Phase 2 Draft

Introduction
to
Holistic
Restoration Forestry

Forested Landscapes
of
Southwestern Oregon and Northern California

By Dennis Martinez

Phase 1, January, 2002
Phase 2, March, 2003

Contents

Part III

Restoration Forestry: Integrating Ecosystem-Based Knowledge with Silviculture and Tree Harvesting Systems

PART IV
The Four Physiographic Provinces of Southwestern Oregon and Northern California

PART V
Restoration Forestry: From Theory to Practice

Part VI
Forest Economics: Financing Restoration Forestry

Introduction to Holistic Restoration Forestry

Forested Landscapes of Southwestern Oregon and Northern California

By Dennis Martinez

Phase 1 - January, 2002
Phase 2 - March, 2003

Introduction

The Introduction to Holistic Restoration Forestry is a first attempt to develop a core curriculum for teaching restoration forestry to forest workers, wildcrafters and cultural harvesters, restoration practitioners, agency and private forest managers, tribal foresters, environmental activists, and students in environmental studies. It is in outline form with each topic summarized or condensed in a running narrative, although some sections have been expanded into final complete form. Two of four writing phases have been completed to date.

The March, 2003, update and revision (phase 2) includes a new section describing forest types from valley grasslands to subalpine forests in the Northern Sierra Nevada Mountains and the Southern Cascade Mountain physiographic provinces. Also, considerable material has been added to the subject of the relationship between the larger forested landscape or matrix and stand level restoration. The section on Conservation Biology and Landscape Ecology has been considerably expanded, especially their relationship to restoration ecology. More has been added about restoration principles and their relationship to silviculture and timber harvest systems. New or revised material is scattered throughout the manual. Phases 3 and 4 will expand the manual to include descriptions of forest types in the California North Coast Ranges and the Klamath-Siskiyou Mountains, as well as provide recommendations for restoration prescriptions tailored to specific forest and vegetation types. The research for this has already been completed, but time and budget constraints didn't permit including the complete write-up in this phase. It will appear in phase 3. Also to be included in phase 3 are more information on Native American cultural activities in the four mountain or physiographic provinces and their forest types, as well as case studies in actual restoration projects. Some attention will also be paid to restoration monitoring and performance standards. Phase 4 will deal with the economics of restoration forestry, including small diameter utilization, slash disposal, restoration in roadless areas, community infrastructure and capacity building, non-timber and non-traditional wood fiber products, and sustainable forestry certification.

This summary is by no means complete. It does not deal with aquatic ecosystem restoration. Other important topics which were not included due to time constraints were wildlife and forestry, exotic species control, landscape photographs (especially historical changes), Native American cultural activities, case studies and examples of on-the-ground forest restoration (both successes and failures), monitoring, a bibliography at the end of each of the three parts, a glossary of forestry terms, and a common plant name/botanical plant name index at the end of the manual.

Native American burning is included in "ecosystem-based knowledge". Intentional fire, and the cultural landscapes which fire helped create and maintain, are not considered a special case here. Indigenous Traditional Ecological Knowledge (TEK) and forest management practices are treated the same as Western Ecological Science (WES). Both are necessary for successful restoration forestry. We simply don't know enough to somewhat arbitrarily exclude human cultural landscapes. They are legitimate reference ecosystems for restoration. An impressive amount of ethnographic research supports this assertion.

I have found it necessary to first uncouple silvicultural techniques and timber harvesting systems from ecological restoration before reconnecting them in a new restoration framework. This is primarily because both industrial and its "light touch" counterpoint (e.g. individual tree selection cuts) are still more influenced by silviculture than ecological restoration. Silviculture is a tool, a means of restoration, not the end. Too often in restoration forestry, the *means* have become the ends. We hope that a new, more holistic restoration framework will better address our present crisis in forest ecosystems. It just may be possible to restore our forests *and* our rural and tribal economies at the same time.

Part I

Why We Need Forest Restoration: Assessment of Current Ecological Crisis

1. Defining Forest Health

Ecosystem scientists use several concepts to describe **forest health**. Among these are "integrity", "function", "resiliency", and "stability", **Integrity** is that which is whole or undiminished. That means that a healthy forest is one which has all of its parts intact. "Parts" include forest structure, composition and ecological processes. **Structure** means the way in which above-ground living and dead biomass is configured or arranged in the landscape. Examples are age, size, and spacing of trees or shrubs; patches of herbaceous plants like ferns, grasses, and forbs; and down wood and snags. **Composition** means the above-ground kinds of plant species as well as mosses, lichens and liverworts which make up the forest, and the kinds of animals (including insects) which live in the forest. It also includes the below-ground fungi and insects which decompose dead animals, litter drop, old plant parts, dead wood, etc., as well as kinds of rock and soil types. Ecological **processes** include all of the biogeochemical phenomena which contribute to ecological **function**. These include fire, water quality and quantity, clean air, litter decomposition and nutrient cycling, genetic flow (exchange of genes between and within populations of a particular animal or plant species), drainage, herbivory, etc.

If enough of the key structures, composition, and processes are intact (i.e. the forest ecosystem has sufficient **biodiversity** to maintain its **integrity**) then we say that the forest **functions** well, possesses **resiliency**, and **relative stability**. Resiliency means that the forest has the capacity to resist normal disturbances like fire or insect and disease infestations (disturbances with which it is historically familiar) without losing its predisturbance function or stability; or, if these kinds of familiar disturbances are particularly intense, it can quickly recover to its predisturbance state. **Relative stability** is related to resiliency. It means that a forest ecosystem has enough resiliency to persist in its structure, composition, and processes - - i.e. its normal function - - over time. It does not mean that forests are static. Change is constantly occurring but it is happening at a rate which - - barring the rare catastrophic disturbance - - is fairly constant over time. We call this a **dynamic equilibrium.**

The kinds of changes we are talking about are "familiar" to forest ecosystems. That means that forests have co-evolved with and adapted to certain disturbance thresholds e.g. certain intensities, mean return intervals, and seasonality of fire. "Foreign" kinds of disturbances are those outside what we call the **historical range of variability**. They are disturbances with which forests have had little evolutionary experience.

2. Why Our Forests Are Unhealthy

A. Loss of Resiliency and Evolutionary Adaptive Capacity

Our forests today are experiencing disturbance events which are completely outside the historical range of variability. In other words, the rates and kinds of changes now happening exceed the adaptive capacity or resilience of forest ecosystems. Forest plants and animals evolve slowly. When change happens too rapidly, evolutionary adaptive opportunities are lost to those kinds of native plants and animals which prefer a relatively stable environment, while evolutionary opportunities are opened up for species which thrive in an unstable environment, such as opportunistic **exotic** (introduced) species or native **generalist** species. Generalist species are those which have a wide **ecological amplitude**, i.e. they can establish themselves in a variety of forest habitats.

B. Loss of Beneficial Kinds of Forest Disturbances

(1) Native American Burning

North American forests have adapted to human cultural practices as well as "natural" disturbances. In the Klamath-Siskiyou Mountains, Southern Cascade Mountains, California North Coast Ranges, and Northern Sierra Nevada Mountains of southern Oregon and northern California, Native Americans have been active forest managers for at least 12,000 years. Indigenous human cultures have been influenced by and have adapted to forest dynamics just as the forest has been influenced by and has adapted to human cultural activities. This is called **human ecology**. Human ecology overlaps with forest ecology.

What kinds of Native American cultural practices have influenced forest ecosystems? Tribal economies depended mainly on intentional or prescription fire. For example, in coastal California, 65% of Indian material culture was based on plants. Of that 65%, around 75% depended on plant species which could not be used unless already burned. The burning stimulated new growth that was more suited to cultural needs (**epicormic sprouts** and **adventitious shoots**). This was also true of most of the Pacific Northwest.

Indians had to fire-manage a variety of cultural products (**culturally modified plants**): baskets, cordage, clothing, structures, musical instruments, snares and traps, hunting and fishing gear, ceremonial items, firewood, games, weapons, tools and cooking implements, medicine, food, and wildlife habitat. To give you just one example of the enormous quantities of plants which needed to be burned on a regular rotational basis, one deer net 40 ft. long took 7000 linear feet of cordage which depended on 35,000 stalks of milkweed or dogbane which had been burned the year before. Up to 150 of these nets were used in a single deer hunt. Burning was done at all elevations below timber line and in most forest types. Fires were usually cool forest underburns done in the fall but sometimes occurred in the spring, and burned mostly understory vegetation, litter, and tree seedlings or saplings without getting into the tree crowns and burning the entire forest.

But the burning was selective. Many places were left unburned for varying lengths of time. Some patches of cultural plants were burned every year, others every 2-20 years or more. Mountain ridges, important travel corridors, were kept relatively open with fire, with only a few scattered old growth trees. Open ridges served as fuel breaks which prevented fires from moving from watershed to watershed. This pattern of Indian burning, along with natural lightning fires, helped maintain a very diverse kind of forest, with large and small sunny forest openings and meadows alternating with denser, shadier forest patches. Some forest types - - e.g. coastal Pacific northwest Red Cedar/Hemlock or Redwood / coastal Douglas-fir - - had relatively close tree spacing (structure) while others - - e.g. interior pine / oak and Douglas-fir - grew in very open, parklike stands or even savanna structure. Native Americans burned forest patches of cultural plants even in coastal Washington and British Columbia, but fire had less impact on tree regeneration due to the cooler and moister climate. And, every several hundred years, particularly during prolonged droughts, fires would get into the crowns of the overstory trees and consume major portions of the forest (e.g. Oregon coast ranges in the mid 1800's). But even these large stand-replacing or catastrophic fires would burn unevenly enough to leave various sized patches of unburned vegetation. Lightning fires were, of course, not dependable enough for managing, in particular places over a long time, the huge quantity of cultural plants and wildlife habitat that tribal economies depended upon. Tribal economies would have collapsed without regular and extensive prescription fire. Still, lightning fires played an important role also in creating and maintaining landscape **heterogeneity** (diversity), especially in interior forests of the Klamath-Siskiyous, Northern Sierras, and Southern Cascades.

(2) How Native American and Lightning Fire Benefited Forests

In what ways did regular low-intensity fire benefit forest ecosystem function and resiliency?

a. Relative Stability

The relatively open forest structure created and maintained by intentional (and sometimes lightning) fire helped stabilize the forest environment. Today's forests are increasingly subject to catastrophic stand-replacing fires because trees grow very close together; smaller understory trees and brush carry fires into the overstory (called **ladder fuels** which lead to **crown fires**); and because too much down or dead wood and forest slash all contribute to a very high **fire hazard**. Today's frequent stand-replacing fires, which are totally outside of the historical range of variability, are mostly the result of fire suppression. Modern industrial forestry, which we will see later has contributed the most to forest degradation, wanted to protect regeneration of commercially viable young trees, so Indians, along with ranchers, railroaders, and homesteaders, were forced to stop burning in the forest. Modern forestry could not have begun until Indian fires ceased.

b. Nutrient Cycling and the Herbaceous Understory Vegetation

Fire contributed to optimum forest function. Nutrient cycling (the recycling of dead plant parts into fertilizer) takes place in several ways. When beatles invade trees they bring nitrogen-fixing bacteria with them. They take nitrogen - - probably the most important fertilizer - - out of the air and make it available to trees in the form of ammonia nitrogen. Insect and bacteria decompose wood (e.g. sow bugs, flat-headed wood borers, carpenter ants, termites) and release nutrients. Mychorrizal fungi help tree roots take up nutrients and water from the soil. Some species of fungi produce spores underground in fruiting bodies called "truffles". Some animals (e.g. northern flying squirrel and California redbacked vole) eat the truffles and inoculate soil, large down wood, and living tree roots with their droppings. Certain lichens and mosses which grow on trees also contribute nutrients when they fall to the forest floor. And, of course, fire breaks down forest litter and needles into usable nutrients.

The above kinds of ways forests get regular fertilization, however, are not the whole story. Following disturbances like fire, **pioneer** or **early successional** plant species which can supply nitrogen to the soil they occupy by "fixing" it from the atmosphere through *Rhozobium* bacteria which inhabit their roots, enrich the soil for future (**later successional**) tree growth. The gaps created in the forest by windthrow, disease, fire, etc. may support a rich assemblage of **forbs** (herbaceous non-grass or broadleaf plants) and grasses whose perennially decomposing roots contribute organic matter to the soil and stimulate biological activity. This is the internal soil environment - - including the soil fauna and flora associated with organic matter - - that assists in the cycling of externally sourced nitrogen and other nutrients mentioned above. Nitrogen-fixing **leguminous** plants (e.g., clovers) help maintain the grasses and forbs. These kinds of dry meadow or forest gap soils are much richer in organic matter - - and may store more carbon - - than typical forest-tree soils, or even some types of woody forest vegetation. The loss of this herbaceous understory in most forest ecosystems, under full **canopy closure** and with **stocking rates** (trees per acre) outside the historical range of variability by a factor up to 40 or 50 times pre-fire suppression numbers has had many negative results:

1. loss of quality habitat for wildlife
2. a heavy litter layer intercepts rainfall and fog-drip before it can get into the soil
3. fungal mats develop underneath the litter layer which also intercept water and create **hydrophobic** (water resistant) **soils**
4. loss of insect pollinators and seed-carrier species, and the plant species they service
5. loss of fine fuels which can carry low-intensity fires (especially in true fir, hemlock, redwood, and cedar forests - pine being the exception because its needles don't lie flat on the forest floor like the others).

6. loss of ground water due to heavier **evapotranspiration** (water loss) by shrubs and trees, putting stress on mature and old-growth trees, which in drought years can lead to beetle and other insect epidemics, as well as serious mistletoe infestations. Woody plant invasions are slowed by the forb-bunchgrass association due to the formidable bunchgrass root systems.

7. loss of soil organic matter, fertility, and biological activity

8. loss of important soil carbon storage sites

9. loss of soil permeability and infiltration capacity (in some soils)

10. loss of soil oxygenation (in some soils)

These are examples of the interrelationships between forest structure and function: structure influences function and function in turn influences structure. And it underscores the reciprocal relationship between plant and animal composition and forest structure.

As dense stands of conifers replace the former abundant diversity of understory plants, only litter and needles are found on the forest floor. Since conifer needles are saturated with chemicals used as a defense against insect defoliators, they decompose too slowly to be of much use for adequate nutrient cycling. Fire releases the nutrients in the needles (and other kinds of leaves) rapidly, but without regular fire the needle litter will slowly build up again. And nutrients will stay locked up in the litter. Although total nitrogen will be decreased by volitization to the atmosphere by fire in the short term, more nitrogen will be made immediately *available* to plants following fire.

c. Hydrologic Function

Another important function is the way water flows through forest ecosystems (**hydrologic function**). Indian fire thinned forest trees as well as understory brush. These tree and brush species all take up huge amounts of water in a process called **evapotranspiration**. Water is pulled up to the leaves and released to the atmosphere. Little trees and brush today choke forest stands. Old trees suffer from competition by the younger trees. Consequently, many old trees die during droughts. Drought-stressed old growth is vulnerable to beetle infestations. Wood-boring beetles sense when a tree is in distress and send out "pheromones" (chemical messages) to other beetles to enter the targeted tree.

Indian fire and lightning kept older trees well-spaced while destroying much (but not all) tree and brush regeneration which now competes with the larger trees. Less water was lost to evapotranspiration, therefore more water was retained in the soil (ground water). More groundwater kept springs, aquifers, and streams flowing well into the dry months. Many seasonal or "ephemeral" streams today used to flow all year long. More water **quantity** meant better quality habitat for aquatic species like salmon or trout. The water was also cooled as it flowed underground to the headwaters of streams, thus contributing to **quality** aquatic habitat. Fish need cool water in the warm months. Water moved evenly and steadily through the system, and was released slowly into streams. The watershed acted like a giant sponge, absorbing and then releasing water slowly. Today, water is released too rapidly following heavy rains and causes flash floods. This is partly due to extensive soil compaction resulting from heavy logging equipment; and partly due to abundant clear-cuts in the snow belt where snow - - not intercepted by overstory trees - - piles up and then melts rapidly following heavy rains. Our region is called the "warm snow belt" because we often experience rain-on-snow events that cause flash flooding. It is also partly due to the general imbalance in forest vegetation due to fire suppression coupled with forest ecosystem simplification caused by industrial logging. These are examples of "foreign" disturbances with which the forest is not familiar.

d. Net Primary productivity

Net primary productivity measures the function of the whole forest ecosystem in terms of the total annual incremental growth of all plants. This should be distinguished from the annual incremental growth of commercially important tree species (**timber productivity**) which provides the silvicultural basis for so-called "sustainable" timber harvesting, i.e. you cut no more each year than the new tree growth which is added each year. Net primary productivity measures the growth of all plant species - not just trees. Good annual growth could mean good function. But this is not always the case. That is why we need to measure as many key functions as possible.

Fire suppression has encouraged more shade **tolerant** tree species like Grand Fir, White Fir, incense cedar, red cedar, and western hemlock to outcompete the more sun-loving **intolerant** species like pines, oaks, and Douglas-fir. The shade tolerant species can grow in the shade of the dominant intolerant species until they overtop and shade them out. Indian fire created a mosaic of diverse habitats - - very shady to very sunny - - across the landscape (landscape **heterogeneity**). Thus more kinds of species (**composition**) thrived in this more diverse kind of forest - a forest with numerous openings and meadows of varying sizes and shapes (**structure**) as well as denser unburned places.

e. Secondary Productivity

Secondary productivity measures the animal species which are supported by forest plant species (**net primary productivity**) in their **diversity** (**species richness**) and their population levels. As we saw above, diverse forest habitat encourages species richness or diversity. Again, with the suppression of Indian fire management and lightning fires in order to save commercially important tree species for industrial logging, the forest lost a critical kind of familiar disturbance. It should be noted, as we shall see later, that species richness is not necessarily sufficient in itself to contribute positively to forest ecosystem function. The *kinds* of species (**composition**) in any assemblage or association is also important. Quantity doesn't always indicate quality.

Why animal species richness and composition is important to the function of forest ecosystems

- We've already discussed the role of certain **arboreal mammals** (mammal species that spend at least part of their lives in trees) like northern flying squirrel and California red-backed vole in spreading fungi spores which inoculate tree root tips and thereby enhance the **nutrient cycling** function of the ecosystem. Lack of forest underburning is leading to a lack of food sources for many arboreal mammals, some of which rely on herbaceous vegetation in the more open understory in addition to truffles, bark, needles, etc. of the shadier forest.

- Insects and birds, as well as some mammal species, act as pollinators and seed-carriers for numerous flowering plants. This contributes to **genetic diversity** (see below) and was the result of the widespread use of Indian fire. With the forest now closing up, sunny openings with flowering plant diversity are being lost. Studies show, for example, that up to 90% of forest insects inhabit non-conifer flowering plants and grasses.

- Herbivores like deer or rabbits can devastate forest vegetation unless kept in check by predators like cougars and wolves or coyotes. These predator species are called **top carnivores**. Large healthy populations of top carnivores prevent excessive grazing or browsing of forest plants which preserves their roles in the ecosystem. One important role is **herbivory** (browsing of plants by animals) which, in light to moderate amounts, assists in rejuvenating plant growth as well as stimulating optimum flower and seed production. Herbivory has an effect similar to cool forest understory burns on vegetation. Native Americans were key top predators - along with wolves, cougars, etc. Hunting served an important role in protecting native forest plants. We are now experiencing massive imbalances in predator-prey relationships. This is contributing to overgrazing and overbrowsing of native vegetation. Many top predators are either extinct or threatened with extinction, including Native Americans.

- Several different animal species may perform the same function in the forest. (e.g. several insects and birds may pollinate the same flowering plant). This is called **redundancy**. The more varied or diverse the forest habitat and the more species which do similar ecological jobs, the better the redundancy. Redundancy contributes to forest **resiliency**, i.e. if one or two species are lost, there will still be others to take up the slack. Numerous species lack sufficient numbers to play an effective role in ecosystem redundancy because of lack of enough habitat diversity due to fire suppression.

f. Genetic Diversity

Plants and animals adapt slowly over time to changes in their environment. If the rate of environmental change is familiar, species have time to adapt and evolve enough to keep pace with change, i.e. those species which are better adapted will survive to reproduce. This is called **natural selection**. Natural selection is the principal mechanism of evolutionary development. Even subtle genetic differences in a diverse environment can confer a survival advantage on a population or species. That is why **monocultures** - - like plantations of the same genetic population of a tree species - - are particularly susceptible to disease.

Habitat diversity coupled with environmental change at a rate which doesn't exceed the historical range of variability offers evolutionary opportunities for many forest species. But changes which are too rapid and/or of a foreign nature open up evolutionary opportunities for non-native and native weedy species which take hold and thrive in an unstable environment. That is why weedy species are now moving into excessively disturbed forest ecosystems and crowding out more stable or **conservative species**, i.e. species which require specific and relatively stable ecological **niches** or habitats. The simplification and homogenization of forests as a result of plantation forestry and fire suppression bring evolution for conservative natives to a standstill. And so these species slowly drop out of the forest.

Scattered large clearcuts (**staggered setting clearcuts**) fragment the forest and separate populations of plants and animals. Species can no longer exchange genes between their scattered and separated populations (**metapopulations**). This lowers genetic diversity (**genetic fitness**) within each disjunct population. Species then exchange fewer genes - - including genes which have adaptive value - - resulting in **inbreeding**. Inbreeding causes physiological and behavioral problems, as well as lower survival and reproduction rates. Genetic variation enhances the ability of species to persist over evolutionary time even as their environment changes. Thus habitat diversity leads to plant and animal diversity or richness.

As plant species slowly die out or become less abundant and poorly distributed across the landscape, pollinators also die out. E.g., an insect will visit flowers for nectar or pollen only to the point where enough individual plants in a population make it a "cost-effective" use of energy. When the plant population is too low, they will move on to another patch instead. The remaining plants in the patch will then go unpollinated and die out. Pollinators too will eventually become extinct. That in turn will cause the loss of insect prey sources for birds and some arboreal mammals (e.g. northern flying squirrel…the squirrels rear their young on insects, 90% of which live on non-conifer flowering species) and reptiles and amphibians, which will also experience survival difficulties. These prey-predator linkages are part of what ecologists call **food chains** or **food webs**. If they unravel too much, the whole ecosystem begins to lose **integrity**, which in turn causes loss of **relative stability**, **function**, and **resiliency** in an ever-descending spiral of degradation. At some point or threshold, damage is irreversible without the assistance of restoration.

C. The Western Concept of Nature and Its Role In Ecological Degradation

We have discussed ecological degradation caused by the cessation of Indian burning enforced by law, genocide, and relocation (the reservation system). We have shown that large-scale and intensive industrial timber harvesting could only begin to take its pervasive modern form with the stopping of Indian fires in order to save commercially important tree **reproduction** or **regeneration.** We well now discuss the part played by Western (European) philosophy of nature in the rise of and the justification for destructive industrial timber harvesting as well as the counter-industrial resource conservation and wilderness preservation movements of the past century.

We have said that the forest is constantly changing at a familiar rate, and that any disturbances or rate of change which is not familiar (i.e. **outside the historical range of variability**) can cause loss of **resiliency** such that the ecosystem is not able to recover to its predisturbance state.

European Christian philosophy has long held the view that God reveals Himself in nature. To know the universe is to know God. This has been a major driving force in the development of Western science, although its original motivation has been long forgotten. Sir Isaac Newton, the father of modern physics, believed that God made a perfectly balanced universe which, once created, would continue to function perfectly as long as it was not interfered with by anyone. God was like a master clock-maker in Newton's thinking, and nature was like a finely tuned clock. It was perfect just like God.

It is not surprising that in an industrial age a machine metaphor was used to describe nature. Nature, like a perfectly balanced machine, was capable of rebalancing herself if disturbed. Philosophers call this **homeostasis**. Homeostasis is based on the belief that nature operates like a machine. That belief has a religious or metaphysical basis. It is not the way that we now know nature to be - - ever changing and highly complex, yet vulnerable to damage and degradation caused by human cultural practices which are ecologically inappropriate because they are foreign to the way forest ecosystems have evolved.

Modern cultural practices which are foreign to forest ecosystems include both industrial exploitation and wilderness preservation. Putting "industrial" and "wilderness" together in the same philosophical stew may seem counter-intuitive to those of us who have grown up with the idea that they are opposites. But in fact the one is impossible without the other.

How is this so? Both embrace the traditional Western philosophical assumption that nature is static, and that if nature is disrupted by humans, she will balance herself like a machine without the need for human assistance or restoration. E.g. Gifford Pinchot, the father of modern "scientific" forestry, held that society could harvest timber indefinitely, because nature would rebalance herself as long as the annual cut didn't exceed the annual growth of trees (**"sustainable forestry"**). John Muir, the father of modern wilderness preservation, believed that as long as humans did not interfere in nature, she would continue to exist in an optimally functioning "pristine" state. Thus, if suppression of *human* ignited fires (like Indian burning but not "natural" lightning fires) which has now been in place for a century - was practiced by industry to save trees or by advocates of wilderness preservation to preserve nature in a pristine condition, nature would continue to function optimally.

Since Indian and lightning fires were a familiar disturbance for forests, its suppression has in fact done the opposite. It has led to forest degradation - loss of resiliency, integrity, relative stability, and optimum function. So has large-scale timber harvesting. We will discuss the negative ecological consequences to forest ecosystems caused by the cultural belief in homeostasis in more detail, as well as how restoration forestry can assist in reversing forest degradation, in later sections.

Part II

The Role of Ecosystem-Based Knowledge in Addressing Forest Degradation

1. Native American Traditional Ecological Knowledge (TEK)

Indigenous peoples who have lived sustainably and in harmony with their environment for long stretches of time in one place possess detailed knowledge of the ecosystems in which they live. This is called **Traditional Ecological Knowledge** (**TEK**). TEK is a belief-practice-knowledge complex which serves as a cultural guide on how to relate to the natural world. TEK includes detailed ecological knowledge of plants, animals, stars, etc. as well as tribal stories and spiritual knowledge. TEK is rapidly disappearing under the impact of global industrial culture which is now threatening forest ecosystems as well as forest peoples and their languages, cultures, and knowledge. Unlike much of Western scientific knowledge, which resides in written form in libraries, TEK is largely an oral knowledge system which lives in the minds and hearts of living indigenous elders. Preserving TEK therefore requires the preservation of indigenous societies.

Like modern Western ecosystem science (next section), which has become aware only very recently of the dynamic and changeable nature of forest ecosystems, native peoples understood and continually adapted to change. TEK accumulated knowledge regarding ecological changes over time - remembering even great global floods and giant beavers. Unlike Western science, however, TEK was based on long term observations of nature in one place - - **synchronic** as opposed to the **diachronic** or cross-sectional short-term observations of science.

Native American TEK in northern California and southern Oregon is badly fragmented because native societies have been badly fragmented, especially in southern Oregon. But much is still retrievable from cultural work done by anthropologists decades ago (**ethnography**) and which can be found in libraries and university archives. Assembling this knowledge from ethnographic accounts as well as from current ecological research by forest scientists who study forest history can contribute to our knowledge of historical forest structure and composition. We will discuss this in greater detail below under "Reference Ecosystems".

2. Western Ecosystem Science

A. Descriptive Ecology

The past 30 or so years of scientific research on forest ecosystem dynamics has led to a more complete understanding of how whole ecosystems function (**descriptive ecology**) and how they are connected with the greater landscape (**landscape ecology**). It is now recognized that ecosystems are far from static. While homeostasis continues to have a measure of influence (e.g. concepts like predator-prey balances and climax forest succession), it is now generally recognized that ecosystems change continually. **Dynamic equilibrium** is a more accurate description than homeostasis. (See above, I.A.1. and 2. "Defining Forest Health" and "Why Forests Are Unhealthy".)

But descriptive ecology has yet to seriously challenge the old Western cultural belief that ecosystems function best when undisturbed by humans. Thus, the kind of structure and composition of historical Indian fire-managed forest ecosystems - - **cultural landscapes** - - is still not recognized as a legitimate ecological baseline **(reference ecosystem**) for conservation and restoration. Ecologists tend to study what is here now more than what used to be here. They take the present forest - - mostly industrially driven **secondary succession** (second-growth forest following a disturbance like logging or fire) - - as a given. Although the field of **historical ecology** is beginning to come into its own, it is still too young to have been incorporated into most ecological descriptions of forests. (More detail on historical ecology below in section on reference ecosystems for restoration.)

B. Landscape Ecology

Landscapes are defined by Forman and Godron in their 1986 book, Landscape Ecology as: "…a heterogeneous land area composed of a cluster of interacting systems that is repeated in similar form throughout." According to Diaz and Apostle in Forest Landscape Analysis and Design, landscapes include "areas drained by major streams, within which climatic regime, geomorphic processes and natural vegetation patterns are fairly uniform. A landscape is larger than a stand and smaller than a region, and thus can vary greatly in size." In the geographical area covered by this manual, southwestern Oregon and northern California, roughly four regional forested landscapes or physiographic provinces occur: (1) Klamath-Siskiyou Mts., (2) Southern Cascade Mts., (3) Northern Sierra Nevada Mts., and (4) California North Coast Ranges.

Landscapes, from Forman's perspective, have three kinds of basic structures or "elements": **matrix**, **corridors**, and **patches**. The **matrix** is the most connected part of the landscape, i.e. the vegetation type that is most contiguous, e.g. mature forest. **Patches** are areas of vegetation that differ from what surrounds the matrix or other patches. **Corridors** are landscape elements that connect similar patches through a dissimilar matrix e.g. riparian zones and roads. The matrix – corridor – patch model is based on **island biogeography theory** where patches of habitat are compared to islands in an ocean matrix.

Landscape **heterogeneity** is measured by the amount of variation in and between landscape elements, e.g. matrix, corridors, patches. Landscape **structure** influences **function** and function in turn shapes structure in complex and continuous feedback loops. The historically and ecologically appropriate kinds of landscape diversity enhance the **resiliency** of the forest landscape (See the discussion of reference ecosystems below [D.] under "Restoration Ecology").

An alternative model to **Island Biogeography Theory** is the **Landscape Continuum Model** proposed by McIntyre and Hobbes in 1999. The landscape is conceptualized as a continuum or gradient of possible vegetative conditions ranging from intact vegetation to fragments or relicts of cover. As Lindenmayer and Franklin point out in *Conserving Forest Biodiversity* (2002, p. 17):

"The Focus of the **corridor-patch-matrix** model is on the form or structure of landscapes, whereas the **landscape continuum** model emphasizes the function of a landscape across varying structural gradients of vegetation cover. Simultaneous consideration of both models is useful because it can lead to greater awareness of the range of conditions that occur in real landscapes and, in turn, the diversity of responses to such varying conditions by different biota."

C. Conservation Biology

(1) Definition

Conservation biologists define their discipline as "science in the service of conservation. It is a mission-oriented, applied science, analogous to emergency medicine. Conservation biologists have a job to do and that job is to find out and demonstrate how to save the biodiversity of planet Earth. Although biology and its subdisciplines - especially ecology, systematics and genetics - are the core disciplines of conservation biology, the practice of conservation biology brings in philosophy, sociology, political science, law, history, geography, the natural resource fields, and other disciplines, as they relate to conservation problems." (Reed Noss in Wild Earth, vol.2, no.1, Spring 1992, p.5)

Typically, conservation biology focuses on large-scale conservation planning across watersheds, ecosystems, and jurisdictional boundaries on private and public lands. It is concerned with saving threatened and endangered species and the habitats and niches which they occupy or formerly occupied. Saving at least some representatives of all ecosystems and habitats across an entire region is another important goal. Other important goals are maintaining viable populations of all native species in natural patterns of distribution and abundance; sustaining ecological and evolutionary processes; and maintaining a conservation network that is resilient to environmental change. It is perhaps best known for its work in conserving or reintroducing top carnivores like wolves or grizzly bears by planning conservation **set-asides** in order to connect presently fragmented habitats and to enlarge or protect "core" habitats.

Whereas **wildlife biology** has long been involved in conserving or restoring habitat for game mammals and birds, recent environmental laws protecting non-game species have resulted in an increase in funding for non-game wildlife research. This led to the formation of the Society for Conservation Biology (SCB) in 1985. Wildlife biology's emphasis on practice, and conservation biology's focus on scientific theory, and its application potential, are slowly merging into a unified discipline. Conservation biology has moved from ecological theory to conservation practice, and seems to be attempting an integration or synthesis of the two very different approaches to conservation. But, as is the case with descriptive ecology, conservation biology is yet to recognize indigenous cultural landscapes as legitimate reference ecosystems. As we shall see below, **restoration ecology** - - the theoretical basis for the practice of **ecological restoration** - - is now bringing its theory into longstanding restoration practice. Both practice and theory are now in place to influence conservation biology.

(2) Matrix, Corridors, and Patches in Landscape Ecology and Conservation Biology

How restoration ecology can come together theoretically with conservation biology, as already noted above, is in paying more attention to habitat conditions in the matrix within which the habitat "islands" are embedded. Rather than writing the matrix off as a homogenous sacrifice zone which is too often conceptualized by conservation biologists as either hostile or neutral habitat - - and therefore suitable only for wood fiber production - - we ought to consider the matrix as heterogeneous - - providing good habitat for some at-risk species or with the potential for restored quality habitat. We also need to consider the interrelationships between patches and matrix as well as within-patch habitat quality. Matrix or patch habitat quality may be more important for species dispersal and protection than patch size, shape, or distance between patches. Quantity (e.g. large reserves) is not necessarily quality habitat for target species.

Timber harvesting prescriptions should further restoration/conservation within the matrix. The reference or baseline ecosystem for matrix restoration needs to include historic Indian burning patterns, in addition to other natural disturbance regimes, at all elevations and in all vegetation and habitat types. Animal dispersal between patches may depend on the habitat quality of the matrix. Animals may well perceive "quality" habitat in fundamentally different ways than conservation biologists. Island Biogeography theory is to a large degree human-centered and overly reductionist in its assumption that patches and corridors are more valuable habitat than the matrix.

(3) Traditional Ecological Knowledge (TEK), Restoration Ecology, and Conservation Biology

Indigenous **Traditional Ecological Knowledge (TEK)**, the accumulated knowledge of a particular place over many generations, can inform scientists about animal movements and habitat needs. This kind of information currently exists in conservation biology and restoration ecology in fragmentary form and has been based on short-term cross-sectional (**diachronic**) studies of short duration. Research seasons are based on the academic calendar year and foundation funding timelines. Western science lacks long-term (**synchronic**) animal studies.

The integration of TEK and historic Indian burning patterns - - seasonality, selectivity, extent, intensity, and mean and variable return intervals - - with so-called "natural" disturbance regimes (i.e. undisturbed by humans) is not generally accepted by ecologists at the present time. Instead, natural disturbances are used as a guide for developing human disturbance regimes, i.e. management. We would agree with that perspective if the wood-fiber production goals of matrix management were sufficient for biodiversity conservation. We see the matrix as both existing habitat and potential *restored* habitat. This kind of matrix restoration and reversal of industrially-driven degradation can be addressed by designing silvicultural/harvesting prescriptions which further restoration - - with wood fiber as a by-product. Economy *follows* ecology. As noted below in "Restoration Ecology and Ecological Restoration", we are not trying to recreate some static past condition (e.g. historic Indian burning patterns in the 14th century), but we are using past disturbance regimes as a *guide* - - especially fire-managed cultural landscapes - - to restore ecosystem function. In the same way, "natural" (non-human) disturbances serve as a guide to better human management of biodiversity. In neither case do we achieve complete historical fidelity. Sustainable cultural practices need to be taken into account to be ecologically on target as part of "natural" disturbance regimes - - given the great length of time of co-evolution between humans, plants, and animals, and the indisputable keystone role of Native Americans as top carnivores and as vegetation managers.

D. Restoration Ecology and Ecological Restoration

(1) Definition

The Society for Ecological Restoration (SER), founded in 1988, has defined **ecological restoration** as follows: "Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices." (See "Overview and Expanded Definition" in SER web page: www.ser.org.) **Restoration ecology**, as noted above, is the scientific theory underlying ecological restoration.

Ecological restoration, like conservation biology, is a young discipline and there is not as yet one universally recognized definition. However, the definition quoted above recognizes that human cultures have influenced landscapes - - for better or for worse - - just as much as landscapes have influenced human cultures. "**Regional and historical context**" and "**sustainable cultural practices**" are concepts which most societies in the world can relate to. The great exception is North America where scientists generally look to reference ecosystems in forests which have remained untouched by human cultural practices - sustainable or otherwise.

"**Critical range of variability**" means that not just any kind of biodiversity or ecological structures and processes, or cultural practices, will lead to recovery of ecological **integrity**. Forest vegetation development can take different directions, depending on a variety of variables in its history (**multiple successional pathways**).

Restoration requires **performance standards** by which to monitor progress (or lack of) toward a defined or desired future state based on a baseline or **reference ecosystem**. This baseline incorporates both **historical authenticity** and **ecological functionality**, i.e. the conceptually reconstructed historical reference ecosystem must be checked or monitored for its ecological function by ecosystem science.

(2) Reference Ecosystems For Restoration

How far back do we go to find a reference point in time? Only as far back as the time of the last known state of good forest health. This past "state" of course has changed just as our restored forest will continue to change. Reference ecosystems are not static. But we need some point in time which is **relatively stable** (i.e. change is fairly slow and fairly constant) with which to begin the process of restoration. As we will see below, ecosystem science can provide monitoring techniques which can check or test the **functionality** of the ecosystem being restored. In North America, that is ideally just before contact between European colonists and Native Americans (**preEuropean settlement** - - usually shortened to **presettlement** or **precontact**). That time period is "ideal" for two reasons: (1) it predates the destructive forest practices of modern industrial society and includes the time period in which Indian peoples were using the kind of fire-management which maintained healthy forest structure, composition, and processes; (2) it falls within the last stable climate regime (the cooling trend of the last 4000 years which is most like our climate today); and (3) the species composition of plant communities and associations has remained relatively stable.

But we can only go back in time to a point where knowledge of the forest's past is still retrievable. It usually takes a combination of the sciences of **historical ecology** and Native **Traditional Ecological Knowledge (TEK**) to successfully reconstruct past forest conditions.

Once an ecosystem is degraded, it is not recoverable in its ecological details, just in its key features of integrity. In extreme cases it may not even be recoverable in its broad ecological features. That is why conservation is always the first step in protecting forest ecosystems.

Historical ecology uses a variety of scientific techniques to reconstruct the past, including pollen analysis (**palynology**), fire history of trees through fire-scar dating (**pyrodenchronology**), packrat midden analysis, study of silicon remains of grasses (**phytolith analysis**), **archaeology**, historical photograph interpretation, **ethnohistory**, and **ethnography**, early botanical and zoological surveys, old diaries, land surveys, interviews with elders, etc.

Several different techniques are usually required to retrieve the known past of a forest - at least in its ecologically critical features (**authenticity**). We can then begin to understand something about its fire history, tree **stocking rate** (how many trees per acre), tree spacing and age-classes, species composition of plants and animals, etc. **Functionality** is tested with techniques which measure **net primary productivity**, **secondary productivity**, **hydrologic function**, **nutrient cycling**, **genetic diversity, decomposition rates** and other functions. (See I, 2.b., (2), (b), above)

Part III

Restoration Forestry: Integrating Ecosystem-Based Knowledge with Silviculture and Tree Harvesting Systems

"If you don't know where you're going, any road will take you there" goes a wise old saying. **Restoration forestry** could be defined as the harvest of forest products, both timber and non-timber, under the guidance of ecosystem-based knowledge. But unless we have some kind of ecologically appropriate baseline or reference ecosystem in mind as our restoration goal, the means which we use to achieve our restoration goals - - which in the case of restoration forestry are a variety of silvicultural systems and techniques - - will dominate our goals. In the end, unless our ecology is sound, means will become ends. The tail will wag the dog. Calling a timber harvesting project "restoration" doesn't make it so. On the other hand, unless there are forest by-products that can be sold in local markets at above project cost, there may not be a way to finance forest restoration. Restoration forestry must be able to reverse ecological degradation and achieve its restoration goals while generating revenue from forest by-products.

Part III is about how to integrate or synthesize ecosystem-based knowledge - - TEK, descriptive ecology, landscape ecology, conservation biology and restoration ecology - - with ways to grow and tend trees (**silviculture**) as well as ecologically appropriate timber harvest systems tailored to specific forest and plant community types.

1. Restoration Forestry, Vegetation and Habitat Types, and Forest Successional Processes

A. Forest Diversity, Resiliency, and Relative Stability

(1) The Relationship Between Diversity, Stability, and Ecosystem Function

This manual addresses forest restoration in southwestern Oregon and northern California. Landscape ecology tells us that a **regional landscape** is defined by its most dominant vegetation type or **matrix** together with major connected drainages and landscape scale watershed complexes, similar climatic regimes, and geomorphic structures and processes (topography, dominant rock and soil types), in the forested montane landscapes of our bi-state area. Franklin and Dyrness, in Natural Vegetation of Oregon and Washington, use the term **physiographic province** to describe regional landscapes of similar parent rock, soil types, topography, climate, and vegetation. Conifer species are usually dominant in the overstory. **Patches** and **corridors** of other vegetation types, less common than the matrix vegetation, intergrade structurally as well as interact functionally across the landscape (**natural vegetation patterns**). The more variation in vegetation types - - e.g. in patch size, shape, and composition - - the more landscape **heterogeneity**. Ecologists assume that the greater the landscape diversity or hetergeneity, the greater the **resiliency** and **relative stability** and the more optimum the **function**, i.e. structure influenced function.

The problem with the assumption that a diverse landscape structure necessarily leads to greater resiliency, relative stability, and better function - - even while recognizing that structure influences function just as function shapes structure - - is that it is an incomplete ecological assessment without determining what *kind* of structure and what *kind* of composition (i.e., kinds of plants and animals) lead to a healthy forest. In other words, high biodiversity in itself may not lead to better function. Remember the definition of **ecological restoration**. Since there are usually several possible pathways in forest succession (vegetation development following a disturbance like wildfire or clearcut logging), one successional mode may work better than another in contributing to ecosystem function (the definition's "**critical range of variability**"). If vegetation development is outside of that critical **natural** or **historical range of variability**, it may actually lead to ecological degradation, loss of stability, and diminished function, even if there is high landscape heterogeneity or diversity.

The four principal regional mountain complexes or physiographic provinces covered by our manual are: Klamath-Siskiyou Mountains, California North Coast Ranges, and the western slopes of the Southern Cascades and Northern Sierra Nevadas. The kinds of silvicultural and timber harvesting systems and techniques (e.g. individual tree selection, etc.) with which we choose to pursue our restoration goals must be forest or habitat type specific. Too often, foresters use logging systems which are not appropriate for their vegetation or forest type. We also need an historically authentic reference ecosystem, including a disturbance regime with which the forest is familiar, with which to guide our restoration efforts. And we need to monitor the ecological function of the historical reference model with ecosystem science.

(2) Climatic Climax, Forest Types, Physical Environment, and Interspecific Competition

a. Shifting-Mosaic - Steady State Forested Landscapes

Forest ecologist Dave Perry (*Forest Ecosystems*) draws a distinction between forest **stands** and **forested landscapes** with respect to **relative stability**. A stand is an assemblage of the same dominant or co-dominant overstory tree species occupying the same habitat type or ecological niche and usually of the same age. Stands often are composed of two size classes: relatively large trees dominating a group of small, suppressed trees, most or all of whom will eventually die (**self-thinning rule**). A forested landscape is an aggregation of forest stands of varying ages, sizes, and dominant species within the same forest type.

Perry uses the term **shifting-mosaic-steady-state** to describe **climatic climax forest types** that occupy the landscape within the constraints imposed by temperature and moisture. The moisture-temperature gradient is a function of latitude, rock and soil types, location relative to large bodies of water, and climate (temperature, rainfall, snowfall and snowpack, length of growing season, etc). The forest type is modified by elevation, topography (slope steepness, slope aspect, position on slope, cold basins, etc.), disturbance regimes (past and present), and vegetation.

Since disturbances of varying types, intensities, and rates of occurrence happen on all forest types, the concept of climax forest is highly theoretical, and is used to assess site productivity based on parent rock, soil type, depth and fertility, moisture holding capacity, drainage, etc. in any given **habitat type** within the larger forest type (more about habitat type below).

b. Soils, Vegetation, and Succession

Just as soils determine to some degree the kind of vegetation that will grow on them, vegetation modifies soils.But this process takes place slowly over time. Aerial soil surveys based on vegetation types as soil type indicators are notoriously faulty. For example, the soil on which an open oak stand is growing, and which formerly supported an herbaceous understory (grassland soil type with relatively high amounts of organic matter), will continue to be the same type for some years even after invading conifers have overtopped and killed the oaks. Conversely, high elevation Mt. Hemlock or Red Fir stands which have been burned up by a stand-replacing fire may be invaded by surrounding meadow or montane chaparral vegetation but still retain its conifer soil type. Just as current **seral vegetation types** (pre-climax successional stage) can be in a **climatic disequilibrium**, so climax dominant trees can be an **edaphic** (soil type) **disequilibrium**. Also, soils at the top of slopes are shallower than at the bottom, but when soil slumping (slides) occur on upper slopes, soil depth increases, which causes changes in the vegetation, which in turn slowly changes the soil type, fertility, etc.

Because disturbances at varying temporal and spatial scales are continually occurring, most climax forest types are in a pre-climax successional state, i.e. **seral forest type**. Climate is a single-factor determinant of forest type only on a gently undulating topography with deep, fertile soils and undisturbed vegetation. Regional macroclimate, as opposed to site microclimate, has less effect on forest non-tree understory vegetation than it does on trees. Successional turnover is faster, more random or **stochastic**, and more patchy with herbaceous or shrubby understories. Conventional silvicultural models, therefore, cannot always be relied upon in determining habitat types and potential vegetation in spite of a fairly sophisticated dichotomous key for determining potential vegetation in a habitat type which is in overstory-understory successional disequilibrium. (See Atzet and Wheeler's "Tree Series" classification system below.)

c. Interspecific Competition

Further complicating the picture is the factor of competition among tree dominants or co-dominants. Two species could be adapted to the same soil or habitat type, slope aspect, etc., but one will dominate because it is a little *better* adapted on that particular site. Inter-specific competition, within macroclimatic constraints, is a highly important factor in successional dynamics at the micro-environmental level. Species respond to disturbances in different ways. Survival strategies that work in one habitat type may not work successfully in another, depending on what kind of species are present. Conversely, strategies that work in different habitat types may not work in any of them if certain associated species occur there. The kind of relative competition dynamics between potential climatic dominants determine, in the end and on the ground, which species will dominate. In fact, many forest types never achieve climax; species usually dominate a site which are not climatically dominant, as long as disturbances continue to occur periodically. Even species which persist as climatic dominants for long periods of time, e.g. low elevation Redwood, coastal Sitka Spruce, high elevation Red Fir, and Western Hemlock forest types, often, share dominance in the forested landscape with seral dominants. Restoration ecologists, then, pay attention to the ways species persist following disturbance as much as to the environmental constraints and opportunities of the micro-environment, or stand habitat type.

And, as every silviculturist and forester knows, site productivity - - based on habitat type and potential vegetation - - may be high but shrub competition with forest tree dominants can be intense. This is particularly true at mid-elevation sites that form a transition zone between upper and lower elevation vegetation types. Tree productivity drops significantly. And dominant tree species composition can be different than what the habitat type/potential vegetation model predicts.

The composition of **ecotones** - - transitions between different habitat or vegetation types - - blur the ecological picture still more. One plant community type can pass imperceptibly into another type. On the other hand, ecotones my occasionally be stable enough in species composition to be considered a community itself with its own **modal** (characteristic) species.

In Perry's *relatively* stable **shifting-mosaic-steady-state** model, composition and structure are always changing over time at any one point on the ground, but the larger forested landscape above the stand, series, or habitat type level stays relatively constant. That is, until an infrequent large scale disturbance (e.g. catastrophic fire) occurs. Smaller, more frequent disturbances are always happening at smaller spatial and temporal scales.

(3) Plant Survival Responses to Fire

Fire is a very frequent disturbance event in our bi-state region. Plant responses to fire were classified by fire ecologist James Agee (Fire Ecology of Northwest Forests) in five categories:

1. **invaders** - species which are the first to occupy a site following fire (pioneer species) but are usually short-lived and give way relatively soon to the next successional wave (e.g. ceanothus spp.)
2. **evaders** - species with long-lived propagules stored in soil or tree canopy (e.g. closed cone pines which only open to release seed following fire).
3. **avoiders** - usually shade tolerant, late seral species that slowly reinvade burned areas but have no adaptation to fire and are nearly always fire-killed (e.g. Western Hemlock), but also include some shade intolerant species like Grey Pine or moderately shade tolerant species like young Douglas-fir.
4. **endurers** - species which can resprout from root crown, lateral roots, or aerial crown (e.g. many manzanita and oak species)
5. **resisters** - species that can survive low intensity fires, such as mature thick-barked species like Douglas-fir and Ponderosa Pine.

These five strategies define the **method of persistence** (equivalent to an **endurer** life history strategy) or **reproductive strategy** (**evader**, **invader**, **avoider**) after disturbance. The **conditions for establishment** determine the species capable of responding successfully to **facilitation**, **tolerance**, or **inhibition** pathways (in the Noble-Slayter 3-way pathway model mentioned in below). Critical life history events define the time necessary to reach critical stages in life history, reproductive age, thick bark for fire resistance, longevity, etc. All of these conditions for establishment determine which species will dominate any given site following fire.

B. Forest Succession Theory and Restoration

Pioneer ecologist Clements (1916) proposed a successional model - - the **monoclimax** theory - - which considered climate to be the sole driving factor in forest successional stages leading to a stable and self-perpetuating climatic climax. He saw plant communities as superorganisms with emergent properties similar to developmental stages of an organism.

Tansley (1924) used the term **polyclimax** to describe successional dynamics where climate was not the sole controlling factor. He recognized the possibility of multiple (poly-) climaxes, e.g. serpentine soils, among others.

Whittaker (1953), who worked in the complex topography and soil types of the Siskiyou Mts. of southwestern Oregon, observed vegetation varying continuously across the landscape and "climax" could be shown as a mosaic of populations along complex environmental gradients. Whitaker defined this kind of **prevailing climax** as the vegetation covering the widest area of the region. But this kind of complex model did not lend itself very well to silvicultural management scenarios that preferred a simpler model that focused more on potential vegetation of a particular stand than on landscape ecology, and was never widely used.

Noble and Slayter (1980) proposed a **multiple-pathway** model that incorporated species adaptations to disturbance into the system, and recognized that most systems experience disturbance one or more times. Unlike Clements' superorganism model, Noble and Slayter viewed a plant community as no more than an assemblage of individual species responding to disturbance in their own unique ways.

Most ecologists now view community succession in the same way as Noble and Slayter: a mechanistic focus on individual species responses to disturbance. However, looking for mechanisms of succession at the species level doesn't necessarily invalidate the concept of community. There are both competitive and cooperative interactions between species within a community and between species and their environment, e.g. **mychorrizal fungi** in the soil have a mutually beneficial or symbiotic relationship with plants which link different species underground and enhances nutrient and water uptake as well as disease resistance. Plant communities also interact constantly with animals, with both competitive and cooperative dynamics. Mechanistic individualism, while valid as far as it goes, fails to consider the synergies of community interactions.

The multiple pathway model has been applied within a **habitat type** (site potential for climax dominants) classification framework. This has allowed more detailed site variability to be integrated with the potential vegetation concept. The value of this more integrated model for restoration ecology is its potential for computer modeling various hypothetical disturbance scenarios in any given dominant overstory-understory tree series. While potential vegetation is not necessarily a goal of ecological restoration, that kind of modeling could assist in planning, for example, a prescription window (opportunity) for forest underburns where plant community responses to a particular burn intensity, seasonality, or frequency are unknown.

C. The relationship Between Silviculture and Restoration Ecology

While the larger landscape level flows and interactions, e.g. between patches and matrix, are very important in designing smaller scale stand level projects, timber harvesting and ecological restoration projects actually happen at the stand, not the landscape, level. (**Passive restoration** can occur at the landscape level, e.g. taking cattle out of riparian zones or letting large-scale fires burn.) Therefore, climax forest types or zones are not as relevant as the finer resolution tree series or habitat types. But only to a point. There is quite a difference between harvesting a timber stand and restoring an ecosystem.

Potential site commercial tree productivity is important in silviculture because foresters can design rotation lengths, harvest volumes, and regeneration techniques appropriate for that habitat type. Site productivity - - based on the habitat type model - - is about the physical environment: soil type and depth, and temperature/moisture regimes.

Habitat type is defined as an aggregation of all land areas capable of producing similar plant communities. The dominant vegetation in that habitat type may or may not, depending on which stage of forest succession is occurring, indicate a certain type of physical environment. That is why forest ecologists look at younger understory tree regeneration trends - - future tree dominants - - in unmanaged mature forests.

Restoration ecologists, on the other hand, need far more detailed *historical* information about a site or ecosystem. While the standard habitat type can be of some assistance in determining site soil type and depth, moisture/temperature regimes, etc., in late successional vegetation types, it doesn't necessarily tell us much about the history of site disturbances.

Restoration demands a reference or baseline vegetation type or ecosystem that describes what was there before large-scale industrial extraction and fire suppression. Restoration looks both backwards and forwards, balancing historical fidelity with ecological functionality. Future marketable timber is an important factor in choosing silvicultural harvest prescriptions which favor regeneration of commercially valuable conifer species (or hardwoods in eastern North America) for silviculturists but not for restorationists.

Silviculture, like restoration, can retard or accelerate succession by the kind of harvest prescription and regeneration techniques that are employed. But an historical reference system is not required, nor is a working knowledge of stand or community history. Conventional timber harvesting is really about where present or potential environmental conditions intersect with market conditions plus maximum harvesting efficiency. As we will see later, economy should follow ecology's lead in restoration. Still, forest by-products, including small diameter thinnings and saw logs, have to be generated to pay for restoration.

D. The Reconstruction of Local Reference Ecosystems

(1) The Physical Environment

Reconstructing reference systems usually involves surveying as many sites as possible in the general area with comparable vegetation, elevation, and topography, especially slope aspect. No one site will offer a complete plant or animal species composition because of past ecological degradation. A composite picture of forest structure and composition drawn from several sites needs to be supplemented with as much site disturbance history as is possible to retrieve. (See"Historical Ecology" at end of Section <u>Restoration Ecology and Ecological Restoration</u>.)

The importance of **slope aspect** - - east, west, north, and south slope orientation to the sun - - cannot be overemphasized. A wet surface that is oriented perpendicular to the sun (south slope) loses ten times more water than a north slope. The same native grass species growing on both north and south aspects may differ more genetically than two different species growing on the same aspect. (Adaptive differences like these in different populations of the same species are called **ecotypes**.)

Slope steepness, combined with aspect, is another important factor in vegetation patterns and species composition, e.g. during the winter when the sun is lower in the sky, maximum radiation (heat from the sun) will occur on steeper south and west slopes. Soils are shallower on steep slopes, hold less moisture, and are generally less fertile.

Slope position is also of some importance for vegetation patterns and types; e.g. soils are shallower on upper than on lower slopes; fertility and moisture-holding capacity also differ.

Slope or site exposure is another important factor in determining vegetation types. e.g. any deforested site or ridge exposed to intense radiation or wind. Soil texture is also important, other factors like soil infertility and shallowness being equal. Broadly speaking it can be claimed that coarse-textured substrates favor deep-rooted woody plants, while fine-textured substrates favor shallow-rooted forbs and grasses. Evergreen trees, whether conifers or broadleaf flowering plants (**angiosperms**), seem to tolerate low-nutrient soils, e.g. granitic soils, better than deciduous trees.

These kinds of broad soil indicators can help answer questions about why or why isn't a particular vegetation type present. Randomness and forest disturbance history are also part of the mix in matching vegetation type to soil type. So are moisture and temperature gradients in the microenvironment. This kind of "ground-truthing" of our model is critical for successful restoration.

(3) Landscape Scale Dynamics, Succession, and Local Reference Ecosystems

Deciding whether to keep, accelerate, or reverse successional trends at the stand level requires knowledge of landscape scale interactions within and between the matrix-patch-corridor gradient. Reference models are constructed within the context of the greater landscape. (See section <u>Integrating Forest Stand Restoration with Landscape Scale Ecology</u>, where we discuss Diaz' and Apostle's methods of landscape analysis and design.)

We will be interested, in our analysis, in landscape flows and dynamics which interact with the stand we are restoring: wildlife movements and general quality of wildlife habitat across the landscape; human-use patterns; evenness or unevenness of the seral stage of the vegetation type we are working in across the landscape, i.e., its spatial distribution; the relationship of dominant vegetation to species richness, e.g. are dominants decreasing species diversity?; water flows and erosion potential; fire patterns and fire history; earth movements, like debris-chutes; dominant wind patterns; gene flow between **metapopulations** (animal or plant species whose populations are separated across the landscape).

The goal is to conserve and restore maximum diversity - - but not necessarily any kind of diversity. The kind of diversity or heterogeneity is also important. Restored stand compositional and structural diversity must address *specific* imbalances or insufficiencies at the landscape level as well as within the stand. For example, if the stand we want to restore is in the overstocked "stem exclusion" phase of succession (See Chad Oliver in Section "New Forestry") with full canopy closure and very low diversity, and the surrounding landscape is mostly in the "stand initiation" phase due to recent clear-cut logging or fire, we wouldn't thin to historic stocking levels because of wildlife needs for cover.

We'll only thin enough to reduce fire hazard and release preferred tree species from competition. **In restoration, we don't necessarily want to stay on the successional train. We may instead want to stay at the seral stage of the stand we are working in. It all depends on successional conditions in the larger landscape in which our stand is embedded.**

E. Native American Burning and Arrested Seral Succession

Many meadows, prairies, balds, and other kinds of openings are now in succession to their potential dominant tree species, although soil types like serpentine or shallow soils overlaying an impervious rock strata or places where there is a high water table, may not reach their *climatic* potential tree species. These kinds of **subclimaxes** are common throughout our four physiographic provinces, especially in the Klamath-Siskiyou Province.

They were much more common when Indians were burning the forest, brushlands, and grasslands on a regular basis. By retarding succession they helped, along with lightning fires, to make the land more productive, stable and resilient. (This is called **arrested seral succession**.) Lightning fires on the coast, however, are not common, so Indian burning contributed to most of the openness of the balds and prairies. We may want to emulate that Native subclimax model by removing trees invading these kinds of opens. In the North Coast Ranges of California and southern Oregon, there are large opens called "bald hills" which are now closing in with invading conifers, especially Douglas fir. They have already lost about a third of their former area. The same thing is happening in the Northern Sierras, Southern Cascades, and the Klamath-Siskiyous. Many of the "balds" are partly the result of shallow, infertile soils, steep slopes, south or west slope aspect, and orientation to the Pacific Ocean's prevailing westerly winds; and partly the result of Indian burning.

In the resource-poor and less diverse Redwood Forest Type, these opens were needed to attract game and harvest a variety of cultural plants. This increased the biodiversity of a forest type that is one of the few which can perpetuate its dominant climax vegetation indefinitely unless a *major* disturbance occurs.

2. Physiographic Provinces, Forest Types, and Plant Communities of Southwestern Oregon and Northern California

Note: The following attempt at forest classification for southwestern Oregon and northern California is based on a synthesis of fifteen publications covering the Pacific Northwest and California/Sierran floristic provinces: The Audubon Society Nature Guide to Western Forests by Stephen Whitney; Trees and Shrubs of California by John Stuart and John Sawyer; Fire Ecology of Pacific Northwest Forests by James Agee; Natural Vegetation of Oregon and Washington by Jerry Franklin and C.T. Dyrness; Conserving Forest Biodiversity by David Lindenmayer and Jerry Franklin; Wildlife and Vegetation of Unmanaged Douglas-fir Forests published by the U.S.D.A. Forest Service, Northwest Research Station; California's Changing Landscapes by Michael Barbour *et al*; Wetland Plants of Oregon and Washington by B. Jennifer Guard; Introduction to California Plant Life by Robert Ornduff; Forest Ecosystems by David Perry; Terrestrial Vegetation of California (1988 edition) by Michael Barbour and Jack Major; Preliminary Plant Associations of the Southern Oregon Cascade Mountain Province by Thomas Atzet and Lisa McCimmon; Preliminary Plant Associations of the Siskiyou Mountain Province by Thomas Atzet and David Wheeler; and Peterson Field Guide to the Ecology of Western Forests by John Kricher.

A. The Four Physiographic Provinces of SW Oregon and No. California

The bi-state area covered by this manual includes four physiographic provinces: **California North Coast Ranges** from extreme southern Curry Co., Oregon (the northern limit of the Redwood Forest), south to and including Mendocino County; the **Klamath-Siskiyou Mountains** of southwestern Oregon and northwestern California from the Yolla Bolly Mts. of the inner coast ranges north to the interior montane Umpqua-Rogue Drainage Divide and Coos Bay on the coast; the western slope of the **Southern Cascade Range** from the Umpqua-Rouge Divide south to Mt. Lassen in northern California; and the west slope of the **Northern Sierra Nevada Range** south of Mt. Lassen to about even in latitude with Lake Tahoe. The eastern slopes of the southern Cascades and northern Sierra Nevada are not included. Also not included are the major plant communities in the alpine zone above timberline; coastal strand and dunes although coastal scrub is included to the degree it interacts with coastal forests; most wetlands and riparian forests which will be treated separately in another section of the manual, although some attention is given to dynamics between upper montane/subalpine wet meadows and trees as well as to wet shrublands and woodlands, and the extensive Central Valley Grassland Biome. Interior and coastal montane valleys, balds, prairies, meadows, brushlands and savannas are included.

We have defined **forest succession** as vegetation development that occurs following a major disturbance event like volcanic eruptions, wildfire or clear-cut logging. When **biological legacies** - - enough forest structural and compositional elements, including plant propagules (seeds, spores, roots), animals, down wood and snags, are left following the disturbance - - the forest begins to reestablish itself. This is called **secondary succession**. **Primary succession** is vegetation development from non-organic substrates or rock, as for example, following strip mining.

B. Silvicultural Forest Type Classification Systems

(1) The Moisture-Temperature Gradient

Most biogeographers classify forest or vegetation types by single species climax dominants. Forest types may range across physiographic provinces or whole regions, e.g., Sitka spruce on the western North American coast, and associate with different latitudes, elevations, and distances from the coast in all physiographic provinces, as well as with different species dominants, species associations, and relative dominance of seral and climax species.

We believe that it is more helpful to restoration practitioners to begin with the particular place that they're working in geographically rather than with the larger vegetation type which changes its composition from place to place. Beginning with the physiographic province (the physical and climatic macroenvironment), we then look at what place our vegetation type occupies geographically on the moisture-temperature gradient. This is analogous to "habitat type" used in silviculture to describe the characteristic physical environment or type and its characteristic vegetation *if* stable environmental conditions persist.

The moisture-temperature gradient has three primary spatial dimensions:

(1) distance inland from the warmer, wetter coastal climate to the summer-hot, drier, and colder interior montane climate.
(2) Distance in elevation going upward from the warmer, drier lower elevations in interior montane provinces to the colder, wetter higher elevations
(3) Distance in latitude going north to a colder, wetter climate or south to a warmer, drier climate

These three aspects of the temperature-moisture gradient are, as we discussed in _____, further modified by rock and soil type, water table, topography (especially slope aspect, position on slope, degree of exposure to the elements, and cold basins), depth and length of snowpack, length of growing season, disturbance history, shade-sun gradient, and competition between species adapted to the same habitat type.

Distance inland from the coast, e.g. in the Klamath-Siskiyou divides that province into western and eastern subprovinces. Changes in latitude divides different floristic provinces or vegetation types (equivalent to "climax forest types" in silviculture) into zones or bands along an elevational gradient.

(2) The Atzet-Wheeler Tree Series Model

Forest ecologists who are closely associated with timber harvesting (e.g. Forest Service, BLM, and corporate timber industry) have developed forest classification systems with which to get a quick handle on timber productivity potential for a given forest or habitat type or stand. Foresters often use the term **potential vegetation** to denote **climatic climax vegetation**. **Climax**, according to forest ecologists Thomas Atzet and David Wheeler (Preliminary Plant Associations of the Siskiyou Mountain Province), "is the end point of succession (the same as **potential natural vegetation**) where neither plant composition nor stand structure changes. Net productivity in terms of biomass production is considered to be zero."

We know that the forest is not static because we rarely find climax or potential vegetation in the real world. Eg, old growth forest assumed for a long time by many in both the timber industry and in the environmental movement to be in a steady or stable state, could be burned up by a catastrophic stand-replacing wildfire or endure devastating disease or insect epidemics if frequent low to moderate intensity fires are eliminated.

Climatic climax types could be useful if the landscape function requires more late successional patches or stands, e.g. where extensive clearcutting adjacent to the target stand doesn't offer sufficient habitat for late successional species. But we should be cautious when foresters describe **forest** or **habitat types** and **plant associations** that serve as ecological shortcuts in the service of timber production. As Atzet and Wheeler state: "the [plant] **association** is used to resolve environmental differences [read "simplify"] for silvicultural prescriptions. It can also be used to evaluate productivity [read "timber productivity"], management results, and to extrapolate biological response [read "tree regeneration"]. It is the finest level in the classification hierarchy."

Atzet and Wheeler go on to define **tree series**: "A series is an aggregation of plant associations with the same climax dominant (s)." Here they are talking about overstory and understory indicators or dominants. E.g. if the dominant tree is Douglas fir (*Pseudotsuga menziesii*) and the dominant understory species is long-leaf Oregon grape (*Berberis nervosa*), then the first two letters of the Latin genus and the first two letters of the Latin species names are grouped together. In this case it would be PSME and BENE. The series would be PSME-BENE. Most foresters and forest botanical surveyors use this method. If there are no "climax" forest stands, then future (potential) old growth is extrapolated from younger regeneration dominants in an unmanaged mature 100 to 300 year old forest stand. “Potential vegetation” is therefore used more than “climax” by foresters and resource managers.

(3) The Landscape Continuum and Corridor-Patch-Matrix Models

Our focus in forest restoration is on the relationship of a particular stand to the larger landscape of which it is a part We are less interested in potential or climax vegetation than in the role that *any* current seral stage plays in the landscape. This focus fits in with the **landscape continuum model** i.e. the emphasis on the specific *function* of a given landscape across a structural gradient of vegetation cover as opposed to the emphasis of the **corridor-patch-matrix model** on the *pattern* or *form* of different landscape units, such as the size and shape of the different patches and patch types. **The question that conservation biologists need to ask is: what functional role does a particular vegetation pattern play in protecting a target animal**

species? And the question that restoration ecologists should ask is: what is the role of a particular patch or stand in the function of the larger landscape habitat for the target species? And how can it be enhanced or restored to improve the overall function?

C. Forest Type Classification Systems Appropriate For Restoration Forestry

Restoration requires a different forest classification emphasis than that used in silviculture. For example, we would prefer the concept of **relative distribution** of all tree species to dominance by one species. Tree dominants are usually seral species because of frequent disturbance - - except, e.g., in *some* lowland coastal Redwood Forest and upper montane Red Fir Forest habitat types - - and dominancy can be held by several different tree species at different times and places in a single habitat type or single-tree climax forest.

Another useful concept is that of **indicator species**. An indicator species may occur unevenly in many habitat types, but will *almost* always be found in one particular plant community in fair abundance. Community indicators can be overstory trees, understory trees and shrubs, herbaceous plants, mammals, birds, reptiles, or amphibians. (See Peterson Field Guide to the Ecology of Western Forests for all of these indicators by forest elevational zone.) There could also be several closely associated species as indicators. There are generally relatively few indicator species for a particular plant community; however there may be others less abundant but which are characteristic of that community as a group, even though they may occur elsewhere with other associated species.

A good forest restoration classification system should do the following: (1) give as much attention to understory shrub and herbaceous species as it gives to overstory trees and understory tree regeneration; (2) use current seral dominants or co-dominants as forest type indicators instead of single-tree climax dominants; (3) recognize ecotones as possible stable modal plant communities under certain disturbance regimes; and (4) consider disturbance history in defining plant communities.

We are currently a long way from this kind of multiple-scale system. The forest classification systems in the literature tend to emphasize single-tree climax dominants as indicators of a forest type, although there is considerable variability in how tree types are organized with respect to elevational zones, larger physiographic and floristic provinces, and vegetation types (e.g. "woodland" or "coniferous forest")

(1) Useful Descriptive Ecological Categories

Since we have disconnected silvicultural concepts like habitat type and potential vegetation from forest restoration, we will need to reconnect with other concepts more appropriate to restoration priorities. The following animal and/or plant classifications from descriptive ecology are appropriate for restoration ecology because they are integrative, holistic, and, to a large degree, "succession independent". **But it is important to remember that these categories are only convenient ways to *begin* to get a handle on a community type, and are a human-imposed construct on the raw flux of highly complex and ever-changing natural systems.**

1. **Biotope** is a small area with a uniform environment occupied by a unified community of organisms.
2. **Community** is a group of animal and/or plant species living together and having close interactions, especially through food relationships.
3. **Biocenosis** is a community of biologically integrated and interdependent plants and animals.
4. **Ecosystem** is a system made up of a community of animals, plants, bacteria, etc., and its interrelated physical and chemical environment; however, ecosytems rarely have easily distinct boundaries.
5. **Habitat** is the region where a plant or animal naturally grows or lives; its native environment; where there are enough of the basic necessities - - food, cover, water - - for the species to survive.
6. **Compositional Element** is an ecosystem component with unique animal and plant species.
7. **Wildlife Habitat Element** is a particular structural element within a habitat, e.g. large Oak trees or a doghair patch of Douglas-fir.
8. **Compositional Element** or **Ecosystem Component** is a group of plant or animal species that perform a similar function in the forest, e.g. pollinators or top carnivores.
9. **Niche** is (a) an "opening" or opportunity for a species to find suitable living and reproducing conditions within a given system; and (b) the set of attributes that a given species bring to that opening; an interaction between an individual species and the ecosystem in which it is embedded.
10. **Guild** is a group of species within a given community that share some common interest, e.g. the guild of foliage-gleaning predators, or the guild of hummingbird-pollinated plants; a species group whose members overlap in one or more niche dimensions.
11. **Redundancy** is the ability of more than one species to perform the same functions; maintains functional integrity of the system even though a species may be lost from it; guilds that overlap in functional niches represent the redundancies in ecosystems.
12. **Keystones** are species, processes, or structures, that perform some unique function in the ecosystem, and without which a group of functions or species could be lost.
13. **Biome** is an extensive community of plants and animals whose makeup is determined by soil and climate. This is its conventional definition. But if we include Native Americans as "natural" agents of ecosystem change, we could talk about soil, climate, *and* anthropogenic fire; and we could include animal grazing as well. A biome can be either a forested landscape, a grassland, chaparral or shrub-stepp landscape. We will include biomes (e.g. valley grasslands) in the following section on vegetation types within our four physiographic provinces *if they are within or adjacent to and interact with forested landscapes.*

(2) Useful Biogeographical Forest Classifications

Some biogeographers emphasize the forest type or floristic province over its entire geographical range, e.g. Sitka Spruce Forest Type in a coastal strip from Eureka, California, to Anchorage, Alaska. Others describe forest types within a particular physiographic province or mountain range, e.g. Red Fir Forest Type in the Klamath-Siskiyou Mountains as opposed to the same type in the Northern Sierra Nevada Mountains. Still others use elevational zones within a particular province or range e.g. Mountain Hemlock Zone in the Southern Cascades or elevational zones of, e.g., Mountain Hemlock throughout its geographical range. Finally, some fit climax forest types into larger vegetation types or floristic provinces, e.g. Douglas-fir Type in the Mixed Evergreen Forest of the Temperate Pacific Northwest Floristic Province.

We prefer a classification system that is organized by **physiographic province** as the largest geographic scale within a region. A physiographic province is defined as a landscape or mountain complex with similar geology, topography, soils, and vegetation types or plant communities at similar elevations and slope aspects. Our four physiographic provinces are the California North Coast ranges, Klamath-Siskiyou Mountains, the western slopes of the Sierra Nevada Mountains and the Southern Cascade Mountains.

Floristic provinces are usually larger geographical areas than physiographic provinces and sometimes include vegetation types which have a wide **ecological amplitude**, i.e. they can occupy a wide variety of habitat types and/or places on the moisture-temperature gradient. A floristic province can also include high elevation plant communities that are fairly similar across a wide geographical area or region at similar altitudes after adjusting for latitudinal elevation changes. Lower elevation vegetation types are far more diverse and are not easily classified into different floristic provinces.

Within the physiographic province, we can suborganize by position of vegetation types on the moisture-temperature gradient, e.g. the wetter, warmer western and the drier, colder eastern Klamath-Siskyous as we move inland from a milder maritime climate to a harsher continental climate. Or, from the damper, colder northern region of the Southern Cascades, e.g. Oregon's Umpqua-Rogue Drainage Divide, with a maritime Mediterranean climate, to northern California's summer - hot and drier Mediterranean climate. These would be **physiographic subprovinces**.

Elevation zones are the next smaller resolution division. Elevation zones, e.g. for the west slope of the northern Sierran physiographic province, would include a Valley-Foothill zone (500-2,400 ft.), Lower Montane zone (2,400-6,000 ft.), Upper Montane zone (6,000-8,200 ft.), Subalpine zone (8,200-10,000 ft.), and Alpine zone (10,000-14,000 ft.). Within elevation zones, seral and climax **vegetation** or **forest types** or **plant communities** can be described, along with their **historical disturbance regime** (e.g. fire frequency and intensity)

(3) Recommended Forest Classification System

The following forest classification system begins with "physiographic provinces", the largest geographical unit, and achieves its finest resolution at the "vegetation type" level.

1. Physiographic Province
    a. West Slope of Northern Sierra Nevada Mountains
    b. West slope of Southern Cascade Mountains
    c. Klamath-Siskiyou Mountains
    d. California North Coast Ranges
2. Physiographic Subprovince
    a. Coastal Montane
    b. Interior Montane
    c. Northern Latitude
    d. Southern Latitude

3. Elevation Zones (elevations change with province type)
    a. Valley
    b. Foothill
    c. Lower Montane
    d. Mid-elevation Mixed Conifer Transition
    e. Upper Montane
    f. Upper Montane-Subalpine Transition
    g. Subalpine
4. Vegetation Types (within zones)
    a. Succession and seral or climax dominants
    b. Characteristic indicator and associated species
    c. Understory-overstory association
    d. Disturbance history

PART IV

The Four Physiographic Provinces of Southwest Oregon and Northern California

1. West Slope of the Northern Sierra Nevada Mountains

A. Overview

The geographical area covered by the "Northern Sierra Nevada Mountains" reaches as far south as the latitude of Lake Tahoe, California, to just south of Mt. Lassen in the north. The larger Sierran Floristic Province forms a distinct belt from Crater Lake, Oregon, in the Southern Cascades, south to the San Pedro Martir Mts. of northern Baja California, and includes the eastern Klamath-Siskiyou, and some parts of the western Klamath-Siskiyous and the California North Coast Ranges at higher elevations. These provinces include Pacific Northwest vegetation types in addition to the Sierran types. The Sierran province is more diverse and complex than other California and Oregon mountain ranges. The Sierran Montane forest in northern California and southwestern Oregon is split into two branches or subprovinces: eastern branch in the Southern Cascades and Northern Sierras; and the western branch in the Klamath-Siskiyous and California North Coast Ranges. Rocky Mountain and Great Basin vegetation types reach the eastern slope of the Sierras and western slope subalpine zone.

The Northern Sierras are in the Humid Temperate Domain, the Mediterranean Regime Mountain Division of that domain, and the Sierran-Steppe/Mixed Forest/Coniferous Forest Province. Summers are hot to cool, depending on elevation, and winters are cold and wet, with significant snowpack over 4000 ft. elevation, which lasts until early to mid-summer in the higher zones.

Mid-elevation Sierran Montane forests (2000 to 6000 ft.), including the Southern Cascades and Klamath-Siskiyous montane forests, are the most diverse coniferous forests in North America. It's lower elevational limit at 2000 ft. receives at least 25 inches of precipitation annually, and 80 inches is received at its upper limit of 6000 ft. Above 6500 ft. except for the occasional summer thunder storm, all precipitation falls as snow and below 2000ft. all precipitation falls as rain. The diversity of this zone is partly a result of the abundant moisture. The cold and persistent heavy snowpack in the Upper Montane/Subalpine zones are the main constraints on diversity, as are the hot summers and semi-arid climate in the lower Valley and Foothill zones.

This forest type is John Muirs' "filtered light" cathedral forest of stands of parklike, widely spaced old-growth trees. Today's diverse Mid-elevation Mixed Conifer Transition Forest is very different from what it was like when John Muir was marveling at the beauty of Sierran forests and when Native Americans were burning the forest understories before fire suppression policies. Shade-tolerant and fire-intolerant tree species like White Fir, Incense-cedar, and Mountain Hemlock are regenerating in the forest floor and over time will overtop current seral dominants: Douglas-fir, Ponderosa Pine, Sugar Pine, and Black Oak. Forests are far denser than formerly, with far more young to early mature (30-80 years old) trees, with few large size or old age classes due to selective logging which favors shade-tolerant species, industrial plantation forestry following clear-cutting, and fire suppression. Diversity is rapidly being lost as forests close up.

The historical range of variability included a balance between sunny and shady forest microenvironments and meadow/forest. Sierran dry meadows have lost half of their area to forest tree invasion. Even late successional species require meadows and sunny forest openings because of it's value as habitat for their prey species, e.g., the endangered great grey owl and northern spotted owl hunt meadow voles and mice. Only two mammal species, the red tree vole and the California redbacked vole, can thrive under dense, shady conditions in mature second growth or old-growth forests.

B. Elevational Zones

Ascending in elevation from the Valley Zone through the foothills and above, grassy savannas of Valley Oak, Blue Oak and White Oak mixed with chaparral give way at around 1000 ft. to Chaparral mixed with savannas and woodlands of Grey Pine, Ponderosa Pine, and oaks. At the upper limit of the Foothill zone at 2000 ft., the same lower elevation vegetation types give way to more woodland than savanna and the addition of Interior and Canyon Live oaks. But pine and oak continue to dominate in many places up to 3000 ft. The Sierran Foothill zone has a natural history similar to the California North Coast Ranges with its mix of chaparral, oak/pine savanna-woodland. Tree dominants in the **Lower Montane Zone** are White Fir and Douglas Fir, usually in mixed stands and associated with Sugar Pine and Incense-cedar with Black Oak in sunny opens and on rock outcrops. Going up in elevation in the Lower Montane zone, White Fir gradually replaces Douglas-fir as dominant, although mixed stands of White Fir, Douglas-fir, Sugar Pine, Incense-cedar and Black Oak are also common.

The upper elevations of the Lower Montane zone and the lower elevations of the Upper Montane zones constitute the **Mid-elevation Mixed Conifer Transition Zone** which includes the above species plus Jeffrey Pine on serpentine or ultramaffic soils and higher elevation Red Fir and Lodgepole Pine. There is a great diversity of shrubs and brushland types, and herbaceous understory plants.

The **Upper Montane Zone** (5,000 to nearly 8,000 ft.) forest dominants are nearly pure stands of Red Fir and Lodgepole Pine. Red Fir occurs in dense climax stands with little understory except litter, a few **saphrophytes** (plants that parasitize other plants because they have no photosynthesis due to lack of green chlorophyll), and a straggly understory of pole and sapling Red Fir. Thin-barked Red Fir is easily killed by fire; whole stands often burn up during lightning storms. Lodgepole Pine is a **fire-invader** because heat opens up pitch-sealed **seritoneous cones** (closed cones), enabling lodgepole to quickly colonize a site from seed following fire.

The **Upper Montane/Subalpine Transition zone** (7,000 - 9,000 ft.) combines Upper Montane with Lower Subalpine vegetation types. Pure stands of species-poor, dark, densely packed Red Fir Forest mixes with diverse meadows, with Quaking Aspen groves on meadow fringes. Occasionally Mountain Hemlock associates with Red Fir and Western White Pine. Scattered high elevation pines, e.g. Western White Pine, Limber Pine and Foxtail Pine, occupy thin, rocky soils and form open woods among rocks and boulders with diverse wildflowers in nooks and crannies.

The **Subalpine Zone** (8,000 - 10,000 ft.) forest-meadow structure consists of small islands of Lodgepole Pine, Mountain Hemlock, various subalpine pines, and some juniper (a characteristic Sierran Eastside/Great Basin tree) in a sea of wet meadows composed largely of sedges and wet-adapted forbs and grasses.

C. Vegetation Types by Elevational Zones

NOTE: These vegetation types occur in all four physiographic provinces with similar successional dynamics, and except for certain anomalies and species changes in other provinces, which will be noted in the forest type descriptions, will serve as the only detailed description of these types.

(1) Valley Grassland and Savanna / Foothill Woodland Zones (500 to 2000 ft.)

a. Species Indicators and Associations

Common associates include White Oak, Interior Live Oak, Pacific Madrone, California Bay, Incense-cedar, Douglas-fir, Ponderosa Pine, Canyon Live Oak, Grey Pine (1000 to 3000 ft.), Blue Oak, Valley Oak, White leaf Manzanita, Wedgeleaf Ceanothus, scrub oak species, California Poppy, Western Buttercup and introduced Mustard.

Scrub Oak Chaparral is a rich, mixed-shrub type on moister sites where it may merge with oak woodland. Common **Oak-Pine Woodland/Scrub Oak associates** are Toyon, Poison Oak, Bittercherry, Western Chokecherry, Silktassel, Buckthorn, and Birchleaf Mountain Mahogany.

Common Riparian Associates include White Alder, Bigleaf Maple, White Oak, California Bay, Valley Oak, willow species, and Western Redbud.

The northern Sacramento Valley, forms a "U", with the eastern Klamath-Siskiyous to the west, southern Cascades (to Mt. Lassen) and northern Sierras to the east and north. Formerly an open oak-pine savanna (Valley Oak, Blue Oak, White Oak, Ponderosa Pine and Grey Pine) with a rich diversity of grassland species interspersed with different age-classes of brush patches, it is now turning into more of an even-aged open to closed woodland with large even-aged, dense, **senescent** (old) brush formations, especially Whiteleaf Manzanita and Wedgeleaf Ceanothus. It is composed mostly of Mediterranean-type introduced forb and grass annuals which have replaced the native perennial and annual grasses and forbs (wildflowers)

Diversity is usually very high where woodland/chaparral/grassland mix in Mediterranean hot, dry summer climates. This is because of the diverse ways in which vegetation responds to the harsh summer environment. These diverse micro-site adaptations create a patchwork of diverse vegetation types. Chaparral occurs on sites too dry for woodland and too rocky for grasses (if the watertable or rainfall is too low). These dry conditions occur on flats, depressions, and gentle slopes, where fine-grained, poorly drained soils keep moisture near the surface, but which dry out quickly with the onset of hot weather.

Fire, mostly Native burning but including lightning from rare tropical storms from Mexico, kept the savannas and woodland open and oak stands, brushlands, and grasslands rejuvenated, creating small even-aged vegetation patches. Patches were of different ages, so that all age-classes, indeed all phases of life and death, were present historically. Chaparral burns every 10 to 40 years and can reach temperatures of 1200 degrees Fahrenheit (but more commonly 650 degrees). One half of chaparral species sprout after fire. Sprouts grow faster than seedlings because roots are already in place. Litter is burned up and a mineral seedbed is created (both sprouters and non-sprouters produce abundant seed), but where a site is dominated by sprouters, the chaparral dominants will succeed themselves in a kind of "individual climax". However, on some sites tree species may slowly invade, overtop and kill the brush, and then succession may start again if a fire kills tree species not adapted to fire, e.g. the **fire avoider** Grey Pine compared to **fire-endurers** (sprouters) like White Oak, Blue Oak, and Black Oak. The current expansion of brushlands is encroaching on whatever native herbaceous species still exist. Following a burn, it takes about five years for chaparral (both sprouters and non-sprouters) to reassert its dominance, replacing rich herbaceous communities dominated by drought-evasive annuals, including **fire endemics** (species which only occur after a burn or only occur in a particular place or habitat type). The seeds of these fire-endemics can lie dormant for decades in the soil (up to 100 years). Chaparral litter contains toxins (**allelopathic toxicity**) which inhibit the establishment of replacement vegetation.

b. Broadleaf Woodland/Savanna Types

- **Deciduous Oak Savanna/Woodland** includes White Oak, Blue Oak, and Valley Oak. White Oak forms savannas and woodlands in all four provinces. Blue Oak dominates in the foothills surrounding the Sacramento Valley up to about 2000 ft., in both the Sierras and Klamath mountains, with Grey Pine and the evergreen Interior Live Oak on moister sites (White Oak can also grow on moist soils). Black Oak is present but is more common in the Mid-elevation Mixed Conifer Transition Zone up to around 5000 ft. Valley Oak grows on deep fertile, and moist valley and foothill soils, occurs in open savannas, and dominates riparian vegetation of Sierran rivers flowing through the Sacramento Valley.
- **Evergreen Oak Woodland** includes Canyon Live Oak on rocky, dry canyon sides in all four provinces. Interior Live Oak, the most drought-resistant of evergreen hardwoods, forms nearly pure stands on drier woodland sites in the outer (western) California North Coast Ranges and on moister ones in the inner (eastern) Coast Ranges, Klamath-Siskiyous, and Sierran foothills. Tanoak, California Bay or Laurel, and Pacific Madrone can be dominants in the four provinces. California Bay grows in pure, dense stands on moist northern slopes or in canyon bottoms. Pacific Madrone tolerates drier sites and is especially suited to rocky areas. Tanoak has the greatest range of tolerance, dominating many stands and growing as principal understory tree in mixed evergreen forests dominated by Douglas fir at low elevations in the California North Coast Ranges. Tanoak grows in more mixed stands in the Sierras at mid-elevation.

Both Deciduous Savanna/Woodland and Evergreen Oak Woodland offer food and cover as wildlife moves back and forth between open prairie and open or closed woodland. Oak-Pine savanna and woodlands are very rich in wildlife compared to other vegetation types, especially in bird species. The amount of available moisture, along with frequent fire, are responsible for this species-rich mosaic. Savannas occur on drier soils with herbaceous understories because shrubs can't compete with trees on dry soils after the trees have established deep root systems. Savannas are transition from woodland to grassland but may also be stable, modal communities with their own particular species associations - - provided there is frequent fire. Understory shrubs are confined to moister sites on steeper, rockier terrain. On sites intermediate between woodland and brushland, savannas may occur with shrub understories instead of grass and forbs.

(2) Lower Montane Zone, Including Mid-Elevation Pine Forest and Lower to Upper Montane Transition Zone (2000 to 5500 ft.)

Indicator plants are Pondrosa Pine, Jeffry Pine, Black Oak, Greenleaf Manzanita, Kit-Kit-dizze (Mt. Misery), and Western Wallflower.

Ponderosa Pine mixes with Black Oak, Incense-cedar, White fir and Douglas-fir. There are few pure stands of single-tree dominants, which are more common on the Sierran East Slope. Ponderosa Pine and Black Oak dominate drier sites.

Lower Montane forests are highly diverse, especially at their upper elevational limits where they transition into the Upper Montane Zone. Dense shrub layers of Kit-Kit-disse and Greenleaf and Whiteleaf Manzanita dominate forest understories in more open stands on moderately moist sites. Seedlings and saplings of shade-tolerant Incense-cedar and White Fir grow on the floor of closed canopy stands. In the absence of disturbances like fire, they will eventually dominate most of the upper elevations of the Lower Montane Zone as well as the lower elevations of the Upper Montane Zone. Common associated smaller tree and shrub understory species include (trees) Pacific Dogwood, Dwarf Chinquapin, Tanoak, White Alder, Pacific Madrone, Bigleaf Maple; (shrubs) California Hazelnut, Red Huckleberry, Thimbleberry, gooseberries and currants.

Jeffrey Pine, confined to infertile and toxic serpentine and ultramaffic soils, doesn't mix with Ponderosa Pine, It replaces Ponderosa Pine at higher elevations. The elevational range of Ponderosa Pine is from 500 to 5,500 ft, but it can grow at higher elevations on dry ridges and south slopes, while Jeffrey Pine grows from 4,500 to 6,500 ft.

Either White fir or Douglas-fir dominate on higher, cooler, moister ground. White fir has its lower limit on cool, moist, north slopes. Black Oak tolerates the hottest, driest, rockiest places. Sugar Pine likes cool sites with adequate soil moisture in the summer. Incense-cedar and Douglas-fir have the widest ranges of tolerance for moisture; Incense-cedar and White Fir have the greatest tolerances for shade. Douglas fir replaces White fir at lower elevations in mid-slope forests of both the Northern Sierras and Southern Cascades, and ranges as far south as Yosemite. As elevation drops and moisture decreases, the dominant hardwood component gradually gives way from Tanoak, to Pacific Madrone and Canyon Live Oak with Chinquapin on cooler sites.

Most herbaceous species in the lower elevations of the Lower Montane zone are exotic annuals, although this probably was not the case before livestock were introduced. Perennial grasses and forbs probably dominated before a combination of drought and overgrazing left the competitive advantage to drought-avoiding introduced annuals. This kind of displacement of native or natural vegetation by alien species is called **disclimax** because it is outside the bounds of natural succession. Native grasses still occur but are unevenly distributed. Remnant native perennial forbs include Blue Larkspur, Water Peony, Sulphur Flower, Hooker's Evening Primrose, Pussypaws, and Skyrocket.

Because of the high diversity of this forest zone, there are many forest insect "pest" and parasitic fungi spices. Dwarf Mistletoe is a serious parasite on true firs, Douglas-fir, and Incense-cedar. White Pine Blister Rust hits Sugar and Western White Pines. Firs weakened by fungi, mistletoe, and/or drought are susceptible to infestations by Fir Engraver Beetles, Fir Borers, and defoliators like Spruce Budworm, Douglas-fir Tussock Moth, and Needleminers. Western Pine Beetles, Ippes Beetles, Mt. Pine Beetles, and Red Pine Beetles infest all pine species.

a. Douglas-fir/Hardwood Forest Type

Douglas-fir, Ponderosa Pine, and Sugar Pine, when mature enough to develop fire-resistant bark (**fire resister**), will remain dominant as long as fires are not too intense. These three conifer species need fire-created mineral soil to regenerate although Sugar Pine is more adapted to establish in soils with some litter. If moderate severity fires occur in stands dominated by Douglas fir where Pacific Madrone and Tanoak are understory species, the hardwood species will by top-killed (**fire-endurers**) and Douglas-fir will remain dominant. But if Douglas-fir is young it will not be fire tolerant, and as a **fire -avoider**, will be killed. Madrone and Tanoak will resprout and dominate Douglas fir for decades. Eventually, a mixed forest of Douglas-fir overstory and tanoak understory will dominate. All-sized forests with multiple-aged **cohorts** (a stand of the same age) are common. High severity burns favor sprouting hardwoods over conifers, or regenerate pure stands of knobcone pine. Closely repeating fires eliminate conifers, favoring **fire-endurer** species (sprouters) like manzanita, and oaks and **evader-species** like knobcone pine within the Douglas-fir/hardwood vegetation type. Fire-return intervals in the mixed-conifer forest type have averaged 10 to 40 years with a large range (3-70 years). This type transitions to the White Fir type at the upper part of the Lower Montane Zone, with mixed stands of White Fir, Douglas-fir, and Tanoak on cooler, moister sites.

b. White Fir / Mixed Conifer Forest Type in the Lower Montane/Upper Montane Transition Zone

White fir forest is the dominant community on relatively mesic sites in the Lower Montane Zone, occurring at elevations from 4,000 to 7,000 feet. Up to five species of conifers may be present in any given White Fir stand: Red Fir, Sugar Pine, Incense-Cedar at higher elevations, and Douglas-fir, Incense-cedar, Ponderosa Pine, with Black Oak at lower elevations. Giant Sequoia associates with White Fir in the central and southern Sierran provinces. Individual White Fir stands are relatively even-aged in varying stages of successional development, i.e. the overall forested landscape is uneven-aged, but that is changing as White Fir and Incense-cedar regenerate in the shady understory.

White fir comprises 80% or more of the large trees in individual stands, and can live 300-400 years. Sugar Pine is a characteristic important associate in White fir forests. Sugar Pine seedlings germinate on both litter and bare mineral soil, but develop poorly under shady conditions.

Dense thickets of White Fir and Incense-cedar saplings often dominate the understory. Understory tree and shrub species cover 5 to 30% of the stand. Several species of the Pacific Northwest Floristic Province occur also: Pacific Madrone, Chinquapin, Pacific Yew, and California Nutmeg. At lower elevations on rocky sites, Bigleaf Maple, Black Oak, Canyon Liveoak, Greenleaf Manzanita, Mt. Misery, Deerbrush Ceanothus and Whitethorn Ceanothus dominate. These species, all sprouters, are favored by frequent fire. California Hazelnut and Pacific Dogwood are restricted to relatively mesic sites. Other species occurring commonly are Scoular's Willow, Chinquapin, Bittercherry, and gooseberry species.

In riparian White Fir forests, a special plant community occurs which includes White Alder, Bigleaf Maple, Redtwig Dogwood, Western Azalea (a serpentine indicator), Nevada Gooseberry, Thimbleberry, Oregon Ash, Black Cottonwood, and Ninebark. Spikenard and sedge species are common understory associates.

Herbaceous cover in White Fir forests is sparse, comprising less than 5% of the forest floor. But in moist swales and drainage bottoms it may approach 100% cover. If riparian habitats are included, 50 to 100 species may occur in relatively small areas in this moist White Fir Type.

At lower elevations, understory herbs include Clintonia, California Strawberry, Rattlesnake Plantain, Wild Ginger and Hartweg's Iris. Following fires, two nitrogen-fixing species occur: Broadleaf Lupine and Small-Flowered Ceanothus.

In typical White Fir communities where coverage is no more than 5%, dominant species include Trail Plant, White-flowered Hawkweed, Bedstraw, Hooker's Disporum, and Chilean Osmorhiza. In openings with more sun, Bracken Fern, sedge species, and Pine Violet are common. In sites where a heavy litter layer occurs, herbaceous vegetation is limited to Prince's Pine and White-Veined Wintergreen. But there is a high diversity of **mychorrizal saphrophytes**, i.e. fungi that derive at least part of their nutrients from dead wood and decaying organic matter in the soil.

Finally, recreational and logging disturbances have caused an increase in Incense-cedar at the expense of White Fir and Sugar Pine. Air pollution is another serious problem because White Fir, Ponderosa Pine, and Jeffrey Pine are the species most sensitive to this type of oxidant damage.

(3) Upper Montane / Upper Montane-Subalpine Transition Zones (5,500 - 9000 ft.)

a. Overview/Indicator and Associated Species

Upper Montane Forest is dominated by the climatic climax Red Fir Forest Type, with associated Mt. Hemlock, Jeffrey Pine, and Lodgepole Pine in the upper parts, and White fir in the lower. Upper Montane forest is transitional between drier, warmer types at lower elevations and moister, colder subalpine types above. The dominant Red Fir Forest extends from around Crater Lake, Oregon, in the Southern Cascades in the north to the Southern Sierra Nevada Province in the south. North of Crater Lake, Red Fir is replaced in the same elevational zone by Pacific Silver Fir, although it is taxonomically closer to Noble Fir. Pacific Silver Fir ranges into the southern Canadian Rocky Mts.

Most precipitation falls as snow (100" or more annually). Less than half of the ground surface is dominated by forest vegetation. Over half consists of lakes, rock outcrops, talus slopes, meadows, and montane chaparral. Both Mt. Hemlock and White Fir occur in mixed stands with Red Fir. Small to medium stands of mostly pure Red Fir are forested patches in a meadow matrix. [See previous section for more information about the structure and composition of the Red Fir Forest Type.]

b. Red Fir Forest Type

Red Fir typically grows in dense, dark stands composed of two age-classes: older (100 to 500 years old) overstory trees and young understory saplings. It is one of the few classic climatic climax forests despite a moderate severity and frequency fire regime because relatively few individuals of other tree species can regenerate in its dark interior. Understory composition is often limited to **saphrophytic** herbs, i.e. plants without chlorophyll which live off of decaying organic matter. These **saphrophytes** include Snow Plant, Corelroot, Indian Pipe, Sugar stick, and Pinesap.

On steep, hotter slopes with dry, rocky soils, Montane Chaparral or brush replaces Red Fir. Dominants are Bush Chinquapin, Huckleberry Oak, Mt. Snowberry, Greenleaf Manzanita, Rabbitbrush, Sticky Current, and Red Flowering Currant. These shrub species replace pioneer or early successional herbs following fire and are in turn shaded out by Lodgepole Pine. Shade-tolerant Red Fir seedlings may grow under the shrubs and eventually overtop the pines. Lodgepole Pine forms thickets on burned ground which is either too wet or too dry for Red Fir. Jeffrey Pine forms moderately dense stands on south slopes with good soil and occurs with White Pine and Lodgepole Pine on rocky outcrops and thin gravelly screes. Aspens associate with Lodgepole Pine on damp flats near meadows or lakes.

Red Fir forests have a moderate severity fire regime, with frequencies and intensities intermediate of other forest types. Mean fire return intervals vary from 40 to 65 years, with a range of 5 to 150 years for any given area. Lightning frequencies are high compared to other elevational zones. Native Americas burned at these higher elevations as well, especially meadows and montane chaparral for wildlife habitat and cultural plant rejuvenation. These burns, however, probably don't show up as fire scars where Red Fir forest was burned with low intensity fires and because of Red Fir's rapid decay rate.

In the central Sierras at Yosemite National Park, Red Fir has the highest fire incidence of all vegetation types in the Upper Montane Elevational Zone. Fires in Red Fir forests vary widely in intensities, resulting in variable fire severity in space and time. Fire severity increases in stands with down windthrown trees mixed with dense thickets of small trees. Younger trees are fire-intolerant (**fire avoider**), but older trees with thicker bark have more tolerance (**fire-resister**) to fires of moderate severity.

c. Jeffrey Pine Forest Type

Temperatures above 6,000 ft. fall below the minimum necessary for sufficient growth of Ponderosa Pine in an increasingly shaded forest. Where shade exceeds 50%, Ponderosa Pine seedlings are too spindly to withstand snow loads while prolonged snowpacks in a shorter growing season exposes seedlings to fungi living in snow. Jeffrey Pine, which grows in all four provinces, replaces Ponderosa Pine. Jeffrey Pine stands, once open and parklike, are getting denser with clumped shrubs and an herbaceous layer dominated by mostly native perennial bunchgrasses, e.g. Idaho Fescue, Western Fescue, and Needlegrass. It either grows in pure stands or dominates mixed stands on serpentine and ultramaffic soils.

Associates include Red Fir, Lodgepole Pine, Western White Pine. Principal understory indicator is Greenleaf Manzanita. Thickets of scrub oak and ceanothus species occur in the understory.

d.Upper Montane Meadows (See **Subalpine Elevational Zone**)

(4) Subalpine Elevational Zone (8,000 to 10,000 ft.)

a. Overview / Indicator and Associated Species

Characteristic tree species are Mt. Hemlock, Western White Pine and Whitebark Pine. Forest tree cover drops from nearly 100% in the Lower Montane and Lower Upper Montane Zones to 25% in the Subalpine Zone. True subalpine vegetation types begin above the Lodgepole Pine band. As in the Upper Montane zone, all precipitation falls as snow except for the occasional summer thunderstorm. Growing season is 7 to 9 weeks and frosts can occur anytime. Winds are severe. Soils are undeveloped with little or no humus. Parent rock is often decomposed granite that results in shallow, coarse-textured, quick-drying soils. All tree species are long-lived, growing for centuries (Foxtail Pine of the Southern Sierras and the Klamath Mts. can live 2000 years). Litter and fuels are extremely low. There is little shrubby vegetation except for willow species, Western Huckleberry, Wax Current, and a high elevation Creambush species.

Mt. Hemlock is the most common dominant of Sierran subalpine forest, and forms extensive, pure, dark stands with sparse ground flora. Western White Pine is moderately abundant, scattered in small groups interspersed with Red Fir, Lodgepole Pine, and Mt. Hemlock on dry, exposed granitic slopes.

Whitebark Pine is the most typical timberline conifer and grows in pure or mixed stands with Lodgepole Pine at lower elevations on extremely rocky substrates. It fills the same ecological niche on the West Slope as Limber Pine on the East Slope (a Rocky Mt. type).

Non-coniferous vegetation of the subalpine zone is dominated by Quaking Aspen, which has one of the broadest distributions of any North American tree. It grows in pure stands fringing meadows and in rock piles with good groundwater. Stands are typically open with a lush understory growth of grass and forbs. It is shade intolerant and sprouts from existing root systems, and can form a dense stand of **boles** (trunks) of the same clone. It grows on **mesic** sites (moderately moist but not saturated) in the early part of the growing season, but willows grow only on sites with a high water table. Without regular fire, stands stagnate and regeneration from both seeds and clone sprouts gradually disappears. Quaking Aspen regeneration is presently not sufficient to replace older, senescent stands.

Most subalpine trees are not adapted to survive fire. Mt. Hemlock is a **fire-avoider** and Lodgepole pine is an **evader/invader**. It invades a site following fire, quickly establishing fast-growing seedlings from seeds released from serotinous (closed) cones opened when heat from fires melts pine sap. Western White Pine is an avoider, while Whitebark Pine is a weak resister, having thin bark but subject to fires of patchy intensity and extent. Since subalpine forests exist in a marginal environment for tree establishment and growth, a fire that kills most or all of a stand can create meadows that persist for decades or even centuries. But once closed, the forest canopy may stay closed for centuries (Mt. Hemlock lives 600-1200 years).

Fire return intervals are difficult to determine in subalpine forests because fires leave very few trees with which to check fire-scars. Fires are, however, known to be infrequent, with return intervals ranging from 30 to 300 years for Whitebark Pine and up to 1500 years for Mt. Hemlock. Crown-fires are most common in Mt. Hemlock forests, but it takes 300-350 years to accumulate enough fuel for crown fires to occur. That fact notwithstanding, weather-driven fire can crown-burn stands with low fuel accumulations and in any seral stage of development.

Mt. Hemlock is susceptible to Laminated Root Rot, which can take out parts of stands in successive waves of infection, leaving sizeable gaps. These gaps are usually filled by Mt. Hemlock regeneration. By establishing in these gaps littered with nutrient-rich decaying older trees, they are better able to withstand future infections, i.e. they grow more vigorously.

Lodgepole Pine, in a dominant Mt. Hemlock forest, will invade a site formerly occupied by Mt. Hemlock following fire. After around 100 years, Mt. Hemlock is the dominant understory tree. Aging Lodgepole Pine (100-200 years old) is increasingly susceptible to beetle attacks. At 250 years, the stand is dominated by Mt. Hemlock.

Since Lodgepole Pine is not affected by Laminated Root Rot, it has a competitive advantage in infested Mt. Hemlock stands where there is enough sun for this shade-intolerant conifer to become established. The fire-return interval in Mt. Hemlock/Lodgepole Pine mixed forest determines forest successional dynamics and composition. A return interval of 200 years favors Lodgepole Pine and disfavors Laminated Root Rot. A return interval of 600 years maintains Mt. Hemlock stands infested with Laminated Root Rot (like our present situation).

b. Subalpine/Upper Montane Meadows

Subalpine meadows are partly the result of permanent high water tables, partly due to lengthy snowpacks and short growing season, and partly because of periodic fire, especially in relatively drier meadows and conifer stands which burn up and revert to meadows during long periods of drought and/or exceptionally windy weather events. There are three basic meadow types: (1) Wet Meadow; (2) Woodland Meadow; and (3) Short-hair Sedge Meadow

(1) Wet Meadow dominant species are **rhizomatous**, i.e. underground vegetative growths which regenerate new plants and maintain a tough, durable sod. Typical species are native perennial sedges, rushes, and grasses. Some wet meadow subtypes are susceptible to severe trampling by livestock. The Sphagum/Fine-leaved Sedge subtype, which grows on an acidic substrate of organic muck, is an example. The subtype most resistant to trampling is wet meadow dominated by rushes which have tough, fibrous roots, but which are low in palatability and nutrition. The most common wet meadow is the Fine-leaved Sedge/Grass subtype that occupies drier, well-drained sandy loams. It is the best developed of wet meadow types. On the drier meadows, species dominance changes from late spring to late summer as the soil dries out. Most wet meadows are climatic and edaphic climaxes.

(2) Woodland Meadow is composed of scattered grasses and forbs interspersed with Lodgepole Pine, willow species, Quaking Aspen, and Black Cottonwood. They were formerly wet meadows that have since partly dried out, leaving a mosaic of wet patches, with the drier patches invaded by trees. This type is rich in herbaceous species.

(3) Short-Hair Sedge Meadow is dominated by sedges that form a tough sod and will withstand trampling well. This type is also highly palatable and nutritious. It begins growth early in the season and goes dormant in the summer, so it is very important early-season forage. But once the sod is broken, it will take decades to recover. Even after 50 years of rest from sheep grazing, some of these meadows have experienced radical species composition shifts and per cent of bare ground has been increasing

2. West Slope Southern Cascade Mountain Physiographic Province

A. Overview/Indicator and Associated Species

The Southern Cascade Mountains range from around Crater Lake at the southern margin of the volcanic pumice (cinder fields) ecological and floristic province, bordering the Klamath-Siskiyou Mountains to the west in the Rogue Umpqua Drainage Devide, and to Mt. Lassen in northern California. The Northern Sierra Nevada Mountains begin just south of Mt. Lassen.

The vegetation types of the southern Cascades are a continuation of the Sierran types to the south. The principal types are Ponderosa Pine Forest which dominates a narrow belt of 1500 ft. as an ecotone and/or modal community between the Lower Foothill Woodland and the higher Mixed Conifer Forest; a Upper Montane Shasta Red Fir/Red Fir Forest; and a high elevation subalpine vegetation type designated as the "High Cascades".

The Mixed Conifer Forest, which straddles the equivalent Sierran Lower/Upper Montane Elevational Zone, includes mixed dominance of White Fir (near the northern limit of its range). Sugar Pine, Ponderosa Pine, Incense-cedar, Douglas-fir, and Black Oak. Shasta Red Fir (a subspecies of Red Fir found more frequently than Red Fir north of the Sierras), Red Fir, and Lodgepole Pine dominate in the Upper Montane zone.

Ponderosa Pine is dominant in the Mid-elevation Pine Forest and is usually associated with Incense-cedar and Black Oak. Characteristic understory shrubs are Whiteleaf Manzanita, Big Manzanita, and Poison oak. White Fir is dominant over 3000 ft., but from 2500 to 3000 ft. any one of five conifers can dominate individual sites. Sugar Pine and White Fir are more abundant on mesic sites while xeric sites are dominated by Incense-cedar and Ponderosa Pine. Important understory species are Snowbrush Ceanothus, Bittercherry, Snowberry, Baldhip Rose, and gooseberry species. Western Dogwood, Western Yew, Vine Maple, and occasional Canyon Live Oak are characteristic of moist sites.

White Fir and Jeffrey Pine are replaced by Lodgepole Pine, Western White Pine, and Mt. Hemlock at higher upper montane and subalpine elevations. A two-tiered canopy layer of a Shasta Red Fir overstory and a Lodgepole Pine understory occurs occasionally. Some Shasta Red Fir stands are climatic climaxes; in other areas Shasta Red Fir is superceded by Mt. Hemlock at the upper margins and White Fir at the lower margins of its elevational range. It is replaced by Pacific Silver Fir on protected sites toward the northern range limits of Shasta Red Fir. Pacific Silver Fir replaces Shasta Red Fir altogether north of Crater Lake, occupying a similar ecological niche. In the northern Sierras, Red Fir is the principal climax tree species, but Noble Fir, its close taxonomic relative, is never climax in the Northern Cascades.

Note: *The elevational zones for the northern Southern Cascades are a little lower for the same forest types than for the Northern Sierras. The difference is not significant. Refer to Sierra Nevada section for elevation information.*

B. Elevational Zones

(1) Valley/Foothill Elevational Zone

The reader is referred to "Valley/Foothill Elevational Zones" section of the "West Slope Sierra Nevada Mountain Physiographic Province" for more information on the basic features of this zone, which in broad terms are common to both the Northern Sierras and Southern Cascades. More information will also be included in the "Klamath-Siskiyou Mountain Physiographic Province". There are three principal valley vegetation types in the Klamath-Siskiyou/Southern Cascades Transition Zone: the northern Sacramento Valley in California and the Rogue and Umpqua valleys in southwestern Oregon. These valleys are the warmest and driest zones west of the Cascades. However, there are climatic differences between these valleys. Sacramento Valley in the south is warmer and drier than the Rogue Valley to the north, although the difference is not significant. Both valleys are in the Montane Mediterranean Regime of hot summers and mild, wet winters. Vegetation types are also very similar. The Umpqua Valley of southern Douglas County, Oregon, however, is in the transitional zone between the drier Montane Mediterranean zone to the south and the more humid Maritime Mediterranean Willamette Valley bordering Oregon's central Cascades to the north.

a. Northern Sacramento Valley

The vegetation types for the northern Sacramento Valley have been described for the Northern Sierras. It's virtually the same for the Southern Cascades in northern California. In Oregon's Rogue Valley, which straddles the Siskiyou Mts./Southern Cascades divide, Douglas-fir is found at lower elevations than in the Sacramento Valley/Foothill Zone and associates with White Oak, Black Oak, Pacific Madrone, Ponderosa Pine. Grey Pine is missing, reaching its northern limit south of Burney in Shasta County. Chaparral and herbaceous species are very similar to the Sacramento Valley, although Toyon is missing; the Buckeye tree species is also absent.
[More detailed descriptions of non-tree vegetation in the northern Sacramento Valley can be found above in "Valley/Foothill Elevational Zone" in the section on the "West Slope of the Sierra Nevada Mountain Physiographic Province".]

b. Rogue Valley

Mixed Conifer/Hardwood Forest is probably the climatic climax type in the Rogue Valley. Like the Sacramento Valley, Native American burning kept the Rogue Valley in a constant state of arrested seral succession or fire-climax favoring a mosaic of savanna, dry and wet prairie, and chaparral patches in different stages of succession. Douglas fir was probably common on hillcrests, more mesic north slopes and in riparian zones. Presently, Douglas-fir and Incense-cedar are invading White Oak/Pine woodlands, and Ponderosa Pine is invading some Wedgeleaf Ceanothus and Whiteleaf Manzanita brushlands established on moister sites. Most of the native valley perennial grassland species have largely disappeared, having been replaced by introduced annual grasses and annual and biennial forbs, including a few exotic mesic perennial grasses like Tall Fescue which are not common in the drier Sacramento Valley. Perennial native grass dominants, judging by existing remnant stands, were probably California Oatgrass, Red Fescue, Lemmon's Needlegrass, and Wild Blue Rye. There are also more introduced *perennial* forbs and grasses than are present in the Sacramento Valley.

c. Umpqua Valley

The Umpqua Valley of southern Douglas County, Oregon, just north of the Klamath/Siskiyou Physiographic Province and nestled in the low elevation Transverse Coast Range/Southern Cascade Transition, receives more marine climatic influence than the Rogue. Summers are dry, but not as hot as the Rogue. Where the Rogue Valley is in the partial "rainshadow" of the eastern Siskiyous, and averages around 15 to 25 inches of rain annually, the Umpqua is bounded by lower coastal ranges to the west, and averages 40 inches or more annual precipitation. There are more wetlands here, including wet prairie, wet shrublands, and wet woodland, more typical of the Willamette Valley further north than valleys south of the Umpqua/Rogue Divide.

The grassland composition is significantly different from the Rogue Valley. Wetter-adapted introduced perennial grassland species, typical of the Northwest California and the Pacific Northwest Floristic Provinces, include Tall Fescue, Kentucky Bluegrass, German Velvetgrass, Wild Carrot, Ox-eye Daisy, Klamath Weed and Russian Knapweed. Two highly invasive annual species are also present: Medussahead and Cheatgrass.

d. Valley Wetlands

Like the Rogue and Sacramento valleys, Indian burning kept the vegetation in a fire climax stage, favoring oaks and pines over Douglas-fir and Incense-cedar. Wetlands, also maintained by fire and valued by Native Americans as highly productive sources of important foods like Camas, as well as prime whitetail deer habitat, were interspersed within the greater drier grassland/White Oak savanna with mesic species on sites intermediate in moisture between the wetlands and drier grasslands. Regular Indian fire tended to keep woody vegetation out of many wetland prairie biotopes. Presently, with the cessation of these intentional fires, wet woodlands have replaces former wet prairies.

(1) Wetland Prairie communities were -- and still are in a few remnant patches in the Willamette Valley - - dominated by Tufted Hairgrass which associates with many kinds of other grasses, sedges, rushes, and herbaceous species. In all of Oregon, only 0.2% (800 hectares or 2000 acres) of an estimated 400,000 hectares (one million acres) in 1850 remain.

(2) Wet Shrub Swamp communities are dominated by Nortka Rose and Tufted Hairgrass with scattered wet prairie openings. Characteristic species include Serviceberry, Douglas' Hawthorn, and Douglas' Spirea or Hardtack. Important exotic invaders are English Hawthorn, naturalized apple and crabapple trees, and Sweetbriar Rose, with Scotch Broom on drier slopes. Those species form dense, impenetrable thickets crowding native species and degrading or eliminating wildlife habitat. Only 1% of some 4000 hectares (10,000 acres) of native bottomland vegetation remains, most in the Willamette Valley.

(3) Wet Woodland is often dominated by Oregon Ash, Pacific Willow, Black Cottonwood, Red-osier Dogwood, with an understory of Stinging Nettle associated with a variety of wetland shrubs, sedges, rushes and grasses. These same species also occur in the formerly wide "gallery" forests of valley rivers.

(4) Valley/Foothill Sclerophyllus Shrub (Chaparral) Communities, as in the Rogue and Sacramento Valleys, are dominated by Wedgeleaf Ceanothus and Whiteleaf Manzanita that associates with Whitethorn Ceanothus and Poison oak, and with Deerbrush Ceanothus on shady forest edges. Tanoak, found along with Creek Dogwood and Canyon Liveoak on moister sites, reaches its northeastern limit south of the Umpqua Valley around Tiller in southern Douglas County. Some shrub communities in the Rogue and Sacramento valleys may be climax on very xeric sites, e.g. Wedgeleaf Ceanothus. But most other brush communities depend on fire for continuance, e.g. the Ponderosa Pine/Whiteleaf Manzanita/Hoary Manzanita association where Ponderosa Pine is probably climax. Very few chaparral communities are associated with Douglas-fir.

(5) Valley/Foothill White Oak Savanna/Woodland communities, described above, are suffering from lack of regeneration and stand stagnation in virtually all of the Sierran and Pacific Northwest Floristic Provinces. Also in trouble are Blue Oak stands in the foothills surrounding California's Central Valley, of which the Sacramento Valley is its northern extension, and Black Oak at higher elevations. Valley Oak of the Sacramento Valley floor and surrounding lower foothills, fragmented or removed by agriculture and suburban development, is also not regenerating. The regeneration problem is at least partly the result of heavy livestock and deer browsing of oak seedlings. Where livestock is removed or the deer population is decreasing, oak seedlings are able to survive until they are large enough to avoid browsing animals.

Periodic light ground fires are not a prerequisite for acorn germination and seedling establishment. However, fire releases nutrients tied up in litter and this results in a healthier and faster-growing seedling or stand. Fire consumes some oak regeneration and thus spaces oak trees further apart which also enables them to grow better. Regular burning also increases acorn production and breaks up the overwintering cycle of "pests" like oakworm and caterpillar.

Fire suppression is not the only reason for today's poor oak regeneration and stand conditions. Another reason is late 19th and early 20th century woodcutting practices. Oak was a preferred firewood. Probably most stands were cut at one time or another, White and Black Oaks resprout following fire or cutting with multiple **stems** (trunks) of the same age. This makes for a denser, shadier stand. Oaks regenerate best in the sun.

Trees on the edges of stands could regenerate and the stand could expand outward with single-stem trees, but the use of barbed-wire fencing beginning in the 1870's confined formerly free-ranging livestock to a particular area, and the oak seedlings were browsed out.

Today, most white oak stands are dense with multiple-age stems and around the same age of 100 years, even though their trunks are often only 4-5 inches in diameter. Many suppressed oaks are dying at a much younger age than usual under historical fire regimes. Douglas-fir, Incense-cedar, and White Fir at higher elevations are invading and overtopping these stagnating stands of oaks.

Oaks weakened by suppression, especially during extended droughts, are more susceptible to attack by oak worms and other insects as well as mistletoe infestations. Older trees are particularly vulnerable. Sudden Oak Death Syndrome (SODS) may be related to lack of regular fire. SODS is caused by a **phytophthera** fungus. Fungal spores are often killed by exposure to smoke. There is probably more moss on oak trees today than has historically been the case with regular fires thinning more moss or not allowing it to get established. Moss traps moisture, and moist environments favor phytopthera fungi. Once thinned, and if not too **senescent** (too far along in the process of dying), deciduous oaks will respond to thinning by bole-sprouting the following season and, unless restorative thinning and prescription fire are applied soon, oak regeneration will virtually cease and oak stands will slowly die young.

(2) Lower Montane/Upper Montane Transition Zone Mixed Conifer Forest Type

This mid-elevation zone is composed of forests of forests of Douglas-fir, Sugar Pine, Ponderosa Pine, Incense-cedar, Grand Fir and White fir. It is ecologically analogous to the Sierran Mixed Conifer Forest type, but occurs at lower elevations. It is between the Interior Valley/Foothill and the White Fir types in the south and grades into the Western Hemlock type in the north. Like the northern Sierras' Mid-Elevation Zone, this is a highly diverse elevational band. This vegetation type also occurs in the Eastern Klamath-Siskiyous.

White Fir and Western Hemlock are the climax tree species, with Western Hemlock and its Red Cedar associate dominate in the more mesic habitats in the north. Douglas-fir is a seral species along with some Western White Pine in the north, and is a seral species along with Sugar and Ponderosa Pine, and the most abundant tree species, but is slowly replaced by Ponderosa Pine in the south. White Fir, and Grand Fir at lower elevations in the north, is the dominant conifer understory species in Pine or Douglas-fir stands. White Fir and Grand Fir hybridize where their ranges overlap, at around 3000 ft. elevation, but hybrids are classed as White Fir. Incense-cedar dominates on xeric sites due to extensive development of seedling root systems. Bigleaf Maple and Pacific Madrone are also present.

The shrub-layer is well developed in many stands and is characteristic of sites with low moisture stress, e.g. Western Hemlock seedlings and saplings, Western Yew, Vine Maple, Twinflower, and Western Rhododendron.

The White Fir/Douglas Fir/Yerba de Selva association is the most extensive community type and best developed in the northern subprovince while the southern subprovince has more Sierran associations already described for the Mixed Conifer zone of the Northern Sierra. White Fir and Douglas-fir dominate higher elevation and moister sites.

The most xeric habitat types are dominated by the Douglas-fir/Incense-cedar/Pinemat Manzanita community in the north and by Ponderosa Pine/Incense-cedar/Black Oak/Greenleaf Manzanita in the south, Sugar Pine and Ponderosa Pine can also be present in the north as well as Sugar Pine with Ponderosa Pine dominant in the south. Also present in the understory with the dominant Pinemat Manzanita or Greenleaf Manzanita are Prostrate Ceanothus (sometimes dominant)) and Fremont Silktassel. Greenleaf Manzanita is common in both subprovinces.

The more mesic habitat types are dominated by the White Fir/Twinflower type. In the South Umpqua Rive Drainage of the northern subprovince, Salal is the dominant understory shrub in stands in which Western Hemlock is the projected climax. Other community types in the general Rogue/Umpqua Divide Subprobvince include various mixes of Douglas-fir and Grand Fir at lower elevations with Longleaf Oregon Grape, Salal, Cream Bush (Ocean-spray), Baldhip Rose, Trailing Blackberry or Tall Oregon Grape as potential dominants and/or common associates.

Douglas-fir is reproducing successfully in some stands, but seedlings and saplings of Incense-cedar, Grand fir, and Sugar Pine are also present. Grand Fir is the major climax tree species, but Douglas-fir and Incense-cedar may be minor climax species in the drier Creambush/Salal community. The Douglas-fir/Western Hemlock/Salal is the most mesic type, with Vine Maple, Pacific Yew, and Snow Dewberry as important associates. The Salal/Longleaf Oregon Grape association is the most important low shrub dominant and the

Twinflower/Swordfern/Yerba de Selva is the most important herbaceous association. Western Hemlock is the major climax tree species

(3) Upper Montane/Upper Montane-Subalpine Transition Elevational Zone

Note: See section on the Sierran *Upper Montane-Subalpine Transition Elevational Zone.* The major Sierra Red Fir and Red Fir/Mt. Hemlock forest types and associated communities are very similar to those in the Southern Cascade Mountain Physiographic Province.

(4) Subalpine Elevational Zone

Note: See section on the Sierran Subalpine Elevational Zone. The major Mt. Hemlock/Mt. Hemlock-Western White Pine-Lodgepole Pine/Subalpine conifer forest types and associated communities are very similar to those in the Southern Cascade Mountain Physiographic Province.

3. Klamath-Siskiyou Mountains
(to be included in phase 3)

4.California North Coast Ranges
(to be included in phase 3*)*

PART V
Restoration Forestry: From Theory to Practice

1. How To Achieve Restoration Goals Using Ecosystem-Based Knowledge and Silvicultural Techniques

We have established a reference point in time and space for the kind of forest structure and composition specific to our region and forest type that we wish to restore. We have done this conceptual reconstruction using what information is still retrievable from the existing literature surveys, and from our personal experience in our forest. Where necessary, we have filled in critical gaps in our knowledge with techniques from ethnography and historical ecology, including oral interviews with local elders. Even a simple mapping of old growth conifer stumps (hardwoods decompose much faster) will reveal important information about precontact forest structure. Selected tree borings may tell us about age-classes, fire history, and insect or disease epidemics. Our own experience in the forest may be the most valuable knowledge of all. We will now present a brief summary of the most important scientific disciplines and forest management and harvesting systems which are available as tools with which to reconstruct reference ecosystems and design the appropriate restoration prescriptions.

A. Limitations of Western Ecological Sciences (WES)

Western ecological sciences (WES) are important in this reconstruction process. But WES has its limitations. Like the conventional forest classifications which we have discussed above, science abstracts general principles or conceptual elements out of their specific historical contexts for replication and testability on a broad scale. **Traditional Ecological Knowledge** (TEK) is place-specific, incorporating the accumulated knowledge of many generations (**synchronic** observations). WES studies are usually short-term or cross-sectional (**diachronic**). WES doesn't yet recognize human cultural landscapes as legitimate reference ecosystems, even where indigenous sustainable cultural practices have led over long stretches of time to high biodiversity, relative stability, resiliency, and enhanced function.

For these reasons, historically authentic baselines are more useful to restoration forestry than attempting to model future secondary successional outcomes. **Systems theory** and **modeling** do have a role to play. They can simulate, e.g., various disturbance scenarios in order to find out what would happen, say, to fire behavior in a stand thinned with a certain silvicultural prescription. But their predictive powers are usually limited in space and time. There are too many unknowns about future changes in climate, etc. (**stochasticity**). Forest ecosystems are too complex. The model is only as good as the accuracy of the information put into it. Too few scientists have long-term personal experience in a particular forest. Substituting abstract science for personal experience in the forest is not sufficient for good restoration forestry. Knowledge is more than technique; it is also experience.

B. Integrating Forest Stand Restoration With Landscape-scale Ecology

Our work reconstructing a reference ecosystem involves both forest stands and the greater landscape of which they are a part. Restoration forestry is an experimental field. There is much we don't know about how degraded forests will respond to our restoration efforts. We should not, therefore, attempt restoration beyond the stand level in our present state of limited knowledge. On the other hand, we need information about the larger landscape because it is connected in many ways with stands. And, of course, we won't be prepared to restore landscapes unless we first experiment with stands. However, a strong case can be made for multiple-entry, large-scale thinning of smaller diameter trees to reduce fire hazard where fire risk is high - both near human settlements and in places where quality animal habitat is at risk or in dry forest types during prolonged drought. Larger saw logs would have to be harvested to pay for this thinning and equally important slash disposal - - while leaving the biggest and best for future old-growth. Representatives of all species and age-classes should be maintained in sufficient quantities for future long-term (100-200 yrs.) timber harvesting rotations as well as for future permanent old growth and quality wildlife habitat.

(1) Diaz' and Apostle's Landscape Analysis and Design Process

The following is from Diaz and Apostle's Forest Landscape Analysis and Design. Their landscape approach was used by the Rogue River National Forest in planning **future desired conditions** for the Little Applegate Watershed in the Siskiyou Mountains of southwestern Oregon.

There are two phases to landscape level planning: an analysis phase and a design phase. The **analysis phase** identifies:

1) landscape elements (matrix, patches, corridors);
2) landscape flows (animals, humans, water);
3) relation between landscape elements and flows;

4) natural disturbances and succession;
5) functional linkages to adjacent areas.

These are mapped, often with the assistance of Geographical Information Systems (GIS), on mylar overlays.

The **design phase** for restoration, unlike Diaz' and Apostle's Forest Service Forest Plan reference point, refers to our target forest reference condition developed from historical/ecological surveys of several different ecologically comparable stands which may be scattered some distance across a landscape within a fairly extensive matrix. In other words, our stand reference condition will usually turn out to be a composite of several stands within comparable habitats.

(2) Historical Authenticity vs. Ecological Functionality

With the landscape scale mapping complete, we will have an informed notion of the ecological relationship between landscape and stand. Because those of us who work on private forestlands usually don't have any say-so about the greater landscape (unless we are a public land agency or large corporate holding), the ideal reference ecosystem may be considerably modified by severe forest fragmentation and degradation over which we have no control. We may have to sacrifice **historical authenticity** for **ecological functionality**. Restoration is often a question of balancing fidelity to an historical reference ecosystem with some measure of functionality. Optimum functionality may likewise be impossible to achieve in some degraded forest landscapes. E.g., a woodlot which has a tree stocking rate many times higher than the reference forest, but which is surrounded by clear-cuts, should not be thinned beyond the point where its role as a plant and animal refugia is compromised. It is because of these kinds of fairly common situations on private lands that knowledge of landscape flows - - particularly wildlife movements - - is critical. It also underscores the need for private landowner cooperation in restoration forestry (**community-based forestry**), **Ecosystem management** was endorsed by public land agencies because it was necessary to cross jurisdictional boundaries (private, state, federal) in order to protect threatened species as required by tough environmental laws. Conservation biology has a similar problem protecting species like far-ranging top carnivores.

(3) Ecological Integrity

Finally, landscapes which consist of a fairly balanced mix of forest plantation or farmland monocultures and natural forests with high restoration potential may in the end still retain its overall **integrity**. It depends on the degree of fragmentation, e.g. if there are enough large patches or stands with good **interior-to-edge ratios** (i.e. large enough for considerable interior habitat). Conservation biology plans buffers outside of its core preserves where human economic activities still allow the larger ecosystem to function reasonably well, with enough corridors to connect the larger stands for wildlife habitat and dispersal corridors. The landscape may still be functional if not historically accurate. This is one reason why both **conservation biology** and **restoration ecology** prefer the use of the concept of **integrity**. Integrity means whole or undiminished. The larger the landscape the greater the chances are that it will contain enough quality habitat to function adequately - even with human economic activities. Integrity depends to a large degree on scale. But as we have emphasized before, every effort should be made to design silvicultural prescriptions that further ecological restoration or conservation and still generate forest by-products that can pay for restoration. The matrix, usually ignored by conservation biologists, can contribute both scale and quality habitat to the recovery of ecological integrity by providing sufficient **redundancy**.

C. The Use of Ecologically Appropriate Silvicultural Techniques and Timber Harvesting Systems In Restoration Forestry

The logging methods of the past century have too often followed the "one size fits all" mindset. It has been about efficiency, not ecology. The means have become ends. As research ecologists have learned more about how forest ecosystems function, some foresters and scientists have responded with alternative **light touch** silvicultural techniques and timber harvesting systems. We will discuss these alternative approaches to industrial forestry below. It should be kept in mind that they are *timber* harvesting systems and don't necessarily have to do with restoration forestry. Light touch systems like individual tree selection or uneven-age management may be as ecologically degrading or inappropriate as industrial clear-cut logging. It all depends on the regional forest type and the restoration objective and that depends on the historical reference condition and disturbance history of a particular forest type or seral stage.

(1) Ecosystem Management

R.E. Grumbine defines ecosystem management in the Journal of the Society of Conservation Biology (March 1994, pp.27,31): "Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term". With the advent of stiff environmental laws beginning in the 1970's, federal and state resource agencies have been required to protect endangered or threatened species, especially old growth or late successional species. They have needed to cooperate across jurisdictional boundaries in order to do this. The Clinton Forest Plan of 1993 mandated a balance between timber harvesting and ecosystem protection. A team of forest research scientists (Forest Ecosystem Management Assessment Team or FEMAT) asked for $10 million to study complete (all seral stages) forest ecosystems as well as plant and animal community interactions. They received only $2 million. Both the general public and the timber industry put highest value on old growth forests. So that is what FEMAT studied. The focus was put on protecting late successional species like the northern spotted owl, and on protecting rapidly diminishing runs of anadramous fish (e.g. salmon). Both owls and salmon became **"umbrella"** or **indicator species** of forest health with a powerful public appeal. While this appeal has promoted protectionist aspirations of the environmental movement, it has also turned research attention away from early and mid successional communities and species and onto late successional ecosystems and species.

Keep in mind that ecosystem management is an ambitious attempt to continue harvesting timber, even some old growth, in the face of major reductions in the former level of harvesting *and* protect ecosystem integrity. Clearly, federal agencies don't have the financial and institutional capacity to do this without massive subsidies. Late successional reserves were established (although they are also entered periodically) and less mature forests - - the greater landscape matrix - - were sacrificed to intensive timber management and harvesting. The promise of ecosystem management has not been fulfilled in practice by public land agencies.

What about the concept? It **is** holistic in its approach to ecology and economy. But it has some theoretical problems: a. Even if all forest seral stages were protected or restored, there is no historically accurate reference ecosystem: "**Future desired conditions**" are based more on current social values then authentic forest history and functionality; b. human values in the end determine how far to go ecologically; e.g. the focus on old growth *alone* because of its high social and economic value. Grumbine's definition puts ecology *within* a "complex sociopolitical and values framework", whereas human economic activities should be put within a framework of ecological restoration. Silviculture and timber harvesting should further conservation or restoration. c. An inherent conceptual limitation always present in any ecosystem-focused forest management approach is the very definition of "ecosystem": What exactly is an ecosystem? An ecosystem for a grizzly bear may be up to 650 square miles in area, whereas a vernal pool may be only a few square feet. It all depends on the particular species that you are targeting. The danger in using the term "ecosystem management" is that is too easy to call *any* given forest preserve, or park and ecosystem. An example is Yellowstone National Park which is touted as a complete ecosystem but which in fact is insufficient all-year habitat for grizzly bears and elk. This has resulted in a confusing series of policy changes in park management over the years - e.g. first culling overpopulated elk herds and then allowing them to overbrowse their range because it is believed that Yellowstone is a complete ecosystem, and therefore starving elk and denuded vegetation are "natural" and nature will in time rebalance herself (homeostasis).

The research focus on old growth forest types and species has trickled down from the current literature in forest ecology to field practices of alternative light touch foresters. Their reference ecosystems are often late succession forest structure and composition. Full canopy closure is the preferred structure. Little attention is paid to non-tree composition or early and mid successional stages of forest growth. It is often assumed that there is too much early seral forest because of the high density of clearcuts. But opportunistic weedy species - - often introduced "pioneer" annual plants which quickly colonize clearcuts - - are not ecological analogs to more stable native species, especially perennials, which were maintained in forest openings for long periods of time by Indian burning (**arrested seral succession**). In fact, so-called early, mid, and late successional species are often found together in unlikely associations. There is high initial species richness in clearcuts before they quickly close up and become plantation monocultures, but it is unstable, often non-native, and is short-lived. Our preferred reference ecosystem is the Indian fire-managed forest, with repeating mosaics of all seral stages within the matrix and which were relatively stable in time and space.

This, in fact, is what historical old growth forests were like: a mix of all seral stages at the landscape level, but in some forest types the dominant overstory conifers lived for several centuries. If these dominant trees were relatively fire resistant (for example Redwood or Douglas-fir) they would remain standing in place for hundreds of years while the understory vegetation was changing its mosaic patterns in response to periodic fire, windthrow, etc. which continually create gaps in the forest canopy - - slowly but continually recycling early, mid, and late successional plant communities.

(2) New Forestry

Jerry Franklin of the University of Washington and one of the intellectual fathers of "new forestry", considers its objective to be the "development of forest management systems which better integrate commodity production with maintenance of ecological values." Structurally complex old growth is the reference system at the stand level. Like ecosystem management, it is an integral part of industrial forestry but seeks to mitigate some of the negative ecological effects of traditional practices like high-grading the biggest and best trees, clear-cutting, intense slash fires following logging, short timber rotations, etc. A particular emphasis is put on retaining enough biological legacies for maintenance of the means of forest regeneration following timber harvesting, i.e. propagules like seeds and roots, down wood, snags, wildlife habitat, seed trees, etc. Attention is also paid to the effects of harvesting on the larger landscape ecosystem.

Chad Oliver of Yale thinks that industrial forestry can simulate forest disturbances like fire through thinning prescriptions which create at the landscape level all four of the typical stages of forest succession: (1) stand initiation following clearcutting or fire, (2) stem exclusion, (3) stand reinitiation, and (4) old growth (they will be defined below). This more balanced approach would satisfy society's need for wood fiber and its concern with conserving biodiversity as well as provide long-term carbon storage to mitigate global warming. But it is still the kind of disturbance with which the forest is not familiar because of the scale of clearcutting, the lack of the ecologically appropriate kind of fire based on Indian burning patterns, and the use of short rotations in the simulation of stand initiating wildfires, i.e. the scale and rate of disturbance are outside the historical range of variability. **Shelterwood cuts**, which leave a few scattered trees in a clearcut for seed production or wildlife, and have been a preferred harvesting prescription of new forestry, still work on short rotations. The leave trees are cut in the next harvest before reaching the old growth stage. Little permanent old growth is retained, and the old growth that is retained will still be cut on longer rotations. Jerry Franklin, however, has recently been advocating **variable density management** - - silvicultural prescriptions which place more emphasis on restoring forest diversity by leaving a wide variety of vegetation age and size classes and gaps of varying shapes and sizes following group selection harvesting. The old growth reference ecosystem for Franklin and Oliver is based primarily on Pacific Northwest *coastal* Redwood, Western Hemlock, Sitka Spruce, and Western Red Cedar forest types - - the classic temperate rainforest - - but has been generalized throughout northern California, western Oregon and Washington, and British Columbia where it may be an inappropriate model.

(3) Uneven-aged (All-aged) Individual Tree Selection: "Ecoforestry" and "Worst First Forestry"

This is the ultimate light touch forestry. In the eastern U.S., it's called "**worst first forestry**". Only the trees which nature has already selected for removal are harvested (i.e. **natural selection**). They are usually trees which are suppressed by taller overstory dominants, or are in some way marginal with a likelihood of early mortality. It should be noted here that we may be removing trees that possess genes for superior drought tolerance or disease resistance. We may be depleting the genetic diversity of our forest trees while assuming that nature has selected these trees out. Trees are harvested individually or in small groups. Full canopy closure is the rule. **Natural regeneration** is preferred over artificial planting. In other words, they have taken as a given that secondary succession - - with tree stocking rates, structure, and composition mostly the result of fire suppression and industrial harvesting methods and completely outside of the historical range of variability - - is the "natural" forest state. Historical reference ecosystems are ignored.

Individual tree harvesting favors uneven-aged stands. This can pose a fire hazard in drier interior forests because of "**ladder fuels**" from ground to crown as opposed to the pre-fire suppression interior forests which were a mosaic of post-fire even-aged stands within an overall uneven-aged and multi-species forested landscape. Full canopy closure encourages regeneration of shade-tolerant tree species.. Shade tolerant conifers are more susceptible to disease and insect infestations, even in all-aged and multi-species forests. This also accelerates forest succession to its "potential" or "climax" stage. Pine and Douglas fir tend to get shaded out by Red Cedar, Western Hemlock, Grand Fir, and White Fir. Understory herbaceous plants soon drop out, especially those requiring more sun and regular fire. Structure and composition are more like the "stem-exclusion" forest phase than old growth. Stem exclusion forests result from a densely stocked stand which has grown up to full crown closure with little or no understory plants (40-100 or more years old) following a disturbance like clear cutting or very intense wildfire. Stand reinitiation is the next phase when the forest begins to self-thin and species diversity increases. **Old growth** - - around 300 or more years depending on forest type- - is more structurally complex with higher species diversity, and includes all seral stages. But if the stem exclusion phase contains tree stocking rates far above the historical range of variability due to fire suppression, it will never self-thin to the stocking rate of the historical stand-initiation and old-growth phases. It will be far less diverse and a significant fire hazard. In crowded stem exclusion forests, even dominant larger size class trees - - which will gradually kill the smaller size class in the understory - - will suffer reduced vigor, and as the ratio of sapwood to heartwood shrinks in size, may never reach their full genetic potential for large, healthy old-growth.

Forest underburns are risky in this kind of forest. In cool moist forest environments, it may be impossible to ignite a fire during the safer fall or spring burning seasons. Wildlife habitat deteriorates because of lack of fire. This kind of forest stand did exist under the Indian and lightning fire regime, but did not constitute the dominant matrix. It was more like a patch or corridor - - especially on north aspects and in shady, moist canyons and flats - - which were large enough to supply adequate interior habitat but which also were interspersed with other forest seral stages at the landscape level.

D. Restoration Principles and Ecologically Appropriate Silvicultural Systems For Restoration Forestry

The silvicultural systems described above could have a legitimate role in restoration forestry if the scale and the rate of change are within the historical range of variability. It all depends on (1) the physiographic province, (2) the forest type, (3) the state of the surrounding landscape, and (4) a reference ecosystem which is a balanced mix of historical authenticity and ecological functionality.

Before silviculture can be integrated with ecological restoration, it needs to be disconnected from timber harvesting - - both industrial and light touch - - where it has played a dominant role. Timber harvesting, whether even or uneven-aged or individual or group, must further forest ecosystem conservation or restoration. We need to reconnect silviculture to restoration in a fundamentally different way. Instead of systems driving restoration, restoration needs to drive systems. Means shouldn't drive ends - whether technique or economics.

We need to be very specific about our restoration objectives, choosing the appropriate system or technique regardless of whether it is perceived as politically correct or not. To illustrate how this integration process can work in the field, we will look at two widespread regional forest types: dry interior montane and moist coastal montane. "Dry" and "moist" are shorthand ways to describe *relatively* dry and moist forests.

(1) Dry forests are typically interior types, often dominated by more drought tolerant tree species like pines or drier-adapted, Douglas-fir . Fire was frequent. Five to 20 year mean return intervals were common. Historical tree stocking rates were low (10 to 30 trees per acre), although fire suppression has resulted in stands with stocking rates now as high as 2000 or more stems per acre (**stem-exclusion seral stage**). Catastrophic stand-replacing fires were rare because of the scarcity of ladder and ground fuels and more open tree-spacing. More shade tolerant species like white fir and incense cedar have come up in the understory and are now overtopping pines and hardwoods like oaks. Fire hazard is high. Disease and insect epidemics are increasing in intensity and frequency. Drought stress for some tree species is common. Most stands are composed of more or less even-age second-growth trees of two size classes, with some stands consisting of two age classes (mature and seedlings/saplings), but understories are dominated by shade tolerant **fire-avoiders** which are usually climatic climax species. Little old growth is left. In some places, overgrazing has impoverished understory composition. Livestock have grazed out most of the palatable cool season bunchgrasses which checked woody shrub and tree regeneration and which used to carry the frequent light understory fires.

What is the restoration prescription? Broadly speaking, it is group tree selection thinning, restoring prescription fire, and locating and then seeding missing summer-collected herbaceous and shrub understory species into the ashes following the first fire.

The **group selection** cuts should be done in several harvest entries to minimize ecological degradation which could result from changing the stand environment too rapidly. Cable logging from existing roads will minimize damage to leave trees and soil compaction as well as soil disturbance from heavy tractors that could favor invasion by weedy native and exotic plant species. This gives the leave trees some time (5-10 years perhaps) to adjust to their new environment. It also minimizes sunscald and windthrow. It allows slow moving species like reptiles and amphibians some adjustment time. It doesn't disrupt underground relationships between mychorrizal fungi and forest trees or other plants. **Mychorrizae fungi** greatly enhance nutrient and water uptake as well as disease resistance of plants. How large should the group cuts be in the end? It depends on a lot of factors, but particularly the physiographic province, forest type, elevation, slope aspect, topography, and historical baseline information. It may not be possible to achieve low historical stocking rates (few trees per acre) if the greater landscape is severely cut over (**stand initiation phase**). On the other hand, if there are extensive surrounding overstocked stem-exclusion forests, historical stocking rates would be ecologically appropriate. Forest trees which have invaded dry meadows (meadows in interior montane forests have lost at least half of their precontact area) may require group selection cuts of up to 5 acres. In the steep and complex topography of the Klamath-Siskiyou Mts. e.g. in the Mid-Elevation Mixed Evergreen/Mixed Conifer Forest Type, smaller sized cuts could be made, e.g. up to 1.5 acres. Individual tree selection would be inappropriate in this kind of forest environment. It would only further the invasion of shade-tolerant species. Group selection cuts larger than 5 to 10 acres would also be inappropriate. Too much change too fast.

Should we thin for even-age or uneven-age structure? Again, it depends. If the second-growth stands are relatively even-aged, we may want to allow tree regeneration in our openings or patches by not burning there or choosing a burn window when moist cool conditions will favor a patchy burn. Then later we could open up a new patch with a group selection cut. Our historical baseline suggests that this kind of forest consisted of fire-generated even-aged stands in an overall uneven-aged forest, due to fire events staggered in space and time. Fire events, e.g. in the Klamath-Siskiyou, ranged from one to 1000 acres with an average of around 50 acres. The rugged topography of the Klamath-Siskiyou was an important factor here. The forest consisted of a mosaic of different aged stands. This was also true, to a more limited extent, in the Sierra Nevadas.

(2) Moist Forests are found in coastal mountains of the Pacific Northwest. Typical dominant tree species are Redwood (no. California), Douglas-fir, Western Hemlock, Grand Fir, and Western Red Cedar. The fire cycle was less frequent than the drier interior forest types. Stand replacement fires during drought years did occur over the centuries because of more ladder and ground fuels, closer spacing of trees, and more biomass generally. Fire suppression and industrial harvesting have resulted in an increase in stocking ratio from around 25-100 trees per acre to as high as 3000 trees per acre. There is more vertical heterogeneity (structural complexity) in the moist forest, with more fuel ladders. Fire hazard is high during long droughts. Hardwoods and herbaceous understory plants are slowly being shaded out, although the more shade tolerant species are still prevalent, except in the stem-exclusion phase. Insect epidemics are less frequent because of less drought stress on the trees. But diseases are increasing in frequency and severity. The old growth phase is closer to the current late successional model than drier forest types.

Restoration prescriptions include individual and/or group selection cuts varying in size from a few hundred square feet to about 1.5 acres, except where meadows like the "Bald Hills" of the coastal mountains have been invaded by conifers due to fire suppression and larger cuts may be needed. Heavy ground fuels, including logging slash and large down wood, are common and far above levels in the precontact forest (15-30 tons per acre is not uncommon). Native Americans burned these large balds on a regular basis for cultural plant materials and wildlife habitat (e.g. elk and deer). They also kept smaller patches open at all elevations by burning. The cool moist climate of the coastal mountains mitigated fire effects on tree regeneration, i.e. fewer young trees were burned up and so tree spacing was closer. But patches of varying sizes were burned on a regular basis to attract game and maintain culturally important plants.

Thinning prescriptions would be designed to mimic Indian burning patterns. A combination of small (up to 1.5 acres in several entries) for the matrix and large patch cuts (up to 5 acres) for "bald" or meadow restoration. Fire would be restored to its precontact seasonality, selectivity, intensity, and mean return interval. Missing understory plant species could be located and seeded into the ashes following fire.

This forest type is mostly second growth which is either even-aged or consists of two age classes (mature and seedlings/saplings or younger pole sized trees) and two size classes of the same age due to extensive clear-cut logging. The reference model suggests that this forest was made up of a range of age classes both within and between stands due to the uneven effects of fire in this moist environment. Ecological functionality requires structural diversity at the landscape level (**horizontal heterogeneity**) but less vertical complexity than the old growth model further north in Oregon, Washington, and British Columbia, with all seral stages and habitats represented and the full spectrum of shade and sun repeated throughout the forest, but particularly on upper slopes and at the coastal scrub-forest interface.

E. Restoring Forest Understory Plant Composition

Most Native American burns occurred in the fall. Native shrubs harvested in September, and herbaceous grasses and forbs have set seed by September. Some seeds, like many native grasses, require a one to two month "after-ripening" in order to be viable, e.g. grasses which set seed in July should be ready to use by September; others, such as high elevation types, may require waiting until as late as early November before using. Seeds of missing understory plants -- species which our reference model tells us used to be in the forest - - should be on hand for direct seeding into ashes following a fall (late September to early November) prescription burn.

Burn piles (slash) also offer opportunities for seeding. Slash piles near leave trees where burning would be unsafe can be left for wildlife. Burn pile seeding, following burning, over time will provide islands of native understory plants which will provide future *in situ* seed sources for further restoration.

As with forest tree seed collecting, care should be taken to collect seeds from a similar elevation (within 1000 feet) and from a comparable habitat (similar ecology) within a 100 mile radius if possible. It may be necessary to go further than 100 miles away or higher or lower than 1000 ft. in elevation. Current research suggests that comparable habitat may be a more important factor than distance or elevation. It is important that as much genetic diversity as possible be restored. Collecting should be done from as many different populations of a species as possible within similar forest environments. This will ensure good genetic diversity within the restored population (see section on "Genetic Diversity").

Some forb and shrub species require overwintering treatments in a greenhouse or coldframe to break dormancy. This is called **stratification** and usually involves storing seeds in sterile peat moss at just above freezing for two or three months. Occasionally, chemical treatments are also required to break dormancy.

Direct seeding into ashes following fire is the most efficient way to establish missing understory plants. Sometimes, however, outplanting container or bare root stock is necessary, especially with shrubs and trees. Deciduous hardwood cuttings can be propagated in the greenhouse or coldframe over winter (from fall cuttings). Evergreen plants can be propagated from cuttings taken in spring or summer, depending on the species, and then grown one year in the greenhouse or in field plots for later transplanting. Some moisture-loving woody species can be directly planted in soil from cuttings (November or December). Examples are willows, alders, and Mock Orange.

F. General Guidelines For Group Selection Cuts, Monitoring, and Prescription Fire

We will now consider some general guidelines for group selection cuts for most forest types. Our historical reference ecosystem is based at least initially on the structure and composition of the precontact (preEuropean settlement) forest, i.e. the forest which had not yet experienced disturbances like fire suppression, industrial harvesting and overgrazing with which it was not familiar in an evolutionary sense.

Our reference forest landscape is a mosaic of seral stages, patches, and corridors of varying sizes and shapes - small openings to meadows and balds of hundreds of acres. Forest stands within the matrix were also of different sizes, shapes, ages and tree densities. Large dense stands and corridors with an excellent interior-to-edge ratio alternated with open stands with good edge habitat, favoring more moist environments like flats, riparian zones, and north slope aspects.

Restoration of today's typical overstocked, dense second-growth forests to the patchy reference forest requires the patch or group selection thinning approach. The following guidelines for re-creating tree groupings do not apply to all stands. But they apply to enough stands and forest types to serve as general recommendations. It should be noted that our emphasis on restoring hardwoods like oaks, while necessary in most low to mid elevation forests because of their importance for wildlife and cultural/economic species, is not applicable to higher elevation forests nor to some moist forest stands. These guidelines are best applicable to the Klamath-Siskiyous, Northern Sierras, and Southern Cascades

(1) Guidelines For Thinning Tree Groupings

Note: Landscape scale conditions surrounding the site need to be taken into consideration when designing thinning prescriptions. For example, overstocked conifer stands surrounded by significantly open areas or meadows may be retained without heavy thinning in order to maintain wildlife cover, sources for truffles (for wildlife and human food), etc.

1. Thin to release preferred tree species, especially on south and west aspects of sun - loving oaks, pines, and other intolerant species.
2. Thin to release future old - growth; favor existing large young trees with noticeable old - growth characteristics such as rugged, rugose bark, 50% or more live crown, good architecture for wildlife (e.g. dead limbs down bole as in a "wolf" tree or "grouse - ladder"), etc. **It is difficult to prescribe exact minimum diameter sizes for leave trees because of the great variability of forest environments. If we had to give an exact figure, we would say 20" dbh or greater as off-limits to cutting. However, in cases where a significant number of cultural/wildlife trees are in danger of being overtopped by trees over 20" in diameter, I would recommend some selective cutting on south and west aspects of preferred leave trees. Another problem area is invasion of <u>dry</u> meadow and balds or opens by conifers larger than 20" dbh; here I would recommend leaving scattered leave trees or leave tree clumps following thinning of *some* trees over 20" dbh. Another factor to consider is the commercial value of larger trees if cultural or ecological considerations require their removal. This could at least partly offset the costs of thinning, slash piling and fire ($500 - $1000 an acre or more is not uncommon).**
3. Thin to release commercially valuable species (Douglas-fir, White Fir, Ponderosa Pine) to be available in a subsequent thinning entry or a very long timber harvesting rotation.
4. Leave most well - defined clumped tree groupings intact unless favoring a preferred species needing release or removing very suppressed young trees, especially conifers which are susceptible to beetle infestations because of low vigor, releasing commercially valuable trees, or releasing any tree for future old growth or timber harvesting.

Note: Suppressed Douglas-fir or Ponderosa and Sugar pines not released early enough or with a very poor sap - to - heartwood ratio may never achieve their original genetic potential for size or vigor. First thinning should be made around 30 years following stand initiation but before the stem-exclusion phase has progressed too far.

5. Consider wildlife cover: leave some tree / shrub clumpings intact, even dense "doghair" conifer stands.

6. Consider forest canopy escape routes for arboreal mammals: leave some branches, which arch over roads or opens.
7. Thin some tree groupings down to one or two large leave trees in order to keep balance between denser, shadier areas and open, sunnier areas; favor future old - growth, and significant wildlife or culturally important trees.
8. Favor multi - aged leave trees where possible, especially in moist coastal forest types.
9. Favor scattered leave trees which stand alone between groupings.
10. Do multiple thinning entries (every 5 - 10 years) so as not to alter the forest environment too much at one time (e.g. to avoid sun scald, windthrow, disruption of mycorrhizae connections, too rapid degradation of reptile and amphibian habitat, etc.)
11. Avoid thinning during bird - nesting season, usually mid-April through mid-July; favor thinning on frozen ground in winter; if thinning must be done in some phase of song bird nesting season, conduct a thorough survey for nesting sites before harvesting, and if some nests are located, leave a sufficiently large buffer (perhaps 50 or more feet) around them. If raptor nests are discovered (e.g. owl, eagle), much larger buffers will be required.
12. Don’t enter stands with heavy equipment to avoid soil compaction; do cable logging from roads; don't operate heavy equipment on saturated roads.
13. Create snags by girdling live trees (in groups if possible) and leave some down trees over 12" dbh for down wood. Protect from firewood harvesters by putting sand on and / or nails in snags and downwood; post signs to discourage harvesters (see no. 14).
14. After falling trees, lop and scatter smaller branches and cut to within 12" of ground (be sure not to scatter on patches of native plants); pile branches over 2" in diameter for either wildlife piles or burn piles determine which kind of pile by proximity to leave trees: make wildlife piles where too close to leave trees to safely burn and flag wildlife piles so they wont be burned later by mistake; leave some limbs over 8" on ground for downwood and some 2 - 8" diameter sizes stacked for local firewood. More down wood should be left in moist coastal forest then dry interior forest. Five to ten tons per acre compared to under 5 tons per acre; determine tonnage by using standard transect/plot survey methods.

Special note on slash disposal and piling:

(a) broadcasting wood chips onto the forest floor is not recommended: they lie too flat and dense to burn easily in future prescribed understory burns; fine fuels like native grasses and forbs will carry future fires.

(b) Make slash piles low (3-4 ft. maximum height) and spread piles out more horizontally in order to maximize ground coverage of ash for sowing of native grasses and forbs following burning.

(c) Ring piles down to mineral soil with a McCloud too, to prevent fire creep into surrounding duff; watch burn piles carefully, especially on hot afternoons when winds may come up suddenly in late afternoon.

(d) Don't burn on tree stumps or roots, which can smolder for weeks or months before erupting in windy weather. Be sure to keep piles away from the driplines of leave trees; piles to close to leave threes can be left as wildlife habitat.

(e) For greater efficiency, thinning and burning should be done simultaneously, with part of crew thinning and part putting thinnings and slash on burn piles.

(f) When doing thinning and slash piling in one operation, make as many small (but as wide at the base as possible) as are safe to make in order to protect soils from intense heat damage, especially soils that are either very dry or very wet, and avoid as much as possible stacking and burning slash repeatedly in one pile location.

(g) Lopping and scattering branches and tips under 2 inches diameter should be limited to lightly covering and in contact with the ground - - but not on patches of native herbaceous plants which should have been marked with colored irrigation flagging - - in order not to leave large amounts of carbon on the forest floor; the carbon:nitrogen ratio should be maintained in favor of nitrogen because too much carbon ties up nitrogen (decomposers use nitrogen to shred and consume wood fiber) and this imbalance can lead to the favoring of woody shrubs and trees over herbaceous understory species. Slash from 2-8" diameter should be either piled as firewood when it is close to roads or as wildlife or burn piles when it is too far from roads to be conveniently utilized as firewood; slash over 8' diameter, and especially slash over 12" diameter, should be left as permanent down wood unless over 5 tons an acre or more is already down in interior montane low to mid-elevation sites; more can be left on the forest floor in Pacific Northwest coastal low to mid-elevation forest types.

15. Sun-loving species like oaks and pines are preferred: release oaks and pines within conifer groupings as much as possible without disrupting group and prune oaks where they lean out from clumps so as to avoid snow - breakage of leaning, horizontal limbs.
16. Avoid cutting any tree with nests, or with cone - leavings at base of tree, or with woodrat nests at base of tree.
17. Cover rusty junk piles with slash for wildlife habitat.
18. Consider, if possible, acorn productivity during good mast years as a guide to how much attention to pruning and releasing is needed to maintain best acorn producers.
19. Before logging, salvage any native plants or trees, which may be impacted by the thinning operation. Mark with irrigation flagging before beginning work.
20. Possible experiment in comparing one entry with two entry thinning
    (1) no thinning
    (2) one entry thinning
    (3) two entry thinning (5 - 10 years)

Note: Stratify stand / habitat types so as to have environmentally comparable sites.

(2) Survey Methods Appropriate For Restoration Forestry

Various kinds of pre-project surveys need to be performed. **Percent plant cover** is usually done by eye along randomly selected transects every so many meters or yards depending on scale and budget. Probably a better survey would be a **plant density count** along the transects. Percent cover can be misleading with respect to regeneration directions of understory herbaceous vegetation. What are the future herbaceous dominants, based on the *number* of individual young plants. A plant species which is significantly larger than its associates could be shrinking in number but still cover the most ground.

On highly variable sites like the Klamath-Siskiyou Physiographic Province, it is probably better to **stratify**: use random transects in comparable vegetation types, topography, aspect, etc. rather than cross through very different kinds of habitat with one transect.

Some standard silvicultural surveys, used primarily in determining the volume of merchantable timber available for harvesting, are of little utility for restoration. For example, foresters do **timber cruises** which employ random transects intersected at regular intervals by plots of varying sizes to learn **basal area** of dominant trees. Basal area is the total square footage (diameter at breast height or dbh) per acre of a forest stand and is determined by estimating the square footage of each tree bole (trunk) in the plot and multiplying by the number of trees. Basal area does tell us something about the density or stocking rate of the trees, but little about how the trees are arranged in the stand (stand structure). Structure is critical information for forest restoration.

The plots used in timber cruises can also tell us about the type and percent cover of herbaceous vegetation, percent of canopy closure, type and percent ground litter, large woody debris, bare earth and rock outcroppings. But so can other types of vegetation surveys which employ random transects. Unlike the standard timber cruise, transects which are stratified (sampling different kinds of habitats separately) are more useful for restoration. Age-class and fire-scar studies to determine fire frequency are important. Increment borings to determine tree ages by counting tree rings can tell us a lot about past stand structure.

The general rule is to get as much detail as possible on site variability and as much information about patterns of relationship in the stand as possible. As forest ecologist Dave Perry (In <u>Forest Ecosytems</u> p. 174) says: **"…be skeptical of broad, general principles which frequently reflect the human need to organize diverse observations more than they mimic ecological reality…The key is to remember that our generalizations are just that; as a sage pointed out long ago, do not confuse the finger that points at the moon with the moon itself."**

There is no substitute for personal knowledge of the restoration site. The key question with which to begin is: why is that species here, and not in a closely adjacent area? Is it soil type change, aspect, high water table, site disturbance history, moisture holding capacity of the soil, overgrazing by livestock or deer, temperature (e.g. low basins which are cold pockets), proximity of seed sources and wind direction, etc? Once these kinds of questions can be answered, the restorationist will be better equipped to match vegetation to soil type, etc. As we do this over time, we learn plants that serve as indicators of micro-site conditions.

(3) Photo - Point Monitoring

Set out sets of two - way photo - points. Set a four foot long No. 4 (1/2") rebar in ground with orange flagging fastened to top. Set another rebar in a particular line of view (clear of vegetation so it can be easily seen) some distance away but in sight. Put 60 penny nails with heads painted orange in ground at base of rebar in case rebar is removed. Put direction arrows on flagging in indelible black ink pointing to opposite rebar. Use large-print forms of heavy paper (12" X 12") with date and time of day while taking photographs which should be taken on the same date and at the same time each season or year.

(4) Transect / Photo - Point Monitoring

Four short (18 "), flagged or painted rebar stakes are driven into ground to make a square plot approximately four by four feet and situated every 25 meters or so along transect lines set out in random directions in order to monitor changes in herbaceous vegetation in meadows and forest opens. Before and after photos are taken in the way described above.

G. Fire Preparation and Prescription Fire Guidelines

(1) Do as much structural fire prep work during thinning operations as possible: limb trees: remove "jackpots" from around leave trees / groupings; pull back duff, especially pine needles over 2" thick, from base of leave trees; cut lop - and - scatter small diameter limbs down to at least 12" from ground.

(2) Cut three-foot wide fuelbreak lines down to mineral soil around leave tree groupings so as to both retain vegetation and limbs down to ground level when appropriate for wildlife cover and protect grouping from fire.

(3) Cut similar fuelbanks around entire stands and in other strategic plans so as to contain fires within relatively small areas (compartmentalize the site).

(4) Use intentional fire in early fall following 1 - 2" of rain or sufficient rain to wet mineral soil surface just below duff (2"). Shady areas adjacent to fire unit will probably need more than two inches of rain because the denser overstory canopy will intercept more rain.

(5) Late spring burns to control non-sprouting brush (when roots are most vulnerable to defoliation because plant energies are concentrated in the spring growth flush) and reduce fire hazard could be used as an interim or temporary strategy until more risky fall burns can be done safely.

(6) Cut fuelbreaks around strategically located dense "doghair" conifer stands for wildlife cover.

Note: The preferred approach is to thin before burning and not use fire for thinning. It is too unpredictable and risky. It also leaves too much standing dead wood that will still have to be thinned later.

(7) Have enough people on hand during a burn to put out fires smoldering in snags and logs, especially one or two committed to night watch. Don’t pile slash on stumps or logs, which can smolder for weeks to months, and then suddenly erupt under windy conditions.

Note: Many places lack sufficient fine fuels to carry fire (except pine needle cover; White Fir, Incense-cedar and Douglas - fir needles lie too flat and dense to burn easily.) Herbaceous plant restoration in the forest understory and in open places, especially on south and west slopes, should first address the problem of soil compaction, and heavy water runoff, and litter washout / exhaustion of soil organic matter caused by a lack of sufficient overstory trees. Recommend planting pine, or hardwoods on these hard, sun - baked slopes with sparse vegetation so as to create more of a savanna or open woodland. This should help establish a more favorable, semi - shady to filtered sun environment for forb and grass establishment.

H. Cultural Harvesting as Vegetation Management

It is expected that public land agencies harbor certain reservations about the ecological value of indigenous cultural plant harvesting, and about the general competence of traditional Native Americans as natural resource managers. But there are experienced individuals in the indigenous community who possess a detailed knowledge of forest dynamics, cultural plants and animals, and plant - animal interactions because they depend to some degree on the resources they regularly use. There is also a millennia - long body of Traditional Ecological Knowledge (TEK) which has been passed down through generations and is a product of long collective experience in the forest ecosystem in which they still live.

Indigenous traditional harvesters can be trusted to know how to enhance and expand existing patches of cultural plants. (See Kat Anderson, Before the Wilderness, "Native Californians as Ancient and Contemporary Cultivators ", pp. 151 - 174.) Here is a counter - example to the propensities of contemporary industrial societies to destroy ecological integrity as a result of human use: ecosystems are enhanced in the act of using. Traditional caregiving and harvesting techniques (a part of TEK) for " Indian potatoes " (edible corms and bulbs or **geophytes**) and basket plants are expected to increase plant population size and health through digging for harvest or weeding, pruning, outplanting, selective harvesting, and intentional fire.

What about the non-cultural ecological associates of cultural plants? How do we determine what belongs together in a restored plant community? Experienced cultural harvesters know this from long inter - generational experience in the field. This kind of local knowledge and TEK is particularly sensitive to ecological associations as indicators of where to find cultural plants. Harvesters who use the resources are best equipped to monitor changes in vegetation over time. In fact, as we point out in the Karuk Tribal Module (Klamath National Forest, Final Plan, 1995), it would be very difficult to practice ecosystem management without this kind of detailed local knowledge. The same holds for tracking local extinctions and invasions by weedy plants and animals.

Note: Paired experiments can be done where a comparison is made over time between the relative effectiveness of cultural caregiving/harvesting and doing nothing on the health, vigor, and size of patches of cultural plants and their ecological associates.

I. Suggested Seasonal Work Schedule For Key Tasks in Restoration

1. Forest thinning - - from end of fire season in the fall to mid-spring before bird nesting season.
2. Fire Prep - - fall to early spring.
3. Remove weedy plants following thinning - - late spring to late summer
4. Take deciduous hardwood cuttings - - early fall to mid winter; grow in nursery in coldframe; augment cuttings with seeds to maintain genetic diversity.
5. Take softwood cuttings - - late spring to summer; grow in nursery; augment cuttings with seeds.
6. Collect seed from remnant on site and off site patches - - summer
7. Finish fire prep and burn following 1 - 2" rain - - early fall.
8. Burn piles - - early to mid fall (covered piles can be burned in winter).
9. Sow seed in ash following burning and plant out nursery - grown container plants - - early fall following rain.
10. Grow nursery plants all year; need shadehouse from mid spring to early fall.

PART VI

Forest Economics: Financing Restoration Forestry

NOTE: *This final section will be detailed out later. Topics which will be considered include: forest certification, softwood and hardwood utilization, small diameter softwoods, non-timber products and wildcrafting, tribal cultural plants, portable milling systems and cooperative sort yards. This proposed section will detail out ways to finance restoration using timber and non-timber by-products. It will also examine other ways to pay for restoration, such as federal and state cost-share grants, stewardship leases, contract bundling, etc.*