A unique vegetation occurs at the edge of the sea that is adapted to wind, fog and salt spray. Photographs by Michael Barbour unless otherwise noted.

CALIFORNIA VEGETATION: DIVERSITY AND CHANGE

by Michael Barbour, Bruce Pavlik, Frank Drysdale and Susan Lindstrom

California is rich. It far exceeds the sum of our myths, memories, and experiences. To the native California Indians, it was home, it was the world, it provided everything. To others, coming from different directions and at different times, California was lush pastures, precious metals, tall timber, a new life, a fresh start. It was and continues to be, all things to all people, endlessly accommodating, an inspired landscape offering prosperity from diversity.

The economic wealth of California is an expression of its natural diversity. The variety of geological substrates, topography, climatic types, soils, vegetation, and species of plants is exceptional. For example, of the world's ten major soil types, California has all ten. Elevations extend from the second highest (14,495 feet) to the lowest (-282 feet) in the United States. Climates and vegetation range from foggy, humid, dripping wet, shaded coastal forest to arid, hot, open desert scrub. As many as 375 distinctive natural communities have been recognized in the state. Plants that compose those communities vary from small, floating duckweed to giant sequoia; from frail herbs which live for only weeks to ancient bristlecone pines; from recent weedy arrivals to those with fossil records extending back millions of years. California has more than 6,000 kinds of native ferns, conifers, and flowering plants. Japan, with a similar area, has far fewer species. Even with four times California's area, Alaska does not match California's plant diversity, and neither does all of the central and northeastern United States and adjacent Canada combined. Moreover, about one-fourth of all California's native plants are found nowhere else in the world.

When economic prosperity is manufactured from natural diversity, change in the landscape is inevitable. California has become a place of change. The California we see today is dramatically different from the one Sir Francis Drake claimed for England in 1579, and from the one Father Junipero Serra claimed for Christianity two centuries later. The early Europeans did not see beauty in wild California because they came from tamed landscapes. From offshore, Drake judged harshly the summertime Big Sur coast with these words:

"How unhandsome and deformed appeared the face of the earth itself! . . . shewing trees without leaves, and the ground without greenness in those months of June and July."

Uncomfortable with this strange wilderness, the Europeans began to rearrange the land into more familiar patterns. Within two centuries, woodlands have been cut and replaced by orchards, highways, and cities; marshes have been drained and converted into farms and airports; redwood forests are now Douglas-fir forests, and Douglas-fir forests are now tanbark and madrone thickets; montane conifer forests have been converted into chaparral, and chaparral into grassland; California prairie has become farms and cities; sand dunes have become city parks, neighborhoods and golf courses. Almost 1,000 alien plant species—many noxious weeds—have been introduced to California. At the same time, 675 native plant species have become highly endangered and another thirty-nine have become forever extinct.

Converting land to serve human purposes invariably erodes natural diversity. This erosion is expressed by the loss of plant and animal species. The extinction of unique gene combinations which have been slowly produced in eons of evolutionary process can be accomplished in seconds of geologic time.

The erosion of diversity is also expressed by the loss of natural vegetation—whole collections of plant species that share a habitat. Early in this century, the pioneer plant ecologist Frederick Clements advanced the notion that vegetation is like an organism—not a collection of independent individuals, but an interdependent community with a life of its own. Today, British biochemist James Lovelock's "Gaia" hypothesis has extended the organism theory to a global level. He contends that the entire biosphere functions as a unified whole—a super-organism—that is able to maintain the environment necessary to sustain life. Although these views may be extreme, it is true that the destruction of natural vegetation produces drastic and often irreversible changes in the landscape that affect humans directly: rivers flood, livestock starves, wildlife populations diminish, soils become sterile, forests stop regenerating, and wildfires rage. All of these changes have occurred in California, so today we look upon a damaged landscape whose diversity, resiliency, and sustainable productivity are greatly diminished. Slowing and hopefully reversing this trend will require an understanding of natural vegetation.

Understanding Vegetation

Vegetation is the plant cover of a region, the clothing over the land. This thin cloth is at once durable and fragile, able to repair and reproduce itself for centuries if the environment remains stable, but subject to irreversible unravelling when environmental stresses become too severe. When vegetation is disrupted, its integrity is fractured. The degraded cover loses ecological relationships, nutrients, and diversity—both plant and animal.

Vegetation plays an essential role in the global movements of water, carbon, oxygen, sulfur, phosphorus and nitrogen. When vegetation is removed, the movement of these substances is altered, and human populations feel the result. For example, hydraulic mining for gold in the mountains of nineteenth century California was a crude practice which directed erosive jets of water onto mountain slopes. Denuded hillsides eroded quickly, creating abnormal sediment loads and devastating floods far downstream in the Central Valley. The state capital was flooded nearly every year. The Sacramento River changed its course in many places, leaving backwater oxbows and stranded settlements past which the main current had once run. State legislators outlawed hydraulic mining in 1875, but it took a long time for vegetation to cover and stabilize the barren slopes. Sediment loads in Delta rivers did not return to normal levels until 1950.

As another example, more than 40,000 acres of green California farm land a year are taken out of production and covered by urban structures. The movement of carbon is noticeably altered by this huge removal of plant cover. Green plants use solar energy and complex biochemical pathways to remove carbon dioxide gas from the air in a process called photosynthesis. Carbon dioxide is then transformed into all the carbon-based chemicals necessary for plant life: carbohydrates, proteins, fats and the hereditary material DNA. In the absence of plant cover, carbon dioxide accumulates in the atmosphere. It traps heat, much like glass panes over a greenhouse, causing a significant increase in global temperature. This relationship between vegetation, carbon dioxide, and air temperature has been called the "greenhouse effect." Unfortunately, California's history of vegetation loss is not unique. On a global level, the rate of vegetation loss is accelerating yearly. Restoration of plant cover will be important in reversing the greenhouse effect.

The Architecture of Vegetation

We have likened vegetation to a covering over the body of the earth, but the covering is not a simple, thin, homogeneous layer. Like a tiered cake, it has several layers. The plants which grow together have different sizes, life spans, root systems, and leaf traits. When one sees a forest, all of these layers and characters are mixed and fixed in memory to give a mental picture of "forest."

A conifer forest in middle elevations of California mountains has four layers of plants. Small herbs, visible only during the growing season, are scattered over the ground. Common herbs include violets, orchids, calochortus lilies, and bunch grasses. In the same layer are prostrate woody plants, such as pine mat manzanita or squaw carpet. Each fall the herbs die back to underground stems and roots, so they are not visible until the following spring. The woody plants retain their leaves and stems all through winter, even when covered by several feet of snow.

Shrubs make up a second, taller canopy layer of plants: green leaf manzanita, bear clover, and dwarf tanbark oak. The shrubs are typically evergreen, retaining their leaves through winter.

A third layer is composed of understory broadleaf trees, shorter than the conifers which tower over them. Mountain dogwood, California black oak, and hazelnut are dramatically visible in spring and in fall when they flower and their leaves turn gold, red, and purple.

Finally, the overstory conifer layer, with evergreen, needle-like leaves, dominates all. Conifer trees are said to dominate the vegetation, because they are the most abundant growth form in the tallest layer. This layer is not completely closed—that is, the canopies of the trees do not all meet and interlock. There are patches of open space between some trees. Looking down on the canopy from above, only sixty to seventy percent of the ground is seen to be covered by the overstory conifers. Plants of the understory tree, shrub, and herb canopies arrange themselves to take advantage of light that passes through gaps between the trees, so that when all four layers are looked at from above, 100 percent of the ground is covered.

Vegetation like the forest just described is found in many parts of California. It has been given a unifying name: mid-montane conifer forest. The architecture of vegetation is defined by the size of plants which make it up, the number of canopies stacked vertically, the growth forms of the plants (tree, shrub, herb), and the leaf traits (evergreen, deciduous, needle-like, broadleaf). A "mid-montane conifer forest" means an open forest dominated by conifers with scattered understory trees, shrubs, and herbs, all growing at middle elevations of mountain ranges high enough to receive winter snow but low enough to have a long, warm, dry growing season.

A red fir *(Abies magnifica)* forest endures the deepest and longest-lasting snow pack of any vegetation in the state. Photograph by John Harris.

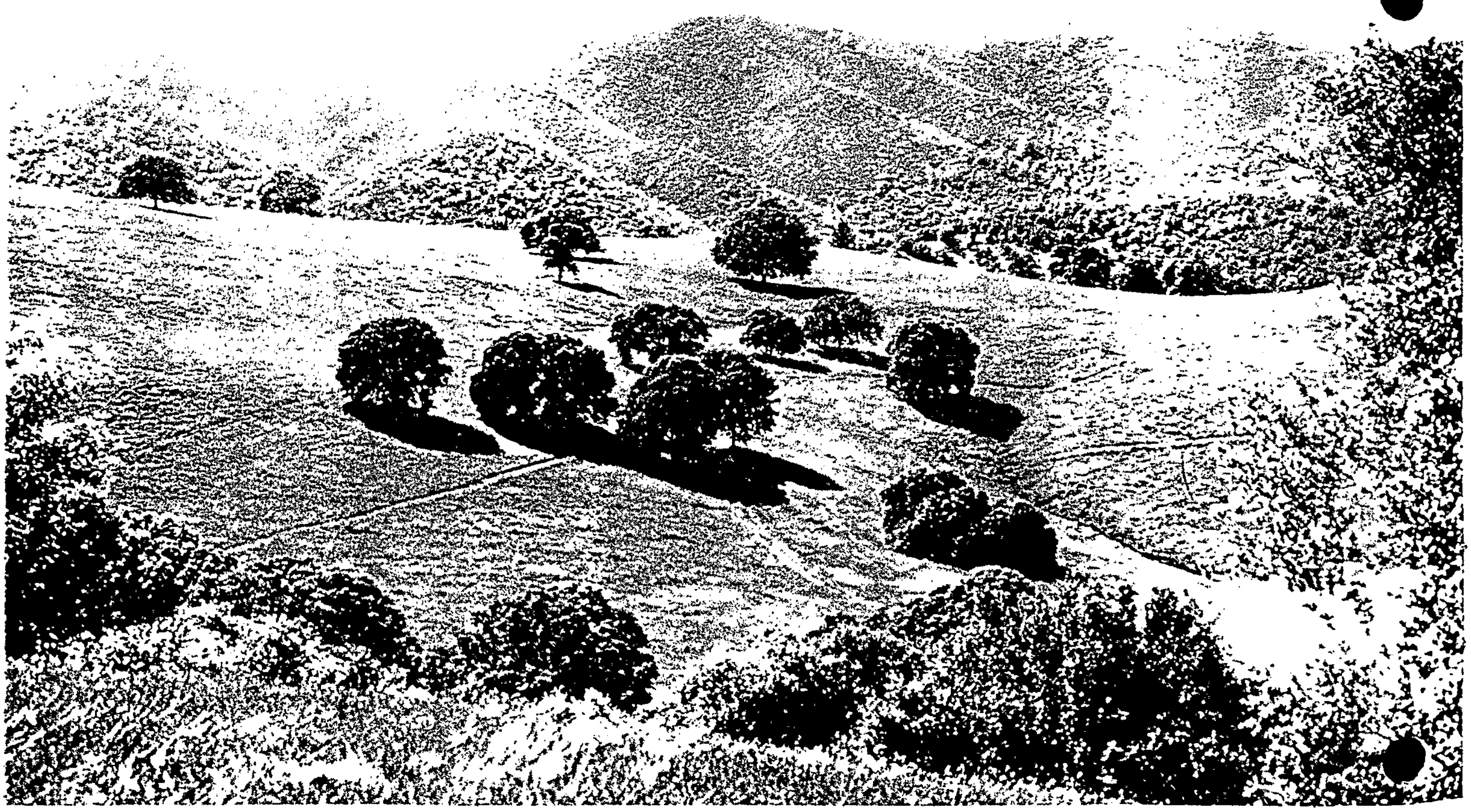
"Mid-montane conifer forest" is the name of one vegetation type; California has dozens of others. Each vegetation type's name includes a geographic term and the dominant plant growth form. From place to place, the identify of the species making up the vegetation may change, but the structure of the vegetation is constant. For example, some other vegetation types of California include Central Valley annual grassland, upper montane conifer forest, alpine tundra, salt marsh, warm desert scrub, coastal temperate rain forest and northern coastal scrub.

A vegetation type may contain many communities, each community differing in the species that make up the dominant plant growth form. In contrast to vegetation types, communities are usually named after their dominant species. Examples of communities within the mid-montane conifer forest vegetation include ponderosa pine forest, Douglas-fir forest, white fir forest, mixed conifer forest, and Sierra redwood forest communities.

A major difficulty in summarizing California's cover is finding a consistent classification system. Botanists have used different schemes to classify the region's plant cover. Some use names that emphasize the dominant plants, for example *redwood* forest or *pinyon-juniper* woodland. Some systems use physical features, for example *stabilized dune, alkali sink* or *freshwater marsh*. Others use systems that emphasize life forms, for example *annual grassland* or alpine *dwarf shrub*. Philip Munz and David Keck in their *Flora of California* list eleven vegetation types with twenty-nine plant communities, but Arthur Küchler uses a system of nine vegetation types and fifty-five communities, the U.S. Forest Service CALVEG description has forty-two "cover units," and the California Department of Forestry and Fire Protection maps thirty-two "cover types," and so on.

Another problem is that some of the systems map existing vegetation, while others map pristine (pre-Caucasian) vegetation. It is impossible to know the actual extent of California's pristine plant cover. However, good estimates can be made based on climate, soil, topography, and present day vegetation patterns. In many places—especially at low elevation—changes in several communities or vegetation types have been enormous; in other places the changes have only been subtle or qualitative.

A mosaic of grassland and oak savanna (in the foreground) with chaparral-covered hills in the background. Photograph by Tom Kittel.



Climatic Diversity

There are many factors that create vegetation diversity in California. Spanning more than ten degrees of latitude, California is a bridge between subtropical deserts in Mexico and temperate rainforests in the Pacific Northwest. Its western border is oceanic, its eastern is continental, and in between the land surface undulates between the highest and lowest points in the lower forty-eight states. Obviously, the geography of California creates climatic diversity which in turn creates diversity in natural vegetation.

Much of California has a climate called Mediterranean, because it is shared with lands bordering the Mediterranean Sea. Winters are cool and wet, summers are hot and dry. Hard frost and snow in winter are rare, but winters can be depressingly damp, cool, cloudy, or foggy. Summer temperatures may be in the 100s and one cloudless, arid summer day follows another, nearly unbroken from May through September. Almost all of the ten to thirty inches of annual rain falls in the months of October through March. This is not a common type of climate, and it is found in only three other parts of the world besides California and the Mediterranean rim: central Chile, the Cape region of South Africa, and southern and western parts of Australia.

Not all of California experiences a typically Mediterranean climate. Some areas are too wet, too cold, too dry or too coastal. Climate in the state varies in three dimensions: from west to east, north to south, and lowland to upland.

Along the coast there is very little temperature change from day to night or from season to season. This is because offshore water is a heat sink: it releases heat to the air in the winter and it absorbs heat in the summer. In addition, the offshore current is cold and air passing over it is cooled. When the cold air nears warm land it forms fog banks, and the fog shields the land from direct sunlight. As a result, summer temperatures along the coast are very moderate. This is a maritime version of the Mediterranean climate.

Moving eastward (inland) less than seventy miles, the moderating influence of the ocean is lost and typical Mediterranean conditions rule. Daily and seasonal temperature oscillations become magnified. Davis, for example, in the middle of the Sacramento Valley, experiences July days with a minimum temperature of 55 and a maximum of 100 degrees F., for a daily spread of 45 degrees F. Along the Bodega Bay coast, directly to the west of Davis, July days have a spread of only 7 degrees F. Winter nights are slightly cooler in Davis than along the coast, with a higher chance of frost, so the annual range of temperature – in addition to the daily range – also greater inland than along the coast.

Aridity increases from north to south. Crescent City, in northwestern California, receives seventy-five inches of precipitation a year (that's over six feet of water), but San Francisco receives twenty-five inches, and San Diego ten inches. The length and intensity of the summer dry period also increases to the south.

Both temperature and precipitation are affected by a third parameter, elevation. As air pushes east from the ocean, it reaches mountain ranges and is forced to rise. The air cools and some of its moisture condenses and falls as drops of rain or – if cold enough – as snow flakes and ice crystals. The rate at which heat is lost with elevation depends on the amount of moisture in the air, so it is not a constant. On average, temperatures in California mountains fall 3 degrees F. for every 1,000 feet of elevation rise. If you know your elevation and temperature, you can confidently predict the temperature at any other elevation in the vicinity.

Annual precipitation increases about seven inches for every 1,000 feet of elevation rise, up to about 8,000 feet elevation. Above that, most of the moisture has been wrung out of the air, and precipitation lessens. Thus, the high peaks of California mountains can be cold deserts. Patches of snow and ice remain on them all summer because of cold temperatures, not because of heavy precipitation. These mountain climates are too cold to be called Mediterranean. An upper elevational limit for Mediterranean climate is about 3,000 feet in northern California, 5,000 feet in southern California.

Finally, winds from the west push over the mountain tops and air descends along their eastern flanks, heating up and drawing moisture from the soil and vegetation. Eastern California lies in an arid rain shadow cast by the mountains. It is this rain shadow which contributes to the desert climate and corresponding sparse desert scrub vegetation. Points of equal elevation on western and eastern flanks show the rainshadow effect. At 7,000 feet elevation on the west flank of mountains in central California is a zone of maximum precipitation. Cathedral-like red fir forests are frosted with fifty feet of snow in winter. At the same elevation on the east flank, open pine woodlands with desert shrubs beneath receive modest snowfalls and only twenty inches of rain a year. The mountain mass "shadows" this east face by drawing off cloud moisture well before the westerlies get this far. Even farther downslope and to the east, the California desert receives less than ten inches of rain a year. The darkest rainshadow is cast upon Death Valley, which receives an annual rainfall of only 1.6 inches of rain.

In local areas, topography also affects climate. Slopes which face south or west are usually warmer and drier than slopes which face north or east. North slopes are shaded from direct sunlight, while south slopes receive sunlight almost at right angles to the ground. South slopes will experience higher temperatures than north slopes, and water will evaporate from soil and plants faster. East slopes receive morning light, when temperatures are relatively low, while west slopes receive

Conifer forests of the mid-elevation range of California mountains typically have four layers of plants: herbs that die back every winter; shrubs that retain leaves and stems under snow cover; understory broadleaf trees such as dogwood, California black oak, and hazelnut; and the dominant overstory conifer layer with evergreen needles.

afternoon light at the warmest time of the day, so west slopes are more arid. The vegetation of opposite slopes, as a result, is dramatically different, even though elevation, distance from the ocean, direction of prevailing wind, and regional climate are the same.

The Geologic Mosaic

The bedrock of California has been derived from many sources. Sediments that accumulated on the ocean floor were gathered as land by the shifting western edge of the continent. Volcanic deposits, formed from molten magma, were spewn as ash and lava onto the land surface. When magma was injected between existing layers of bedrock, it cooled slowly and crystallized as a different array of rocks and minerals. Further modifications were brought about by faulting, mountain uplift, glaciation, and erosion over long periods of time. California is now a mosaic of many kinds of bedrock, each with its own set of chemical and physical characteristics. Those characteristics directly influence soil development, which in turn influences the distribution and abundance of plant life.

Continents can be compared to slabs or plates of material many miles thick which sit fixed onto an underlying skin of the earth, the mantle. The mantle is not static, even though composed of solid basalt. It moves in a cyclic current, like water in a warm kettle. Basalt is heated deep in the earth, it rises and boils up at the surface, moves laterally as it cools, then sinks and is reheated once again, repeating a continuous loop.

One major crack in the earth's surface, far to the west of California, stretches north and south along the middle of the Pacific Ocean floor. Here, new mantle material reaches the surface. As it is extruded to become part of the sea floor, it moves slowly—two inches a year—to the east or west, pushed by yet newer material. As the sea floor moves, so normally do sediments, islands, and continents attached to it. However, 200 million years ago, the Pacific Coast of North America became uncoupled from the mantle: the mantle moved, but the plate stood still. As the mantle reached the edge of the continental plate, the mantle turned down and slipped under. Like a knife scraping butter from bread, the plate's edge removed sea floor sediment. With time, layer upon layer of sediment gathered on the west edge of the continent, and the continent built westward. This sediment became the principal bedrock of California. By 170 million years ago, enough sediment had been deposited to create the base of the future Sierra Nevada and Klamath mountains; and by 130 million years ago, sediment had created the future Central Valley and much of the base of the Coast Ranges.

Then, thirty million years ago, a different pattern of mantle movement began. The San Andreas fault system formed, splitting westernmost California from the rest of the North American plate. Land to the west of the fault began slipping north relative to land to the east, at a rate of two inches per year. Granitic rocks to the west of the fault stand out as unique islands, displaced from matching rocks far to the south on the other side of the fault. The granitic headlands of Point Arena, Bodega Head and Santa Cruz have moved 350 miles north of their original placement near Taft, San Fernando and Riverside.

During the past thirty million years, uplift, volcanism, and the intrusion of a chemically unique rock called serpentinite have added more complexity and mass to the Coast Ranges. Outcrops of serpentinite are concentrated near the San Andreas fault system. Elongated strips and ridges of serpentinite parallel the fault lines and cover 1,100 square miles of California. Unusual vegetation and many rare plants grow on these outcrops. There is a greater concentration of serpentinite here than anywhere else in North America. In honor of this, the California legislature has adopted it as the state mineral.

The Contributions of Soil

Terrestrial plants sink their roots into soil, obtaining moisture and essential mineral nutrients. The amount of water and nutrition available for plants in a soil depends upon the amount of clay present. Clay is the smallest of soil particles. Clay particles are microscopic and have a very regular, crystal-like character, made up of atoms of aluminum, silicon, oxygen and iron. The atoms are attached together in such a way that clay has a negative charge. As a magnet is able to attract iron filings to it, these bits of soil are able to attract positively charged nutrient ions, such as calcium, magnesium and potassium. These nutrients are held by the clay in the soil, preventing them from being washed out by percolating rain water. Soils which have very little clay—sandy, coarse soils—can always be assumed to be low in nutrients. They are also low in water content. Water is retained as a thin film on the surface of soil particles. The finer the texture of the soil, the more surface there is for water to adhere to.

Soil nutrients ultimately come from the raw bedrock, dust, lava or sand that spawned the soil itself. Limestone, granite, loess, sandstone, flood-deposited silt, and a variety of volcanic, sedimentary or metamorphic rocks all differ in chemical composition and the rate at which weathering wears them down into soil. Each parent material forms a soil capable of supporting some species, but not others. Some soils may have concentrations of particular essential elements too low for most plants to tolerate; some may have concentrations too high. Serpentinite rock, for example, produces a soil that is low in calcium, nitrogen, and phosphorus, but high in the heavy metals chromium and nickel. Only certain species can tolerate that combination. The vegetation of serpentine soil is characteristically open and scrubby. Islands of serpentine scrub lie surrounded by oceans of forest, the boundaries between scrub and forest corresponding exactly with boundaries between different parent rocks.

Soil depth also affects plant growth. It generally takes several hundreds to a thousand years to form each foot of soil. The deeper the soil, the more moisture can be stored and the more nutrients are available for root systems to tap. Very young soils are shallow and cannot support the same plant species and the same rate of plant growth as deeper and older soils. In the California foothills, grassland typically sits atop the deepest soils on gentle slopes, while a dense scrub called chaparral covers the shallowest soils on steep slopes. In some places, the distance between grassland and chaparral can be walked across in two paces. Clearly, the two kinds of vegetation are not separated by different climates. They occupy their different sites because of what exists below ground.

Now imagine one rolling square mile of California. Its hillsides face in all different directions. Some are steep and some are gentle. Add to that square mile a variety of soil types differing in chemistry, texture, and depth. This square mile has only one climate, but the vegetation is like a patchwork quilt. Grassland, scrub, woodland, and forest alternate with each other in a jigsaw pattern caused by topography and soil. Each unique patch of vegetation, then, is where it is because of local environment— the microenvironment—and not just because of the regional environment.

Fire: Destroyer and Creator

Mediterranean climates are fire climates. Lightning bolts frequently strike vegetation rather than bare earth. A certain fraction of these strikes will set fire to the landscape if the lightning is not followed by rain. In some places the frequency with which fires occurred in pristine California is preserved in the growth rings of old trees. If a fire scars the outer part of a tree trunk but does not kill the tree, the scar in time will be grown over by new wood and bark and will become buried in the wood. The date of the fire can be determined by counting the number of growth rings formed over the scar. Some long-lived trees have survived many fires, and have as many scars. Fires also leave beds of charcoal on

Introducing a CNPS Plant Communities Program

The California Native Plant Society has embarked on a new program with a goal of providing greater protection for rare plant communities. Because of the rapid loss of habitat in California, the protection of the assemblages of species found in rare plant communities appears to be an urgent and important project for the Society to undertake.

At present, a Rare Community Scientific Advisory Committee is being formed, using the existing CNPS rare plant committee as a model, with representatives from the academic community, federal and state resource agencies, and CNPS. The first task of the new committee will be to adopt a single community classification system based on an existing system such as the Cheatham-Haller, Holland or Forest Service system and to coordinate information with the Department of Fish and Game. When this background work is completed, workshops will be held with chapters on the theory and practice of identifying and measuring plant communities, and the committee will develop joint projects with chapters members. The success of the new plant communities project will depend on the level of involvement of chapter members; the committee looks forward to developing this important new cooperative effort.

To implement the project goal, the project organizers hope to develop a defensible list of plant communities of special concern within two years which will be useful for local conservation efforts.

Marlyce Myers, Bruce Pavlik and Cyndi Roye the ground surface, and in time these become buried by new soil. In some places, layer after layer of buried charcoal occur beneath the current soil surface. The charcoal can be aged by a process called carbon dating. We also have historical accounts, by early pioneers, as to the frequency with which they saw natural fires and the intensity with which these fires burned.

Analysis of this kind of evidence shows that fire frequency was not constant over the entire state. Its frequency depended on the type of vegetation. Grasslands burned more frequently than scrub, scrub burned more frequently than some forests, and other forests burned very rarely if at all. In general, fire was a regularly expected natural event in many Californian vegetation types below 6,000 feet elevation, and the same acre of ground could be expected to burn every ten to fifty years. Fire was uncommon in wetlands, deserts, and at high elevations.

Not only do many Californian plants survive fire, but some appear to require fire in order to complete their life cycle or to remain vigorous. Some vegetation types that require fire to maintain their hold on the land are completely consumed by a fire. Others have an architecture that directs fire down to the ground, where it consumes litter, herbs, shrubs, and saplings, but leaves overstory canopies unharmed. John Muir witnessed both kinds of fires on a summer day while travelling through the mountain forests of the southern Sierra Nevada.

"... I met a great fire, and as fire is the master scourge and controller of the distribution of trees, I stopped to watch it ... It came racing up the steep chaparral-covered slopes of the East Fork canyon with passionate enthusiasm in a broad cataract of flames, now bending down low to feed on the green bushes, devouring acres of them at a breath, now towering high in the air as if looking abroad to choose a way, then stooping to feed again ... But as soon as the deep forest was reached the ungovernable flood became calm like a torrent entering a lake, creeping and spreading beneath the trees where the ground was level or sloped gently, slowly nibbling the cake of compressed needles and scales with flames an inch high, rising here and there to a foot or two on dry twigs and clumps of small bushes and brome grass."

In the past 200 years, human immigrants to California have sometimes increased the frequency of wildfire and sometimes decreased it. Our present public policy of fire suppression is only eighty years old, and it follows an earlier pioneer period during which carelessness and ignorance increased the frequency and intensity of wildfires beyond those of pristine times. By increasing, then decreasing, the natural fire frequency, we have had a profound and unexpected effect on California's vegetation. In the absence of fire, plants requiring fire are replaced by others, normally kept out by their intolerance to fire.

Variations Through Time

Climate and vegetation have changed dramatically during the long history of the California landscape. Ten million years ago a Mediterranean climate began to develop in California. Rainfall declined and summer aridity became more and more pronounced, with a few exceptional periods of unusual cold and heat. In the midst of a glacial age 1 million years ago, California experienced temperatures several degrees colder than at present and desert vegetation was pushed far to the south. Many mountain features were carved at that time by glaciers which descended as low as 4,000 feet in elevation, then retreated to high alpine cirques by 12,000 years ago. About 8,000 years before the present, the climate was several degrees warmer than at present; desert vegetation exploded outward and timberlines pushed higher. That warm, dry period—called the Xerothermic—ended about 5,000 years ago.

Our most recent 400 years of climate appear to have been stable, at least according to one study based on tree ring analysis. Besides telling the age of a tree and its fire history, woody plant growth-rings document past climate. Using a precision borer, a pencil-thin tube of wood is extracted from a tree. Under a low-power microscope, rings can be measured and inspected. The wetter the growing season, the wider the growth ring. Joel Michaelsen and others used tree-rings from stands of big-cone spruce to reconstruct a precipitation history for central Santa Barbara County. They found little cumulative long-term change in overall mean rainfall in the last 400 years, but major fluctuations within that period. The years 1841 through 1845 were the driest, with average rainfall of ten inches per year. The twenty-five-year period 1841 through 1864, a time of intense livestock grazing, was marked by drought. Major vegetation changes occurred at this time in the grassland valleys of California. The wettest period was 1905 through 1909 with a mean of twenty-six inches.

Today, there is evidence that the climate is again warming and drying, possibly because of human activity. Over the past 100 years, the concentration of carbon dioxide has increased nineteen percent. Another century of such change will raise global temperature several degrees, enough to melt polar ice, raise sea level, and shift the location of land habitable for humans. It could be equally likely that the pattern of glacial advance and retreat, characteristic of the past two million years, is not yet broken. We may, in that case, be in the middle of an interglacial and a new glacial advance will begin 15,000 years in the future, bringing colder temperatures and a retreating sea level. Small comfort, however: a glacial advance will have as profound an effect on the location of habitable land as a warming climate. Either way, humans will face an enormous challenge, and California vegetation will inevitably change in response to both climate and civilization.

The history of California's vegetation extends far beyond the last ice age. Daniel Axelrod, of the University of California, has spent a lifetime reconstructing the geologic history of California's vegetation. Through his work we know about the changes in plant cover over the past sixty million years.

Tree ferns, palms, cycads and larged-leaved tropical plants found in the Californian geologic record represent a Neotropical-Tertiary geoflora. Their presence implies a past climate with heavy summer rain and dry frost-free winters. With later climatic cooling and drying, these plants became restricted to the south and the coast. Today they are mainly found in southern Mexico and Central America.

Conifers such as spruce, certain pines, and fir and deciduous hardwoods such as maple, beech and elm that are present in the geologic record represent an Arcto-Tertiary geoflora. Forests forty million years ago were much richer in species than today. An uplift of mountains, a drop in summer rainfall, and an increase in extreme temperatures caused the rich forests to fragment. Redwoods became restricted to mild coastal climates. Pines and firs moved upslope into high montane forests. Many of the Asian elements of this flora, like ginkgo and dawn redwood, disappeared altogether from California.

A Madro-Tertiary geoflora, named for the Sierra Madre of Mexico, is represented in the geologic record by close relatives of modern madrone, live oaks, pinyon, chaparral species and desert shrubs. It moved into California from Mexico as the Mediterranean climate became more and more pronounced. Today, descendants of this geoflora dominate low elevation vegetation throughout most of the state.

Some of California's plants are recent arrivals from other parts of the world. In 1769 Father Junipero Serra founded the first Spanish settlement in Alta California at San Diego Bay. He brought three exotic weed species with him. By 1824 at least sixteen exotic species had became established in California. We know their number and their date of introduction because identifiable plant parts were trapped in adobe bricks made to build the chain of missions. When botanists break open the bricks, they can reconstruct the past surrounding vegetation by sorting through plant parts accidentally baked into the clay. During the Mexican occupation of 1825 through 1848, an additional sixty-three species were added. Pioneer American settlements of 1849 through 1860 brought fifty-five more. In 1925 292 species of non-native plants were part of the flora; in 1951 there were 437 species; in 1959 797 species; in 1968 a total of 975 species.

Nearly a thousand species is a large number, but we can be sure many times more species arrived here but were not successful in their new home. In addition, a diversity of garden and crop plants, ornamental shrubs and trees, and wild plants have been brought to California that cannot live outside of cultivated or manicured landscapes. Something unique in the biology of those one thousand successful weeds permitted them to run wild in California's cover. What makes a successful weed?

The giant sequoia *(Sequoiadendron giganteа)* of the Sierra Nevada is the most massive plant species on the face of the earth. Photograph by William T. Follette.

Herbert Baker, a botanist at the University of California in Berkeley, once concocted a list of traits that the "ideal" weed would possess. No single weed species has all of those traits, or we would be ankle deep in that species. Baker's list of traits for a farmer's nightmare includes fast growth rate, early maturity and reproduction, an abundant production of seeds, a prostrate habit, fragile stems, the capacity for wind or self-pollination, tolerance of full sun, and seeds capable of long-term dormancy in soil. These traits are most easily combined by small, annual, herbaceous plants. Large, perennial, woody weeds such as gorse, eucalyptus, and Scotch broom are obvious in the landscape, but the territory they have claimed and the numbers of their species are very modest compared to annual herbs. Most California weeds originated in other

Mediterranean climate regions and occupied disturbed or degraded habitats there, so they were well adapted to the California of the nineteenth and twentieth centuries. We may be sure that other potentially successful weeds still remain to be introduced to California.

The Changing Vegetation

Does anything ever stay the same? It depends on what span of time we have in mind. Over geologic time, we do indeed live on a restless earth. Land masses shift, plants and animals evolve and migrate, and climates undergo enormous change. The shape, climate and vegetation of California today are relatively recent. A patch of ground now supporting arid desert scrub at one time held subtropical rain forest, and it may do so again in the future.

Changes in Vegetation Types or Communities

Some examples of vegetation types or communities that have changed in acreage from pristine times, 200 years ago, to the present. Pristine (pre-european) acreage was estimated and mapped by Küchler (Barbour and Major 1977); present acreage has been estimated by the California Department of Forestry and Fire Protection (1988).

Vegetation or community	Pristine	Modern	% Change
Forests and woodlands			
cedar-hemlock			
Douglas-fir	2,015,696	1,772,000	−12.1
mixed conifer	13,641,010	9,268,000	−32.1
redwood	2,320,254	1,570,000	−32.3
ponderosa-shrub	1,695,108	2,651,000	+56.4
pinyon-juniper	2,463,517	1,463,000	−40.6
juniper-steppe	909,668	1,469,000	+61.5
oak	9,554,518	9,412,000	−1.5
Scrub			
chaparral	8,500,585	7,762,000	−8.7
montane chaparral	573,051	1,039,000	+81.3
coastal sage	2,473,535	2,507,000	+1.4
saltbush-greasewood	3,104,692	1,299,000	−58.2
Herbaceous			
north coastal bunchgrass	878,711	90,000	−90.0
needlegrass steppe	13,222,242	1,000*	−99.9
annual grassland	1,000*	8,653,000	+8,653.0
tule marsh	1,859,409	576,000	−69.0
alpine meadow	747,370	238,000	−68.2
Urban-agriculture (excluding grazing)	1,000*	15,211,000	+15,211.0

*Our estimates, added to permit calculation of percent change.

A second reason for change is the occurrence of short-term environmental catastrophes, such as fire, disease outbreaks, drought, avalanche, and flood. Following a catastrophe, plants must reinvade the site or begin growth from whatever live parts remain. Where once a montane conifer forest combed the whispering air, an all-consuming wildfire has sent biomass back to ash and bare ground. In a few years, there will be a meadow of perennial grasses and forbs; in a decade, a parkland of aspen growing over the herbs; in a century, an invasion of young conifers beneath the aging aspen; and finally a return to the original conifer forest.

This process of recovery can at times be slow—requiring decades or centuries—and so much longer than a human lifespan to complete that the reality of continuous change escapes the casual observer. Yet changes do inexorably accumulate. Vegetation which changes within centuries is called successional; relatively stable vegetation is called "climax."

These days, human activity is also capable of changing the environment. The new environment sets a process of vegetation change in motion. What had been climax vegetation for millennia now becomes successional, and a new climax vegetation shall come to be. These future climaxes are not predictable. Under the stresses of ozone and acid deposition, what will the new climax montane conifer forests become? With a continued fire suppression policy, what new climax will chaparral become? What new desert scrub climax waits for us, as a result of chronic overgrazing?

During millions of years of geologic time, entire California landscapes have been created and eroded, whole floras migrated north and south as climates shifted from tropical to arid. In historic time, change has come to pass in little more than 200 years—a span of only half a dozen generations. These recent changes in California have been caused by a rising human population, as well as a shift in its ethnicity. Two hundred years ago there were 300,000 American Indians in California. Today, there are nearly thirty million humans, largely of European, Asian, African and Central American extraction. Fewer than 50,000 Indians remain. Human demands on the environment are drastically different than those of the past, but the notion of endless prosperity based on natural diversity is still part of the California myth.

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(This article, printed with permission of the authors, is Chapter One of a soon-to-be-published book, California's Changing Landscape: The Diversity, Ecology and Conservation of California Vegetation, *by Michael Barbour, Bruce Pavlik, Frank Drysdale and Susan Lindstrom. Publication information will be forthcoming in* Fremontia.*)*