmer temperatures at the same elevation, and other factors such as humidity or topography can play lesser roles. Thus, the physiological responses to temperature determined where animals and plants could live. The biogeographical pattern results from an interplay of environmental and physiological factors.

This view differed from Louis Agassiz's view dominant at the time that isothermal patterns delineate north-south zones that are divided by geographical barriers. For the creationist Agassiz, a higher intelligence obviously had put the patterns into place and distributed animals in their proper locations according to the grand design. Climate, for Agassiz, plays a role in revealing the plan or pattern but not in determining distribution of life. Others such as biologists Joel A. Allen or Philip Lutley Sclater followed Agassiz in seeking patterns but offered a variety of alternative and often competing descriptions of faunal and/or floral regions (Sterling 1974, 1977, Agassiz in Sterling 1974).

Furthermore, for Agassiz, species arose essentially where they are now; migration is not an important factor in distributing life forms. Successive creations with catastrophic interludes fit his picture of natural history. For Merriam, in contrast, migration was important. Merriam saw species as moving either from the circumpolar northern zone southward or northward from more southern areas. Past glacial periods had allowed boreal species to move far south, and as the glaciers receded the species could survive by moving upward in elevation (Merriam 1890). In this context, one of Merriam's most significant discoveries was certainly the surprisingly southern existence—at high altitudes—of certain species previously associated only with the northern regions.

The existence on the peaks of a boreal area corresponding to the arctic zone was especially interesting given the southerliness and the

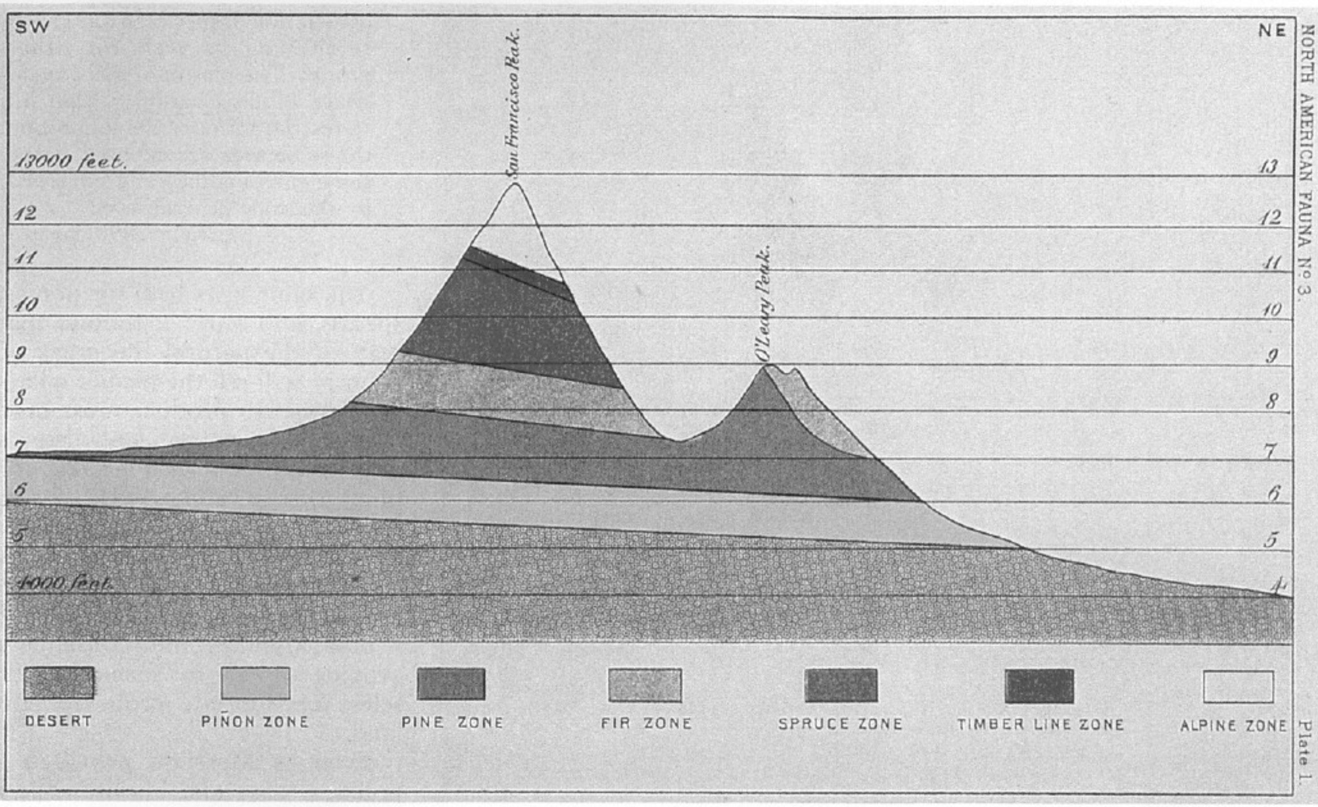

Figure 1. Life Zones (Merriam 1890, Plate I). Original caption: "Diagrammatic profile of San Francisco and O'Leary Peaks from S.W. to N.E. showing the several life zones and effects of slope exposure."

isolation of the mountain. Merriam asked what could have caused the same species and the same zones to exist here as they did in far more northern areas. Looking to the past, he concluded that the small colony of arctic life (like that common in Canada) dotting the top of this mountain and others in neighboring Colorado had resulted during glacial times. San Francisco Mountain represented one of the southernmost points of glacial action, and its peaks may well have once been joined by ice with those of other mountains. As the glaciers receded, the plants and animals settled at the altitudes that provided the conditions they needed to survive. These boreal species were, in effect, stranded.

It might seem that the existence of unique, locally adapted types would demand an additional or alternative interpretation and argue against this general, more global view. But no, Merriam felt that the glacial movements and the stranding of species in local settings should be expected to have produced some local adaptation against a background of similarities. He saw these observations as a general law: "*When the physiographic conditions of a region are in process of change, those forms of life which are sufficiently plastic to adapt themselves to the rapidly changing conditions survive, while those which cannot so adapt themselves become extinct*" (Merriam 1890, pp. 23–24). His focus remained clearly on the zonal patterns rather than on the past migrations or physiological adaptations, but he remained well aware of the underlying processes.

Merriam regarded earlier misinterpretations as not surprising because previous studies had drawn heavily on eastern United States—and hence limited—studies. Though his confidence has not stood the test of time, he felt that his mountain microcosm, which offered so many zones in such a compact area, could provide a better picture. What Merriam saw with his vertically arranged regions was their structural regularity and pattern. He suggested that his case was more ideal, more generalizable than those studied by other researchers. He argued that his case was isolated, a mountain that rises dramatically above the surroundings and remains separated from other areas of similar elevation. It was a western United States case, not complicated by the differences of overlapping areas and domestication characteristic of eastern examples. The western frontier still suggested in 1890 a purer, more natural state. The San Francisco Peaks provided a relatively neat and tidy case, from which Merriam felt he could derive a clear-cut diagram of the basic life zones.

Merriam did realize, of course, that the flora and fauna were not absolutely restricted to the particular altitudes that defined his zones. Rather there were overlaps and interconnections. Indeed, the exact elevations of Merriam's life zones varied from the southwestern to northeastern side of the mountain such that the zones extended lower on the northeastern side. Merriam concluded that this variation occurred because the northern side experiences less sun and hence remains colder, therefore remaining more like higher elevations (Figure 3). Though temperature remains the dominant

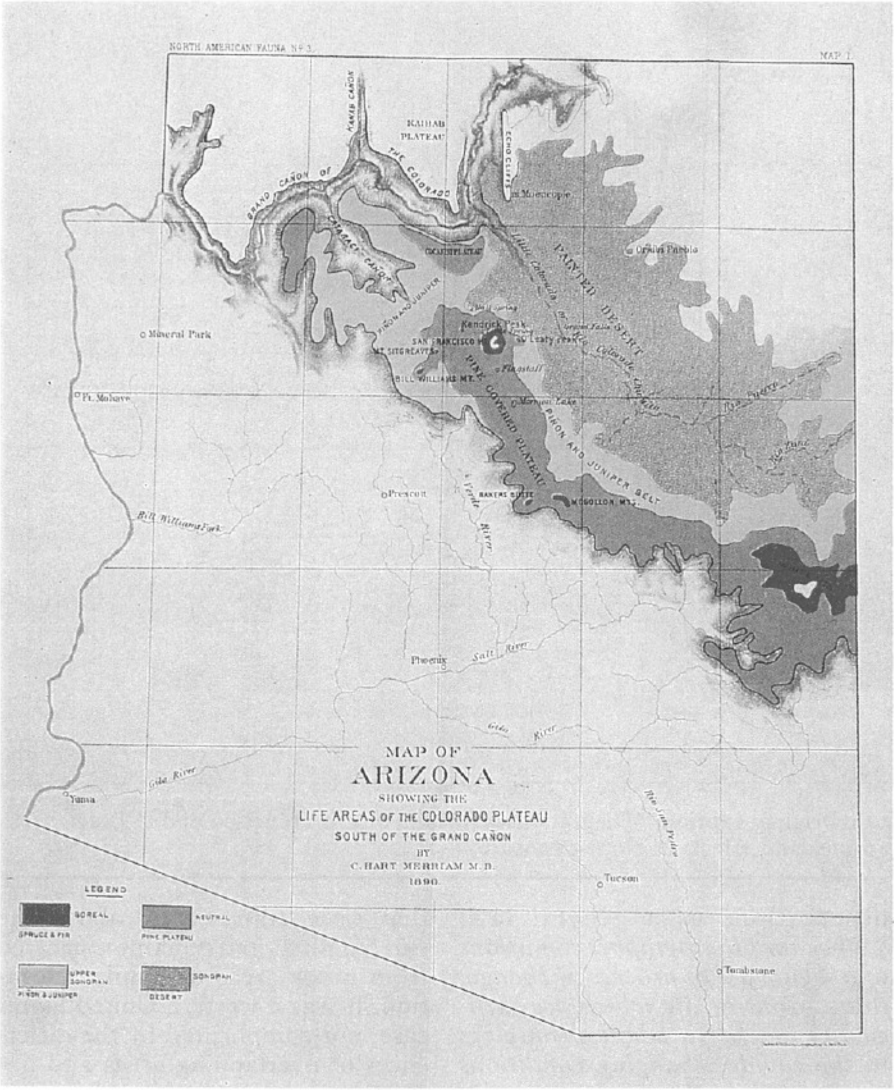

Figure 2. Merriam's Map I (Merriam 1890).

factor, slope-exposure, proximity to and direction from water, and especially humidity all affect the details of the pattern boundaries. Furthermore, some species (and especially animals) wandered between the zones and/or occupied more than one zone. These organisms were not useful for determining which zone was which, but they did reveal the overlaps and interrelations of the zones.

Merriam's job was to look beyond the various irregularities to survey the area and produce generalizable systematized data. In the effort to learn more about the western territories, the USDA wanted generalizations and probably did not wish to become distracted by confounding details. Surveying and cataloging species and their locations could prove useful. Thus, Merriam proceeded to provide detailed lists of the organisms found in each zone, with many specifics common to such regional biological surveys. He felt that these lists should be a fine source of information for those proposing to develop the area.

As Merriam pointed out in a final short section entitled "Relation of a Biological Survey to Agriculture," the regularities and consequent predictabilities offered by zones make up the significance of his survey.

> The present biological survey of the San Francisco Mountain region has demonstrated that mammals, birds, reptiles, insects, and plants so coincide in distribution that a map showing the boundaries of an area inhabited by an association of species in one group serves equally well for other groups. The reason of this coincidence in distribution is that all terrestrial forms of life inhabiting the same area are exposed to the same surroundings and governed by the same general laws.
>
> —Merriam 1890, p. 125

The same laws held for domestic species, and thus "It follows that a map of the natural life areas of a country will tell the farmer what he can expect to produce most profitably on his own farm, and also what crops will not thrive in his neighborhood, thus saving the time and cost of experimental farming, which, in the aggregate, amounts to hundreds of thousands of dollars every year"(Merriam 1890, p. 125). He felt that his maps could consequently provide a guide for farmers as they select appropriate crops for their land.

Even as Merriam provided his practical data and his life-zone interpretation, which broke new ground by providing a new way to organize and understand biogeo-

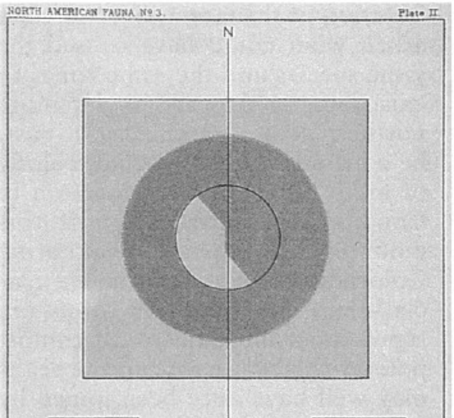

Figure 3. Slope Exposure (Merriam 1890, Plate II). Original caption: "Diagram showing effects of slope exposure on a volcanic cone north of San Francisco Mountain."

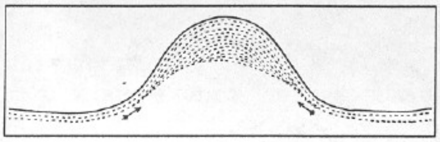

Figure 4. MacDougal's Figure 1, Temperature Inversion Process (MacDougal 1900). Original caption: "Showing drainage of cold air into a valley."

graphical distribution, he also provided suggestions for the studies of future researchers. For example, in his discussion of the influence of humidity, Merriam (1890) acknowledged that "Data are wanting." More specific information would be useful, and there was room for future study. He was leaving the way open for others to explore further and to emphasize other phenomena or to focus their studies in different ways.

MacDougal and temperature inversions

The year after completing his bachelor's degree at Depauw University in 1890 at age 25, Daniel Trembly MacDougal visited Arizona and other western areas as a vaguely designated special agent for the USDA. Then, while teaching at Purdue and the University of Minnesota, he completed his doctoral degree in 1897 from Purdue for research on root physiology, carried out largely during a visit to Germany during 1895 and 1896. With degree in hand, in 1898 he set out once again for Arizona, at about the same age that Merriam had undertaken his study there (Kingsland 1991, Shreve 1939). Though eventually he became more concerned with desert ecology, MacDougal initially spent his time studying the San Francisco Peaks with special reference to the possibilities for agricultural development.

It was likely that residents of Flagstaff, the town at the base of the mountain, and reports from earlier explorations such as Merriam's had convinced the USDA to look more closely at the growing conditions in the area. The area had begun rapid development in the 1880s and 1890s, and many held high hopes for its future. One writer stated enthusiastically in 1887 that the area around the mountain was fine for the cattle grazing that had already begun to develop there and for lumbering. Yet he agreed with the general assumption of the time that grazing and lumbering should give way to more directly agricultural interests, and he promised that "it will be in a few years one of the finest agricultural countries" (Tinker 1969, p. 6). The climate was near perfect:

> Around Flagstaff the sun shines nearly every day, and but few are cloudy. Even during the rainy season, which begins in July and lasts about six weeks, the daily showers are followed by the brightest sunshine. The air is pure and highly oxygenated. The nights are clear and cool, often cold, yet the air is too dry to make the depressure of the mercury injurious to the invalid, and he awakes in the morning with an excellent appetite, having secured what his system so much needs—a delirious and refreshing slumber.
>
> —Tinker 1969, p. 6.

Buoyed by development of the Atlantic and Pacific Railroad in 1883 and by the resulting increased availability of government land for homesteading and ranching, the area had begun to flourish by the 1890s. To escape the summer heat of Flagstaff, some residents established ranches at the base of the mountain. With visits by such explorers as John Wesley Powell, Smithsonian ethologist Victor Mindeleff, and Merriam, interest intensified. A visiting natural science professor in 1888 was said to have been "amazed at the variety of wild flowers that grew in profusion [on the peaks]. Many of them he was unable to classify properly, as their species were unknown to him, and altogether they formed the most interesting collection he had ever made. Not less than sixty specimens were gathered, and yet the plants were not exhausted in their astonishing variety"(Cline 1976).

The locally prominent Riordan brothers entertained visiting surveyors, assisted them in their studies, and obviously worked to make the region more well known and to explore its potential for development. In fact, during the 1890s, farming of potatoes had proven successful, and some areas had begun to grow grains and hay. It remained to be seen what more was possible.

Under these circumstances, in 1898 the USDA authorized MacDougal to visit the region and extend the earlier survey. MacDougal was expected to explore agricultural

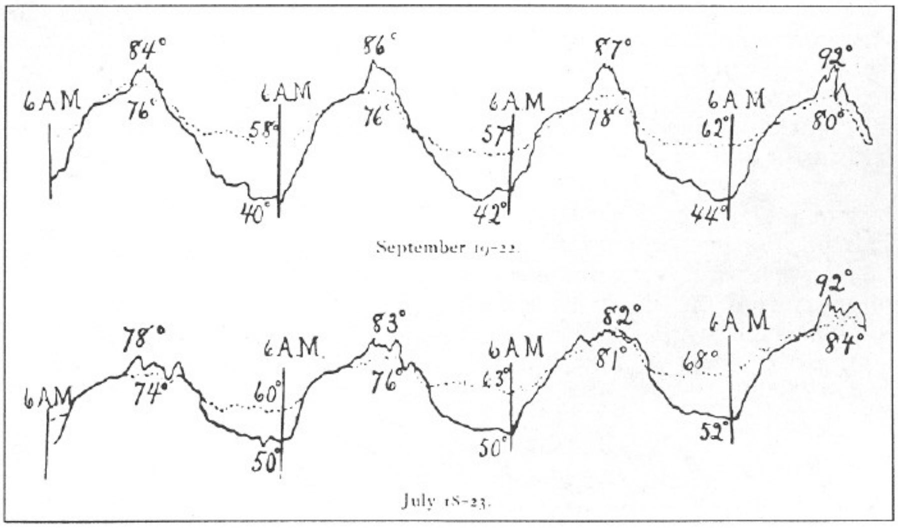

Figure 5. MacDougal's Figure 2, Temperature Inversions (MacDougal 1900). Original caption: "Temperature curves obtained at Flagstaff, Arizona, at elevations of about 2300 meters. The dotted line is the thermographic record for the hilltop, and the unbroken line is the thermographic record for the valley, 100 meters lower. The valley is warmer than the hilltop during a period of only about three or four hours during the middle of the day, but its temperature is lower than that of the hill during almost the entire night of twelve hours. The daily average temperature of the valley is thus much lower than that of the hill."

possibilities for plants. Where Merriam had emphasized regularities and neatly definable zones, MacDougal stressed the irregularities caused by change and process. He saw that elevation alone does not determine temperature or the other factors such as humidity—both factors that Merriam has assumed as central to distinguishing his zones. Instead, MacDougal pointed to physiological processes relating to heating of soil and air and the resulting air movements, which produce biological changes over time. His diagrams attempted to capture this dynamic feature with arrows (Figure 4).

He submitted the results of his study to the USDA in 1898, then the next summer presented a lecture at the Marine Biological Laboratory in Woods Hole, Massachusetts. That lecture began with a straightforward explanation that temperature inversions occur because soil and air conduct moisture, and hence heat, at different rates.

During the day, according to MacDougal the sun provides both soil and air with equal heat, but the soil absorbs more. Likewise, the soil cools more quickly, and if the air is dry the differential conductivity is even greater. As a consequence of this situation, the layer of air (a few meters in thickness) nearest the ground becomes cooled by conduction and radiation to the cold surface of the soil and soon falls to a temperature many degrees below that of the air a few yards above. This phenomenon is termed *inversion of temperature* by the meteorologists, and the effects of inversions of temperatures are well known to those engaged in horticultural and agricultural operations (MacDougal 1900).

This phenomenon has significant practical importance, MacDougal pointed out, because it affects the presence and pattern of frosts. Valleys become colder than the surrounding ridges, for example (Figure 5). If the coldest air lying nearest the ground can be kept moving, the overall temperature remains higher and can help to prevent crop damage. Similarly, MacDougal stated that the inversions would affect biogeographical distribution by influencing ecological conditions.

When MacDougal studied the northern Arizona plateau from June to September 1898 (where June and early July are very dry, and late July to September is the wettest season), he found significant nocturnal inversions, "a fact which must exercise a very notable influence upon the zonal boundaries which cross this region" (MacDougal 1900). Northern plants could drop to much lower elevations in the areas of major inversion, for example. Similarly, grain crops, which normally need warmer conditions, could grow more easily on hills than in valleys. The conditions on hilltops remained more moderate, and indeed he found frosts in the valleys (Figure 5).

As Merriam had noted earlier for his own work, MacDougal recognized that this phenomenon was not new. Indeed, he pointed out that the New England farmers often planted orchards on ridges for just this reason. It was also well known that northern plants are naturally restricted in their southerly distribution by the heat of the summer, balanced by the low winter temperatures—as Merriam had recognized. Similarly, the northern distribution of southern plants is restricted by the cold of winter. As MacDougal said

> In conclusion, I must again remind you that none of the meteorological principles described are in any sense original with myself; but I am able to adduce some very striking observations in illustration of their influence upon vegetation, and it is confidently believed that this work constitutes the first systematic attempt to use such data in explanation of certain seeming aberrations of distribution and zonal boundaries. Furthermore, it is most interesting to note that the effects of cold-air drainage and inversions of temperature have been taken into consideration by the horticulturist and farmer long before this analysis of their relations to the facts of natural distribution of plants and animals was brought forward.
>
> —MacDougal 1900, p. 47.

MacDougal suggested that a simple extension would predict that valleys have lower mean temperatures and lower minimums, and hence that they could support more northern species. Hills would allow more southern species to move northward. Accepting the basic idea of life zones, he did not find them central. Instead, he focused on the shorter time scales experienced locally and sought to explain the irregularities he saw from day to night and day to day. Perhaps, he suggested, "It may be said that zonal boundaries are deflected southward in valleys and northward on ridges and highlands" (p. 43). This generalization would not hold over great extremes, but at least it was accurate for an elevation difference of 300 to 500 meters between a valley and a ridge. "Even with this limitation the configuration of the country may be such as to deflect the zonal boundary from its general course 100 kilometers or more; a fact of very great importance both in biogeography and also in economic operations" (MacDougal 1900, p. 43).

Observations in the San Francisco Peaks confirmed expectations based on the study of inversions. Thus, the pattern of biogeographical distribution was not so neat and regular as Merriam's work had suggested. The effects of temperature differences, inversions, and air currents could explain many of what appeared to be aberrant species distributions. Sometimes there might be special local conditions or limitations of food supply, but MacDougal argued that temperature inversions must be considered a prime ecological factor—along with Chinook winds and rising updrafts that carry moisture from wetter areas—as processes that can cause variation and changes in the basic zonal distributions of species.

For MacDougal, studying the causal mechanisms, or processes, and the variations in pattern revealed much about biogeographical distribution, its significance, and its interpretation that the idealized and static life-zones interpretation alone could not. The biogeographically oriented life zones did not address the ecological questions that MacDougal wanted to answer. His time scale and his emphasis stressed process and flux for providing explanations, even while he did not reject the significance of pattern and stasis as descriptively useful.

Conclusions

Merriam emphasized pattern and regularity; MacDougal stressed process and variation. They drew on a well-defined and dramatic case: a high mountain rising alone out of the surrounding plateau in an arid region. The proximity to Flagstaff and the railroad made this area ripe for agricultural development and improved access. The interests of local citizens provided support and hospitality for the studies. And the area had special biological significance because the San Francisco Peaks are the southernmost limit of glaciation and hence of some boreal species.

It might be tempting to ask: which man provided the better account of what really occurs with biological diversity in varied elevations? Today, one can imagine Merriam's zones very roughly (especially with the help of Forest Service signs) and see how he could have constructed them out of what he could see, especially because he had in mind similar maps of geological strata of the nearby Grand Canyon.

Yet, most viewers will see more differences and irregularities than perfectly delineated zones. Of necessity, moving up the mountain through the different zones requires moving along the irregular contours that experience updrafts or cold sinks. Thus, there are no sharp boundaries between the zones. Indeed, often in the mornings the visitor can feel the cool moist air along the valleys giving way to warmer and drier air on the ridges. By evening, the valleys cool rapidly. Alert observers can feel the process, just as they can see the zonal patterns.

What this case shows is the power of different perspectives in causing us to see things in particular ways. Merriam's search for patterns and regularities provided guidance for planting agricultural crops in the right places. It also made sense of the otherwise peculiar phenomenon that some normally boreal species suddenly appeared in the middle of a vast desert: we expect northern species to occur at high elevations even in more southerly latitudes because of past processes of glaciation and receding of glaciers. Why is the pattern of expected species distribution not followed perfectly? Because of variations in temperature due to sun exposure and other factors.

These other factors, such as contours of land and humidity, received MacDougal's focus. He stressed the micro-climatic variations, the processes, and the changes. While Merriam looked across the continents and across the geological eras, MacDougal looked at the variations from night to day and from hill to adjacent valley. Merriam looked at animals, while MacDougal concentrated on plants. They might appear to offer contradictory conclusions, where MacDougal's irregularities undercut Merriam's patterns. In fact, their data and interpretations complement each other and work together as they look at the same basic phenomena with different foci. Both saw the interactions of organisms with their environments. Both saw changes over time, even though their time scales varied. Pattern and process, stasis and flux: natural processes produce and explain patterns. MacDougal's physiological ecology helped explain Merriam's life zones.

Acknowledgments

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