An Annotated Bibliography of the Biology of Coast Redwood (*Sequoia sempervirens* (D.Don) Endl.)

Prepared by **: Deborah L. Rogers**

For **: The Save-the-Redwoods League**

July 25, 1997

Contents

Introduction

The appreciation of coast redwood, the preparation of well-reasoned plans for its conservation, and the pursuit of a better understanding of the species through research, are all enhanced and supported when currently-available information about the species is well organized and readily accessible. This annotated bibliography of the biology of coast redwood has been prepared with such support functions in mind. The articles are treated here as independent units of information: the bibliography was not prepared with the intent of any particular application other than improving awareness of coast redwood biology and facilitating access to such literature.

Scope of bibliography

As many readers may already be familiar with the annotated bibliography of coast redwood compiled by Emanuel Fritz (1957), that publication may serve as a useful point of reference for describing the current bibliography. To avoid redundancy, the current bibliography covers literature published after 1955 — the year the Fritz bibliography concludes its coverage. A few earlier articles are included here if they are not contained in the Fritz publication. The Fritz bibliography is broad in scope — containing logging statistics, wood working and wood quality information, popular literature, aesthetic/descriptive information, horticultural information, general tree guides or species distribution descriptions, vegetation classification literature, etc. The current bibliography has been largely restricted to biological information.

Given that there is a range of publication media and standards, I have mainly embraced a scientific standard for inclusion and most literature in the bibliography has been published in scientific journals with peer-review standards. Also included here are dissertations and theses, some government research notes and papers, conference proceedings, and occasional other reports as merited. A few overviews that cover various aspects of coast redwood ecology and cultural history are included, but generally excluded are textbook treatments, tree guide references, advocacy publications, and photographic essays.

One final point of contrast between the current and Fritz bibliographies is that the former focuses on coast redwood while the latter also contains articles on giant sequoia and metasequoia. While articles restricted to the other two redwoods are not included here, some articles included in this bibliography do discuss one or both of these relatives in relation to coast redwood.

Organization

Articles on the biology of coast redwood are classified into one of seven major categories. Each article appears only once in the bibliography. The subject of many articles, however, lends itself to inclusion in two or more categories. Categorization decisions were made mainly on the basis of the objectives of the individual research activities. Thus, an article exploring some aspect of redwood physiology would appear in the *Genetics, physiology, and biochemistry* section even though the results might have a bearing on redwood rejuvenation, for example. Similarly, an article that reports on an investigation of propagation techniques for coast redwood might contain physiological information. Readers are encouraged to explore related categories when screening the bibliography for a particular topic.

Paleohistory and taxonomy contains research pertaining to the evolutionary history of coast redwood and its botanical classification. As *Metasequoia* and *Sequoiadendron giganteum* (i.e., giant sequoia) are often reference points or simultaneously considered with coast redwood in evolutionary studies, this category, more than the others, contains references to the two other redwoods.

Propagation and rejuvenation includes articles on breeding, propagation, and the process of rejuvenation — often a prerequisite for the successful propagation of older redwood clones.

Genetics, physiology, and biochemistry covers a range of topics pertaining to the chromosomal composition of coast redwood, molecular genetics, spatial patterns of genetic variation, growth and development, hormonal responses, and biochemical composition (especially leaf terpenes). Some articles in this category could also be legitimately placed within *Paleohistory and taxonomy*: the decision about placement was based on the general objectives of the study.

Ecology contains information about the relationship of coast redwood and its biotic environment. Included are articles on the habitat use of coast redwood forests by birds, mammals, amphibians, and insects; fungal associates in the leaves and the soil; pathology; and soil-vegetation classifications.

Natural disturbances and abiotic influences presents available information on the role of fire, floods, climate, and soils in redwood ecosystems. Fire ecology is the most studied of these abiotic influences. A few articles on treefall in redwood stands are included here — being the result of fire, floods, weather, and/or soils.

Managed regeneration and restoration contains information on artificial regeneration in redwood stands (usually following logging) such as the effects of thinning sprouts on redwood stumps or survival of redwood seedlings. Although most of the articles pertain to *in situ* management, a few studies report on redwoods grown in other countries. While often not directly studying the biology of coast redwood, these articles can provide indirect information on the preferred habitat, ecological flexibility, or responses to environmental changes of the species.

The *General* section contains articles that are broad in scope and are syntheses of biological information and social action — such as proposals for park establishment, reviews of the status of redwood preserves, and recommendations for conservation. Challenging the intended scope of this bibliography, this is not a comprehensive treatment of all such available literature. The sample offered here may be good introductory sources for those initiating an acquaintance with coast redwood.

Within each category, papers are arranged in alphabetical order by senior author and numbered consecutively. A new number series is used for each category facilitating future extension of the bibliography. The numbering system links the articles with individual authors, a comprehensive list of whom appears at the end of the bibliography. The abbreviations used in reference to the source of the articles are defined in a separate list.

0. Paleohistory and Taxonomy

1 Adam, D.P. 1975. A late Holocene pollen record from Pearson's Pond, Weeks Creek Landslide, San Francisco Peninsula, California. J. Res. U.S. Geol. Survey 3(6): 721–731.

This paper presents the first Holocene pollen diagram from the Bay Area, together with a tentative climatic chronology for the past 3,000 years. A sediment core was recovered from Pearson's Pond, in San Mateo County, California, and analyzed for pollen content, macrofossils, soil types, and age. The pollen diagram for coast redwood shows substantial changes over this time period. For example, there is evidence of much more coast redwood approximately 850 A.D. than today in this area, based on pollen density.

2 Adam, D.P., R. Byrne, and E. Luther. 1981. A late pleistocene and holocene pollen record from Laguna de Las Trancas, northern coastal Santa Cruz County, California. Madr. 28(4): 255–272.

This study of the Quaternary vegetation history of coastal California suggests that the vegetation in this region has changed markedly over the past 30,000 years. Three pollen zones are recognized: the deepest (earliest) zone, dominated by pine species and tentatively occurring 30,000–24,000 years B.P. (i.e., before present); the pine-fir zone, 24,000–12,000 years B.P.; and the redwood zone, perhaps 12,000–5,000 years B.P. In the latter zone, pine was virtually absent, redwood was apparently dominant on the more mesic sites, and the drier sites were open grassland.

3 Brown, R.W. 1935. Some fossil conifers from Maryland and North Dakota. J. Wash. Aca. Sci. 25(10): 441–450.

Well-preserved mud casts of *Sequoia* cones from the Eocene (geologic age is in dispute) in North Dakota are described. The species represented by the cones is designated *Sequoia dakotensis* Brown, and is compared with present day *Sequoia sempervirens* and *Sequoiadendron giganteum*.

4 Brunsfeld, S.J., P.S. Soltis, D.E. Soltis, P.A. Gadek, C.J. Quinn, D.D. Strenge, and T.A. Ranker. 1994. Syst. Bot. 19(2): 253–262.

Sequoia, *Metasequoia*, and *Sequoiadendron* reside within the family Taxodiaceae. However, evidence from morphological, chemical and immunological studies from the past 20 years suggests that Taxodiaceae should be merged with the family Cupressaceae. This study presents new data, in the form of DNA sequences from a chloroplast gene. All species from both families were studied, in addition to several reference taxa. The results suggest that Taxodiaceae and Cupressaceae should be treated as a single family.

5 Chaturvedi, S. 1993. Morphological, cuticular, and anatomical studies of some members of Taxodiaceae. Bionature 13(2): 127–131.

Three species in the Taxodiaceae were examined with respect to their leaf anatomy and epidermal features: *Sequoia sempervirens*, *Taiwania cryptomerioides*, and *Taxodium distichum*. Many differences were noted, in keeping with the diversity well recognized among members of this family. For example, in *S. sempervirens* there are two basic leaf (i.e., needle) shapes: in the other two species there is one. The frequency of stomata is highest in *T. cryptomerioides*, and the lowest in *S. sempervirens*. There are three resin canals in *S. sempervirens*, one in *T. distichum*, and none in *T. cryptomerioides*

6 Dogra, P.D. 1966. Embryogeny of the Taxodiaceae. Phytomorph. 16: 125–141.

This paper describes embryo development, beginning with fertilization, in genera of the family Taxodiaceae. The description of embryogeny among the genera is not only interesting in its own right, but provides more evidence for the evolutionary relationships within this family. The author recognizes three types of embryogeny within the Taxodiaceae: 1) Taxodian type (e.g., *Taxodium distichum*, *Cryptomeria japonica*, and *Sequoiadendron gianteum*); 2) *Sequoia sempervirens* type (the placement of this species' embryogeny in a separate category emphasizes its difference from the other genera); and 3) Athrotaxis type.

7 Doyle, J. and M. Brennan. 1971. Cleavage polyembryony in conifers and taxads—A survey. 1. Podocarps, Taxads and Taxodioids. Sci. Proc. Royal. Dub. Soc. 4(6): 57–88.

Embryo development in gymnosperms is different than in angiosperms. One of the peculiarities of gymnosperm embryo development is the widespread occurrence of multiple embryos arising from a single zygote. This is called ‘cleavage polyembryony’ and is best developed among the conifers. In the midst of speculation as to what was ‘primitive’ and what ‘advanced’ among species in the characteristics of cleavage polyembryony, this paper was meant to represent a “new, objective, and factual appraisal of the nature and occurrence of true cleavage polyembryony in conifers and taxads.” This paper deals with the Polocarpaceae, Cephalotaxaceae, the Taxads, and Taxodiaceae. The unusual situation with *Sequoia sempervirens* is described as the most specialized embryo development of any conifer. In this species, unlike other gymnosperms, after the zygote has divided once a cell wall is formed. In other gymnosperms the zygote nucleus continues to divide many times — in some species producing more than 1000 nuclei — before cell walls are formed.

8 Eckenwalder, J.E. 1976. Re-evaluation of Cupressaceae and Taxodiaceae: A proposed merger. Madr. 23:(5): 237–300.

The history of classification of the genera within the Cupressaceae and the Taxodiaceae is reviewed. Several lines of evidence lead to the proposal that the two families should be merged. These two families, in contrast to all other pairs of conifer families, are usually distinguished only by leaf form and phyllotaxis. Taken together, the two families show the same degree of morphological similarity as other single conifer families. Furthermore, *Sequoia*, *Sequoiadendron,* and *Metasequoia* are as closely related to *Cupressus* as they are to other genera in the Taxodiaceae.

9 Endô, S. 1952. A record of *Sequoia* from the Jurassic of Manchuria. Bot. Gaz. 113: 228–230.

A foliage fragment is described from a fossil *Sequoia* from South Manchuria. Dating back to the Jurassic, this *Sequoia* species, named *S. Jeholensis* Endô, is older than any previously described member of that genus. The foliage is strikingly similar to the modern *Sequoia sempervirens*.

10 Fields, P.F. 1991. Neogene paleographic and paleoecologic distribution patterns of the taxodiaceae in the N.W. U.S. Am. J. Bot., SUPPL. 78(6): 113.

This report combines the results of a literature review and new data to update the known Neogene distributions of species within the Taxodiaceae in the northwestern United States. *Taxodium* is the most widespread of the taxa, appearing in 35 of the 58 study sites considered. *Sequoiadendron* is southern and almost always appears alone (i.e., in the absence of other taxodiaceae), being basically restricted to Nevada and California. *Sequoia* is more widespread and co-occurs with two or more other members of the Taxodiaceae (often with *Taxodium*) at nine sites.

11 Fields, P.F. 1993. A newly recognized Neogene Sequoia in the Pacific Northwest of North America. Am. J. Bot. 80(6), Supplement, p 89.

Fossilized foliage from the Neogene (collected from various sites in North America, including Oregon) is found to be a different *Sequoia* species than one identified from the Paleogene (*Sequoia affinis* Lesquereux). Furthermore, the Neogene *Sequoia* species is more similar to the modern *Sequoia sempervirens* in its foliage characteristics than to the Paleogene species.

12 Gadek, P.A. and C.J. Quinn. 1989. Biflavones of Taxodiaceae. Biochem. Syst. Ecol. 17(5): 365–372.

The biflavone content of the leaves of representatives of all genera in the Taxodiaceae was surveyed and the results are discussed in the context of relationships within the family. The data provided evidence of much diversity within the family: in particular, *Sciadopitys*, *Metasequoia*, *Athrotaxis*, and *Taiwania* are each distinguished by a unique chemical signature.

13 Golte, W. 1974. Ecophysiological and phylogenetic bases of the distribution of conifers on the earth's surface, as exemplified by *Fitzroya cupressoides* in the southern Andes. Erd Kunde 28(2): 81–101.

The distribution and habitat of *Fitzroya cupressoides*, a South Andean relict conifer, are compared with those of coast redwood, redwood being considered its North American counterpart. The distribution of both current and fossil conifers is discussed in relation to the thesis that coniferous species distribution is related to the stage of phylogenetic development that they have reached. In German, with an English abstract.

14 Hart, J.A. 1987. A cladistic analysis of conifers: Preliminary results. J. Arn. Arb. 68(3): 269–307.

This paper presents a classification of 63 genera of conifers (including *Sequoia sempervirens*) based on the 'cladistic method'. (The cladistic school of thought holds that the classification of living things should reflect the real evolutionary relationships among species, regardless of how similar or different the species appear. The main alternative school of thought, phenetics, argues that classification should be based on overall similarity among species, even if not based on common ancestry.) Along with the classification, which is constructed from an extensive literature review as well as study of herbarium and living specimens, the author provides an historical perspective of the study of conifer classification and some interesting comments on how preconceived notions of how evolution works have influenced classification efforts. The classification produced supports other studies that have suggested the placement of Cupressaceae and Taxodiaceae in the same family. Whereas traditional approaches to the classification of conifers have emphasized the importance of cone structure, this study revealed that embryological, palynological, and anatomical features can also bases for recognizing relationships among the conifers.

15 Hizume, M. K.K. Abe, and A. Tanaka. 1988. Fluorescent chromosome bandings in the Taxodiaceae. Kromo.2(50): 1609–1619.

The somatic chromosomes of eight species in the Taxodiaceae were investigated using fluorescent banding methods. *Sequoia sempervirens* was distinctive in having six to eight bright bands at the terminal regions of chromosomes. On the basis of the fluorescent banding patterns, the authors tentatively divide these species into four groups.

16 Khoshoo, T.N. Polyploidy in gymnosperms. Evol. 13: 24–39.

This early paper discusses polyploidy in gymnosperms in three categories: polyploid seedlings in the progeny of diploid species, isolated polyploid trees in otherwise strictly diploid species, and polyploid species and genera. *Sequoia sempervirens* is one of the 11 gymnosperm species that are described as truly polyploid in constitution, and the only hexaploid. The history of the discovery of the hexaploid nature of coast redwood and the early theories as to its origin are described.

17 Li, L. 1987. The origin of *Sequoia sempervirens* (Taxodiaceae) based on karyotype. Acta Bot. Yun. 9(2): 187–192.

The author suggests that, based on chromosome patterns, the modern species of coast redwood may have arisen as a hybridization between an ancient species of giant sequoia and metasequoia. The hypothesis also involves a backcross with Metasequoia. A diagrammatic representation of the chromosomes of these three species and the probable evolutionary pathway is provided. In Chinese, with an English abstract and table/figure captions.

18 Li, L. 1988. The parents of *Sequoia sempervirens* (Taxodiaceae) based on morphology. Acta Bot. Yun. 10(1): 33–37.

The author suggests that, based on morphological data, the present-day *Sequoia sempervirens* may have originated as a hybridization event between ancient species that gave rise directly to *Metasequoia* and *Sequoiadendron*. This hypothesis differs from that of Stebbins who suggests that *Sequoia* is not derived from the same ancestral species as *Sequoiadendron* or *Metasequoia*. In Chinese, with an English abstract.

19 Li, L. 1990. Two evolutionary lines of Taxodiaceae. Acta Phyto. Sin. 28(1): 1–9.

Li proposes two evolutionary lines in the Taxodiaceae (excluding Sciadopitys) on the basis of chromosome sizes. One line, composed of *Sequoia*, *Sequoiadendron*, *Metasequoia*, and *Cunninghamia*, is characterized by a relatively rapid increase in chromosome size and relatively slow increase of mean (chromosome) arm ratio. This proposal is supported by other kinds of data from morphology, anatomy, etc. In Chinese, with table, figure, and literature section in English.

20 Mason, H.L. 1936. The principles of geographic distribution as applied to floral analysis. Madr. 3: 181–224.

Various principles underlying the current pattern of California's native flora are explored. The paleohistory of coast redwood is used to illuminate the principle that great movements of floras have taken place in the past and are continuing to take place.

21 Miller, C.N. 1977. Mesozoic conifers. Bot. Rev. 43(2): 217–280.

The Mesozoic era, lasting from about 225 million years ago to about 65 million years ago, was a time in which the conifers rose to dominate the land flora. This paper provides a comprehensive treatment of the history of conifer species, the status of their fossil record, and the likely relationships among extinct and extant species. The fossil record, as known in 1977, shows *Sequoia* to be the only modern genus in the Taxodiaceae that was present in the Jurassic. On the other hand, *Sequoiadendron* is the only modern genus of that family that had not been reported from the Mesozoic. The proposal of merging the Taxodiaceae and Cupressaceae is discussed.

22 Ohsawa, T., M. Nishida, and H. Nishida. 1992. Structure and affinities of the petrified plants from the Cretaceous of Northern Japan and Saghalien X Two *Sequoia*-like cones from the upper Cretaceous of Hokkaida. J. Jpn. Bot. 67: 72–82.

Two fossil seed cones from Japan are described and compared with cones of the modern *Sequoia*, *Sequoiadendron*, and *Metasequoia* species. Two taxodiaceous genera of *Sequoia*-like cones, *Austrosequoia* and *Nephrostrobus*, had been previously reported from the Cretaceous worldwide. One of the two fossil cones is identified as a new genus and species, *Haborosequoia nakajimae*, and more closely resembles *Sequoia* than *Sequoiadendron*. The second fossil cone, being poorly preserved, could not be identified as to species, but more closely resembles *Sequoia* and *Sequoiadendron* than *Metasequoia*.

23 Ohsawa, T. 1994. Anatomy and relationships of petrified seed cones of the Cupressaceae, Taxodiaceae, and Sciadopityaceae. J. Pl. Res. 107: 503–512.

Petrified cones of fossil species are compared with cones of modern species within the Cupressaceae, Taxodiaceae, and Sciadopityaceae in an effort to reconstruct cone evolution in these families. Of relevance to the evolutionary history of *Sequoia sempervirens*, fossil cones of *Sphenolepis kurriana* and *Yezosequoia shimanukii* are considered to be the transitional form between the Cunninghamia-like plant that is known as early as the Middle Jurassic and the *Sequoia*-like plant that is known as early as the Late Cretaceous.

24 Peters, M.D. and D.C. Christophel. 1978. *Austrosequoia wintonensis*, a new taxodiaceous cone from Queensland, Australia. Can. J. Bot. 56: 3119–3128.

A new species (and genus) within the Taxodiaceae is described from a fossilized cone discovered near Winton, Queensland, Australia. Characteristics of the external and internal cone morphology were compared with species of the genus *Athrotaxis* — the only extant genus within the Taxodiaceae that is found in the southern hemisphere — and with other members of the family. Comparisons indicate a strong similarity between the new species and *Sequoia sempervirens*, and only limited similarities with species of the Australian endemic, *Athrotaxis*.

25 Price, R.A. and J.M. Lowenstein. 1989. An immunological comparison of the Sciadopityaceae, Taxodiaceae, and Cupressaceae. Syst. Bot. 14(2): 141–149.

The distinctiveness of the two families Taxodiaceae and Cupressaceae have been questioned since the nineteenth century. Prior to this study, taxonomic treatments of these families had been based largely on morphological and cytological data. In this study, immunological data (from antigen-antibody reactions to seed proteins) were compared for all extant species in Taxodiaceae, and selected species from Cupressaceae and other families. Immunological data indicate that the Cupressaceae and Taxodiaceae form a distinct lineage. Subgroups within Taxodiaceae are at least as different from each other as from the Cupressaceae, supporting Eckenwalder's (1976) proposal to merge the two families.

26 Russell, E.W.B. 1983. Pollen analysis of past vegetation at Point Reyes National Seashore, California. Madr. 30(1): 1–11.

Analysis of pollen cores taken from lake sediments in Point Reyes National Seashore, California, indicates major vegetational changes in the last millennium. Effects of colonization (e.g., grazing) are correlated with some changes in pollen (e.g., increase in grass:shrub pollen). The sudden drop in *Sequoia* pollen and subsequent recovery are interpreted as reflecting the heavy logging of this species in the early 20th century.

27 Sakai, A. 1971. Freezing resistance of relicts from the Arcto-Tertiary flora. New Phytol. 70: 1199–1205.

Many trees species, including *Sequoia*, that once flourished in what is now Japan were eliminated by the end of the Pliocene. The reason for this loss of species is thought to be related to a trend of cooling and more variable temperatures, and reduced and more seasonal precipitation. This study explores freezing resistance in the winter twigs of thirteen species eliminated from Japan at the close of the Pliocene as a means of evaluating this theory. Among those species tested is *Sequoia sempervirens*. The freezing resistance of *S. sempervirens* was nearly the same as that of the evergreen broad-leafed trees, but was less than that of *Metasequoia glyptostrodoides* or *Taxodium distichum*. It is concluded that most of the (tested) extinct species from Japan, except, for example, *S. sempervirens*, could have wintered in the deciduous forests on lowlands and adjacent slopes in Japan during the late Tertiary.

28 Schlarbaum, S.E. 1980. Cytotaxonomic relationships within Taxodiaceae. Ph.D. dissertation, Colorado State University, 232 pp.

The chromosome composition of nine species of Taxodiaceae, including *Sequoia sempervirens*, were studied to describe general chromosome morphology and the presence of chromosomes with specific structures that would indicate cytotaxonomic relationships. All species showed 2n=2x=22 chromosomes with the exception of *Sciadopitys verticillata* (2n=2x=20) and *Sequoia* (2n-6x=66). Diagrams of the chromosomes of all species studied show three patterns — indicating symmetrical, partially asymmetrical, and asymmetrical karyotypes. The patterns shown by *Metasequoia*, *Sequoia*, *Sequoiadendron*, and *Taxodium* show a partially asymmetrical karyotype. *Sequoia* shows the presence of two SAT-chromosome pairs with unusually long secondary constrictions. Tentatively, *Sequoia* is classified as a segmental allopolyploid (one of the possibilities suggested by Stebbins in 1948).

29 Schlarbaum, S.E. and T. Tsuchiya. 1984. Cytotaxonomy and phylogeny in certain species of Taxodiaceae. Pl. Syst. Evol. 147: 29–54.

This paper brings together karyotype data (i.e., chromosome patterns) to study the relationships among the species in Taxodiaceae. Also considered are marker chromosomes, morphological data, and paleobotanical information. In particular, the evolution of present-day *Sequoia* and *Sequoiadendron* is discussed.

30 Schlarbaum, S.E., T. Tsuchiya, and L.C. Johnson. 1984. The chromosomes and relationships of *Metasequoia* and *Sequoia* (Taxodiaceae): An update. J. Arn. Arb. 65: 251–254.

Speculation had earlier been made that *Metasequoia* was an ancestor of *Sequoia*. In the present study, observations were made on the chromosomes of the two species in an effort to discern any obvious chromosomal relationships. The marker chromosome type found in *Metasequoia* was not observed in *Sequoia*, indicating the lack of a direct taxonomic relationship between the two. The fossil record also supports the conclusion that *Sequoia* was differentiated independently from *Metasequoia*, although the authors agree that they probably came from the same ancestral stock.

31 Schwarz, O. and H. Weide. 1962. Systematic revision of the genus *Sequoia*. Feddes Repertorium Specierum Novarum Regni Vegetabilis, Berlin 66(3): 159–92.

The authors compare *Sequoia, Sequoiadendron*, and *Metasequoia* on the basis of the shoots, vascular systems, growth rhythms, needle morphology, epidermal tissues, chromosome numbers, and wood anatomy. Further considering the ecology of these and fossil species of *Sequoia*, the authors recommend combining the genera *Sequoia*, *Sequoiadendron,* and *Metasequoia* into one genus. In German.

32 Serlin, B.S. 1980. An early cretaceous fossil flora from northwest Texas: its composition and implications. Ph.D. dissertation, University of Texas, Austin, Texas, 206 pp.

A small but significant flora has been located in northwest Texas. The plants are believed to be derived from the Albian, Lower Cretaceous. Among the fern, conifer, and angiosperm species identified is *Sequoia* — identified on the basis of leaf morphology, stomata pattern, and anatomical features. Assuming that the early *Sequoia* had similar growing requirements as the present-day *Sequoia*, it would appear that the northwest area of Texas was considerably more moist in the Early Cretaceous.

33 Takaso, T. and P.B. Tomlinson. 1992. Seed cone and ovule ontogeny in *Metasequoia*, *Sequoia* and *Sequoiadendron* (Taxodiaceae — Coniferales). Bot. J. Linn. 109: 15–37.

A detailed study of cone and ovule development in *Sequoia*, *Sequoiadendron*, and *Metasequoia* is described. Sufficient numbers of trees are sampled to allow discussion of within-species variation in these processes. In general, *Sequoia* and *Sequoiadendron* are very similar in terms of cone and ovule development (e.g., two rows of ovules).

1. Propagation and Rejuvenation

100 Adams, D., T. Tidwell, J. Ritchey, and H. Wells. 1990. Effect of nursery-produced endomycorrhizal inoculum on growth of redwood seedlings in fumigated soil. Tree Pl. Notes 41(3): 7–11.

Endomycorrhizal fungi occur naturally on the roots of *Sequoia sempervirens* and are essential to their growth in both natural and nursery conditions. Because the nursery practice of soil fumigation greatly reduces mycorrhizae populations in nursery beds, the fungi must be reintroduced to achieve good seedling survival and growth. In this study, growth of redwood seedlings was compared in: 1) noninoculated beds; 2) beds inoculated with fungi from sudan grass beds; and 3) beds inoculated with the same species of fungi from other redwood beds. Inoculation greatly increased the growth of redwood seedlings. Redwood production beds were the preferred source of inoculum for reasons of efficiency.

101 Afek, U., L.A. Lippett, D. Adams, J.A. Menge, and E. Pond. 1994. Vesicular-arbuscular mycorrhizae colonization of redwood and incense cedar seedlings following storage. HortSci. 29(11): 1362–1365.

Vesicular-arbuscular mycorrhizal (VAM) fungi are important in increasing nutrient uptake of many plants. VAM fungi are known to infect roots of *Sequoia sempervirens* and *Sequoiadendron giganteum*. Viability and efficacy of spores of one VAM fungal species were tested following treatments varying in storage time, soil moisture, and soil temperature. Growth response of incense-cedar, coast redwood, and giant sequoia seedlings to several soil inoculum: potting mix ratios was studied.

102 Arnaud, Y., Y. Fouret, C. Larrieu, H. Tranvan, A. Franclet, and E. Miginiac. 1989. Réflexion sur les modalités d'appréciation du rajeunissement *in vitro* chez le *Sequoia sempervirens*. [Thoughts on the criteria for evaluating *in vitro* rejuvenation in *Sequoia sempervirens*]. Ann. Sci. For. 46 (Supplement): 178s–182s.

What is meant by ‘rejuvenation’ is discussed in relation to previously published protocols for *in vitro* rejuvenation of *Sequoia sempervirens*. Differing criteria for defining the juvenile state, including morphological, biochemical, and physiological factors, affect the efficacy and repeatability of rejuvenation methods. In French.

103 Arnaud, Y., A. Franclet, H. Tranvan, and M. Jacques. 1993. Micropropagation and rejuvenation of *Sequoia sempervirens* (Lamb) Endl: a review. Ann. Sci. For. 50: 273–295.

This review article provides a comprehensive description of the reasons for micropropagation (i.e., *in vitro* vegetative multiplication) of *Sequoia sempervirens*, the difficulties encountered, and the most promising means of overcoming these difficulties. A companion subject to micropropagation in old trees is 'rejuvenation'. This article describes rejuvenation techniques. The value and limitations of morphological, physiological, and biochemical markers of rejuvenation are discussed.

104 Ball, E. 1950. Differentiation in a callus culture of *Sequoia sempervirens*. Growth 14: 295–325.

This early study of differentiation in the tissues of vascular plants was conducted using tissues from burl shoots of *Sequoia sempervirens*. Slices of shoot tissue, grown in culture, were examined over time for cellular differentiation (e.g., formation of tannined cells, tracheids, etc.) and for organismal differentiation (i.e., development of procambium, cambium, and shoot apex). The study includes numerous photographs of magnified shoot tissue in various stages of differentiation.

105 Ball, E. 1987. Tissue culture multiplication of *Sequoia*. *In* Bonga, J. and D.J. Durzan (eds.), Cell and Tissue Culture in Forestry, Volume 3. Martinus Nijhoff, Dordrecht, The Netherlands, pp. 146–158.

This review of the status of tissue culture in *Sequoia sempervirens* presents the attributes of *Sequoia* that predispose it for *in vitro* cloning, the most promising media and treatments, and the success of using various plant parts as donor material.

106 Ball, E.A., D.M. Morris, and J.A. Rydelius. 1978. Cloning of *Sequoia sempervirens* from mature trees through tissue culture. *In* Round Table Discussion: Multiplication *in vitro* d'especes ligneuses. Gembloux, Belgium, pp. 181–226.

Regeneration of vegetative buds *in vitro* in a conifer was first achieved with *Sequoia sempervirens* (E. Ball, 1950). The progress of *in vitro* culture for the species was limited by lack of appropriate culture medium. By the mid-1970s, that barrier to advancing culturing techniques was removed. Although *in vitro* culture of juvenile redwood plants was relatively easy, the main interest was in propagation of mature trees of known genetic quality. This paper reviews the history of *in vitro* culture of coast redwood and reports on experiments to multiply *in vitro* redwood from three sources: basal shoots from mature trees, leaves from basal shoots, and shoots from the upper bole of a mature tree. Culture of plants from the first source — explants from basal shoots — was very successful. Plantlets were generally twice as tall as the seedlings of the same age and had much more highly developed branches. This size advantage was considered a juvenile characteristic: it was not known whether or for how long it would persist. Plants derived from the upper bole of the mature tree grew very slowly *in vitro* and had poor survival. Leaves grown on culture media produced only a few buds and shoots after nine months. However, this latter method was considered to be promising with further refinements in technique. These results suggested that burls shoots and basal shoots of the trunk are juvenile. The experiments are well documented with photographs.

107 Becking, R.W. and L.O. Belletto. 1968. Vegetative propagation of coastal redwood: Rooting of redwood cuttings. Supplement to final report of NSF Grant #4690, 23 pp.

Results are presented from various studies on vegetative propagation (i.e., effective production of healthy rooted cuttings) of *Sequoia sempervirens*. Tests performed include different age classes of donor material, hormone treatments, different sources (e.g., burls, root sprouts, branches) of donor material, varying soil temperatures, and level of sprout origin on stump.

108 Bekkaoui, F., Y. Arnaud, C. Larrieu, and E. Miginiac. 1984. Étude comparative de la rhizogenèse *in vitro* du *Sequoia sempervirens* chez deux clones d'age différents. [Comparative study of *in vitro* rhizogenesis between two different aged clones of *Sequoia sempervirens*]. Ann. Rech. Sylv. 1983, 5–25.

In vitro propagation of coast redwood requires successful rhizogenesis (i.e., root formation). Research is reported on the chemical (e.g., effects of auxins, sucrose, active charcoal), physical (i.e., light and temperature), and biological (e.g., influence of leaves) factors involved in *in vitro* root formation for this species. The responses in material taken from clones of two different ages — 50 and 500 years — are compared. In all tested conditions, rooting success is higher in plants taken from the younger clones. In French, with an English summary.

109 Blazková, A., B. Sotta, H. Tranvan, R. Maldiney, M. Bonnet, J. Einhorn, L. Kerhoas, and E. Miginiac. 1997. Auxin metabolism and rooting in young and mature clones of *Sequoia sempervirens*. Phys. Plant. 99: 73–80.

It has been suggested that induction of rooting is regulated by a balance between hormones. In this study, the hormonal status in young and mature clones of *Sequoia sempervirens* was monitored in comparison with their ability to produce roots *in vitro*. Treatments involving wounding and/or application of a synthetic auxin (indole-3-butyric acid: IBA) were applied. Rooting was not observed in cuttings from clones of either age in the absence of IBA. With IBA, roots appeared on cuttings from both donors, but cuttings from the younger clone rooted more quickly and more profusely than those from the older clone. Following IBA treatment, internal levels of natural auxin (IAA) increased in both, but were higher in the cuttings from the younger clone. It is suggested that the mature clone differs from the younger clone in its auxin metabolism.

110 Bon, M-C., F. Riccardi, and O. Monteuuis. 1994. Influence of phase change within a 90-year-old *Sequoia sempervirens* on its *in vitro* organogenic capacity and protein patterns. Trees 8: 283–287.

In woody plants, the development from the juvenile to the mature phase is reflected in a number of characteristics, including the attainment of reproductive ability. This phenomenon is known as ‘phase change’. Phase change was studied in *Sequoia sempervirens* by growing in culture shoot tips taken both from the base and the crown of a 90-year-old tree. Results showed differences in rooting characteristics and in protein abundance between the juvenile and mature tissues.

111 Boulay, M. 1978. Multiplication rapide du *Sequoia sempervirens* en culture in vitro. [Rapid multiplication of *Sequoia sempervirens* in *in vitro* culture.] Ann. Rech. Sylv. 1977, 37–67.

At the time this research was conducted, *in vitro* culture of *Sequoia sempervirens* had already been practiced for over 25 years. In fact, this species was the first gymnosperm to be successfully maintained in continuous culture. This paper describes an effective method for large-scale multiplication of redwood shoots *in vitro*. The procedure is well illustrated with photographs of redwood cuttings in various stages of development. In French, with an English summary.

112 Bourgkard, F. and J.M. Favre. 1988. Somatic embryos from callus of *Sequoia sempervirens*. Pl. Cell Rep.7: 445–448.

Somatic embryos are vegetative (‘clonal’) copies of a zygotic embryo (the ‘pre-seedling’ inside the seed coat). While tissue culture methods to rejuvenate and propagate tissues of *Sequoia sempervirens* trees have been previously investigated, this study is the first to report somatic embryogenesis for the species. The success of the process was defined by the development of some of the somatic embryos into complete, apparently normal, plantlets. Various culture media were tested and are described.

113 Festa, F.P. and G. Gambi. 1978. Seasonal variations in the natural and induced rooting potential of *Sequoia sempervirens* cuttings. Annali dell' Istituto Sperimentale per la Selvicoltura, Italy, 9: 71–90.

Results from a series of trials suggested that rooting of redwood cuttings was most successful in the summer months. Growth regulators (i.e., IBA) also dramatically improved rooting success: 12 to 15% of cuttings rooted without the application of IBA, while 66 to 78% rooted with treated with IBA. In Italian, with an English summary.

114 Fett-Neto, A.G., S.L. Teixeira, E.A.M. Da Silva, and R. Sant Anna. 1992. Biochemical and morphological changes during *in vitro* rhizogenesis in cuttings of *Sequoia sempervirens* (D. Don) Endl. J. Pl. Physiol. 140: 720–728.

In vitro root formation is essential for the micropropagation of many plant species. Cuttings of *Sequoia sempervirens* were grown in various rooting media. Root growth, chemical changes (i.e., phenolic compounds, peroxidase, isoperoxidase), and anatomical changes were noted over time in an attempt to better understand the process of *in vitro* root formation.

115 Fouret, Y., Y. Arnaud, C. Larrieu, and E. Miginiac. 1986. *Sequoia sempervirens* as an *in vitro* rejuvenation model. N.Z. J. For. Sci. 16(3): 319–327.

Rejuvenation is usually a prerequisite for vegetative propagation of old trees of *Sequoia sempervirens*. Rejuvenation treatments were tested and compared for two clones of coast redwood: one 50-year-old tree and one 500-year-old tree. The older the original tree, the stronger the treatment needed to obtain physiological rejuvenation.

116 Fouret, Y., Y. Arnaud, and C. Larrieu. 1985. Rajeunissement *in vitro* du *Sequoia sempervirens*: Effect du nombre et de la fréquence des repiguages. Recherche de critères précoces de juvénilité. [In vitro rejuvenation of *Sequoia sempervirens*: Effect of number and frequency of subcultures. Research of precocious juvenility criteria]. Ann. Rech. Sylv. 1984, 111–137.

Rejuvenation in coast redwood, as judged by the ability to propagate *in vitro*, was investigated in three clones of widely-differing ages: 1 year, 50 years, and 600 years old. Three different experimental conditions were compared, differing in the number of times the plants were subcultured in medium containing a growth hormone (cytokinin). For the oldest clone, the best results were obtained for the maximum number of subcultures (17). The earliest marker for rejuvenation was the reactivation of the apex. However, the authors recommend a more conservative approach of using a suite of markers: apical meristem activity, rooting time following induction, and rooting rate.

117 Fouret, Y., C. Larrieu, and Y. Arnaud. 1989. Rajeunissement *in vitro* chez le *Sequoia sempervirens* (Endl.): Recherche du protocole le plus efficace. [*In vitro* rejuvenation of *Sequoia sempervirens* (Endl.): Research of the most efficient protocol]. Ann. Rech. Sylv. 1988, 55–81.

Results are reported from an extensive study of rejuvenation treatments using a 500-year-old tree of *Sequoia sempervirens* in an effort to produce viable, rootable cuttings. (Vegetative propagation of such old trees is difficult). Eight protocols were tested: the morphological, biochemical, and physiological responses to each are reported. Three treatments were found to be effective, and one of those is proposed as the most practical for consistent micropropagation of rootable cuttings. In French, with an English abstract and table and figure captions.

118 Gil-Albert, F. and E. Boix. 1978. Effect of treatment with IBA on rooting of ornamental conifers. Acta Hort. 79: 63–77.

Cuttings of numerous species and cultivars, including coast redwood and giant sequoia, were taken at different times of the year. Cuttings were dipped in a hormone (i.e., IBA) solution and planted in a standard rooting mixture. The optimum time of year and hormone concentration for rooting the cuttings is reported for each species tested. Regardless of treatment, virtually no cuttings of coast redwood rooted.

119 Greene, H.A. 1933. Artificial vegetative propagation of redwood. Madr. 2: 110.

The author describes a method for small-scale vegetative propagation of coast redwood. His technique makes use of existing suckers at the base of a mature tree and maintains the cuttings close to the parent tree until new roots are formed.

120 Hansen, J.H. and D.W. Muelder. 1963. Testing of redwood seed for silvicultural research by x-ray photography. For. Sci. 9(4): 470–476.

Given the low level of seed germination often observed in coast redwood, it is desirable to be able to isolate the good seed from the others. This study provides details of an x-ray technique found to be useful in classifying the seed of coast redwood into a) seed without a discernible embryo and b) seed with an embryo. Fifty seeds from each of seven seedlots were x-rayed: of these, 58 to 99 percent were lacking an embryo. Possible causes of poor quality seed are discussed.

121 Horrey-Charrier. P. 1988. Isolation of protoplasts in *Sequoia sempervirens*. Ann. Rech. Sylv. 1987, 35–59.

Protoplasts (cells without cell walls) were removed from plants of coast redwood that were grown *in vitro*. The age of the plant affected the success of this procedure: best results were obtained with plants less than 35 days old. Only 12 percent of the viable protoplasts divided, with 76 percent of these only dividing once or twice. In French, with an English abstract.

122 Huang, H.-J., Y. Chen, J.-L. Kuo, T.-t. Kuo, C.-C. Tzeng, B.-l. Huang, C.-m. Chen, and L.-c. Huang. 1996. Rejuvenation of *Sequoia sempervirens* in vitro: Changes in isoesterases and isoperoxidases. Pl. Cell Phys. 37(1): 77–80.

Rejuvenation of mature trees of *Sequoia sempervirens* may be required before successful vegetative propagation. In this study, two enzyme systems (peroxidases and esterses) were compared in adult, juvenile, and rejuvenated (by repeated grafting) tissues of coast redwood. Both qualitative and quantitative differences in the enzymes were noted between the adult and juvenile tissues. The rejuvenated shoots displayed enzyme patterns identical to the juvenile shoots. This work suggests that isozymes might be useful as markers for phase-change in coast redwood.

123 Huang, L.-C., L.-Y. Lin, C.-M. Chen, L.-J. Chen, B.-L. Huang, and T. Murashige. 1995. Phase reversal in *Sequoia sempervirens* in relation to mtDNA. Phys. Plant. 94: 379–383.

Evidence is presented which suggests that mitochondrial DNA (mtDNA) is involved in plant maturation. Sections of mtDNA taken from juvenile and rejuvenated adult shoots of *Sequoia sempervirens* show similar patterns, while they differ from mature adult shoots.

124 Huang, L.-C., S. Lius, B.-L. Huang, T. Murashige, E.M. Mahdi, and R.Van Gundy. 1992. Rejuvenation of *Sequoia sempervirens* by repeated grafting of shoot tips onto juvenile rootstocks *in vitro*. Pl. Physiol. 98: 166–173.

After four successive grafts onto rooted juvenile stem cuttings, shoots from a mature *Sequoia sempervirens* were apparently rejuvenated. Characteristics of rejuvenation that were observed included ability of cuttings to root, branch profusely, and grow vigorously. Leaf proteins associated with juvenile, but not mature, plants were found in the rejuvenated plants. Full rejuvenation was maintained for three years following grafting.

125 Kough, J.L., R. Molina, and R.G. Linderman. 1985. Mycorrhizal responsiveness of *Thuja*, *Calocedrus*, *Sequoia*, and *Sequoiadendron* species of western North America. Can. J. For. Res. 15: 1049–1054.

For purposes of determining appropriate nursery procedures for commercial production of seedlings, the effect of three species of mycorrhizal fungi were tested in combination with two fertility treatments on the growth of seedlings of *Sequoia sempervirens* and three other western conifers. Over a one-year period, the coast redwood seedlings that had been inoculated with a fungal species continued to have higher biomass than those lacking the fungi, even when the seedlings received a high dose of supplemental fertilizer. Coast redwood seedlings were more responsive to the presence of mycorrhizal fungi than were giant sequoia seedlings. In the latter species, the seedlings growing without mycorrhizal fungi but in a high fertility environment had the same biomass, after one year, as those inoculated with a fungal species. It is suggested that the differences in responsiveness of coast redwood and giant sequoia may reflect an ecological adaptation.

126 Kuo, J-L., H.-J. Huang, C.-M. Cheng, L.-J. Chen, B.-L. Huang, L.-C. Huang, and T.-T. Kuo. 1995. Rejuvenation *in vitro*: Modulation of protein phosphorylation in *Sequoia sempervirens*. J. Pl. Physiol. 146: 333–336.

Phosphorylation is a process involved in regulating protein (including enzyme) activity in plants, and thus affects cell functioning. Differences in phosphorylation activity were noted between cells from mature *Sequoia sempervirens* versus those from juvenile stem cuttings. Furthermore, the phosphorylation pattern of mature shoot tips grafted onto juvenile rootstock changed toward the juvenile pattern after repeated graftings. This suggests that the pattern of phosphorylation in cells of *Sequoia sempervirens* can be used as an indicator of the ‘age’ of the tissue; an observation useful in *in vitro* culture of the species.

127 Libby, W.J. 1982. Cloning coast redwoods. Cal. Agric. August, 34–35.

The introduction of this paper emphasizes the importance of choosing the appropriate genetic source when producing seedlings or other planting stock from *Sequoia sempervirens*. Various options in technique (e.g., cuttings versus tissue culture) and source of donor material (e.g., naturally-occurring seedlings, well-adapted older trees, etc.) for vegetative propagation are discussed.

128 Libby, W.J., Y.T. Kiang, and Y.B. Linhart. 1972. Control-pollination seeds from cuttings of coast redwood. Sil. Gen. 21: 17–20.

Earlier successes with flower induction and controlled pollination of redwood cuttings were built upon, culminating with techniques that consistently provided viable seeds. The best results were obtained by removing cuttings from trees shortly before the strobili opened. The most effective pollinations were those in which dry pollen was brushed between open scales of the female strobili.

129 Libby, W.J. and B.G. McCutchan. 1978. “Taming the redwood”. Am. Forests 84(8): 18:23, 37–39.

Results of many experiments in breeding and propagating the coast redwood are presented. Issues concerning controlled pollinations and development of rooted cuttings are discussed. The potential benefits of breeding, selecting, and propagating selected redwoods are explored.

130 Linhart, Y.B. and W.J. Libby. 1967. Successful controlled pollination on detached cuttings of coast redwood. Sil. Gen. 16(6):168–172.

Controlled pollination of *Sequoia sempervirens* is used to breed trees for particular traits and to produce pedigreed families for genetic research. In this study, the results of controlled pollination of cuttings collected with unopened buds were compared both with those of cuttings taken after natural pollination and those from cones which ripened on the intact tree. It was not necessary for cuttings to root to produce cones with viable seed. Cones and seeds from the intact tree were larger than the other two sources, but growth rates of seedlings from all three sources were comparable.

131 Mahdi, E.F.M. 1985. Phase reversal in woody perennials by grafting of adult shoot apices onto juvenile rootstocks *in vitro*. Ph.D. dissertation, University of California, Riverside, California, 208 pp.

Repeated grafting of adult *Sequoia sempervirens* shoot apices onto fresh seedling rootstocks *in vitro* resulted in progressive restoration of juvenile traits, as evidenced by regained rooting competence and shoot vigor. Four repeated grafts caused adult shoots to display features that were similar to juvenile shoots, and five grafts seemed to permanently install juvenility. Adult shoots also produced adventitious shoots with increasing intensity after each successive graft. The reappearance of juvenile traits was also accompanied by changes in proteins that were extracted from the shoots. Proteins of rejuvenated adult tissues were identical to those of seedling tissues.

132 Makino, R., H. Kuroda, and K. Shimaji. 1985. Morphological observation of the calli dervied from four coniferous species *in vitro*. Wood Res. 71: 1–12.

Callus (i.e., unorganized) tissues were cultured *in vitro* from four tree species including coast redwood. The development and differentiation within these tissues were tracked. Xylem and phloem cells differentiated. High growth rate of callus tissue was correlated with a loose intercelluar contact and lack of formation of dermal tissue. The results indicate that tissue organization might be controlled by growth rate.

133 Monteuuis, O., C. Pages, and P. Sarran. 1987. De l'amelioration des conditions de bouturage en cascade du *Sequoia sempervirens*. [Conditions to improve stem culture in *Sequoia sempervirens*]. Ann. Rech. Sylv. 1986, 111–131.

Results suggest that shoot cuttings taken close to the base of seedlings rooted more readily than those taken from other positions. Rooting of cuttings also varied among clones. Applied auxins had no significant effect on rooting. Notching at the base of cuttings to expose root-forming tissues increased rooting percentage and root quality. In French, with an English abstract.

134 Power, A.R., R.S. Dodd, and W.J. Libby. 1988. Cyclophysis and topophysis in coast redwood stecklings. Sil. Gen. 37(1): 8–14.

The quality of coast redwood stecklings (i.e., rooted cuttings) is affected by both cyclophysis (i.e., effects from degree of maturation of the donor plant) and topophysis (i.e., effects due to the position of the cutting in the donor plant's architecture). The results from this study suggest that both conditions affect the rooting ability and the growth characteristics of redwood cuttings. Rooting was more prolific and occurred more quickly, and plagiotropic effects were less severe in cuttings taken from younger (i.e., seedlings) redwood donors than from the older hedged clones.

135 Que, G.N. 1983. Propagation of *Sequoia sempervirens* by *in vitro* cultured shoots. Forest Science and Technology Linye Keji Tongxun 1: 4–6.

Procedures for obtaining stem cuttings, cultured *in vitro*, from coast redwood are described. The apices of young shoots from seven- to eight-year-old plants were grown on a medium containing growth hormones and other nutritive agents. After six months, the cuttings had reach 4 to 6 cm in length. One year later, after transferring the shoots to a nursery seedbed, the shoots had grown to an average of 18 cm. In Chinese.

136 Restool, D.F. 1957. The response of isolated stem segments of *Sequoia sempervirens* (Lamb.) Endl. cultured *in vitro* to various chemical and other environmental treatments. Dissert. Abstr. 1957 17(4): 734–735.

Various treatments, including chemical additions (e.g., yeast, adenine sulfate, etc.), light variations, and temperature changes, were tested on segments of redwood stems for their efficacy in enhancing tissue growth. The addition of 3% yeast extract to the basic medium, with three other substances, improved the growth of surviving cultures. The supplementary substances were more effective in darkness than in light. Growing the cultures at 24ºC. provided better growing conditions than at 21ºC. or 30ºC.

137 Sul, I-W. 1995. Development of *in vitro* regeneration and gene transfer systems for conifer species. Ph.D. dissertation, University of Illinois at Urbana-Champaign, Illinois, 127 pp.

The optimum medium and growing conditions were investigated for *in vitro* shoot establishment and proliferation of *Sequoia sempervirens* stem segments. Using *in vitro*-grown needles of *Sequoia*, shoot organogenesis and somatic embryogenesis were induced. The influence of genetic factors and various growth hormones in combination with 2,4-D, was studied. The optimum combination for shoot organogenesis was the same for all three clones tested, while the optimum recipe differed among clones for maximum *somatic embryogenesis*.

138 Sul, I-W. and S.S. Korban. 1994. Effect of different cytokinins on axillary shoot proliferation and elongation of several genotypes of *Sequoia sempervirens*. In vitro Cell. Dev. Biol. 30: 131–135.

Considerable investment has been made in devising a reliable protocol for *in vitro* propagation of clones of *Sequoia sempervirens*. In this study, the effect of using various concentrations of different plant hormones (cytokinins) on development and growth *in vitro* was investigated. The use of zeatin in the culture medium improved shoot production and growth. As several genotypes were tested, genetic effects were noted and discussed.

139 Teixeira, S.L. 1981. Factors affecting rhizogenesis in stem cuttings. Ph.D. dissertation, University of California, Riverside, California, 238 pp.

In clonally propagating many plants by tissue culture, rooting of the shoots that have been generated can be a major task. This research focused on the *in vitro* rooting of shoots of four tree species, including *Sequoia sempervirens*. For *Sequoia*, shoot cultures from three developmental phases were studied: juvenile shoots from young seedlings, transitional material from sprouts that emerged at the base of a cone-bearing tree, and adult shoots from cone-bearing branches. The rooting of *Sequoia* shoots required a two-step process *in vitro*: 1) an induction period of two weeks; and 2) the emergence and elongation of roots during the subsequent four weeks. Different nutrient media were used for each stage. The optimum protocol resulted in 100% rooting of shoots from seedlings, nearly 100% rooting from basal sprouts, and about 40% rooting of shoots from mature branches. In all cases, root primordia were evident after two weeks in the emergence and elongation medium. Rejuvenation seemed to occur in adult *Sequoia* shoots by simply proliferating them *in vitro* through repeated subcultures.

140 Tranvan, H., F. Bardat, M. Jacques, and Y. Arnaud. 1991. Rajeunissement chez le *Sequoia sempervirens*: effets du microgreffage *in vitro*. [Rejuvenation of *Sequoia sempervirens*: results from *in vitro* micrografting]. Can. J. Bot. 69: 1772–1779.

Prior to this study, micrografting had been used to successfully rejuvenate and propagate giant sequoia, western redcedar, and Maritime pine. Here, micrografting was attempted with coast redwood by producing shoots *in vitro* from a 500-year-old tree and then grafting them onto rootstocks from a one-year-old tree. The mortality rate was high and only a few of the surviving plantlets exhibited normal upright growth. However, with improvements in technique, micrografting was considered a promising rejuvenation technique for this species. In French, with an English abstract.

141 Tufuor, K. 1973. Comparative growth performance of seedlings and vegetative propagules of *Pinus radiata* (D.Don) and *Sequoia sempervirens* (D.Don) Endl. Ph.D. dissertation, University of California, Berkeley, California, 207 pp.

This body of work advanced the science of vegetative propagation in both *Sequoia sempervirens* and *Pinus radiata* and provided comparisons of seedlings and rooted cuttings from the same parent trees in terms of growth and wood quality characteristics. Rooted cuttings of coast redwood had similar rates of height growth, but lower diameter growth, than their seedling counterparts. Cuttings taken from various positions within six mature (200 to 400 years old) redwood trees were compared for rooting ability, survival, and stem form. Cuttings taken from basal sprouts had the best rooting ability, and those from stem sprouts, the worst.

142 Walker, N. 1985. Réjuvénilisation et culture de méristèmes en cascade. [Rejuvenation and repeated meristem culture of *Sequoia sempervirens*]. Ann. Rech. Sylv. 1985, 25–47.

Two redwood clones, one mature and one juvenile, were used to evaluate the success of rejuvenation attempts in culture. Morphological and physiological criteria were used. Increasing evidence of rejuvenation was observed with each successive meristem culture. After four successive cultures, the rooting percentage had greatly improved, but not all juvenile characteristics had been recovered. In French, with an English summary.

143 Walker, N., E. Dumas, A. Franclet, and F. Bekkaoui. 1985. Technique de culture *in vitro* des méristèmes de *Sequoia sempervirens* et *Pinus pinaster*. [Technique for *in vitro* meristem culture of *Sequoia sempervirens* and *Pinus pinaster*]. Ann. Rech. Sylv. 1984, 87–109

This body of research explores the most effective protocol for *in vitro* meristem culture of coast redwood and Maritime pine. The effects of growth regulators and pH of the growth medium are studied. An initial pH of the nutritive medium of 6.2, reduced to 5.6 after six to seven weeks, was found to be most favorable. The addition of kinetin reduced the survival of explants, while the addition of activated charcoal increased survival over the control. In French, with an English summary.

144 Whiteman, J. and H.V. Wiant, Jr. 1967. Rooting of cuttings from second-growth redwood trees and sprouts may be practical. Tree Pl. Notes 18: 13.

This brief article reports results from comparing the rooting ability of cuttings taken from basal sprouts versus those from branches of second-growth redwood trees. Cuttings from sprouts rooted better than those from branches of the parent trees.

2. Genetics, Physiology, and Biochemistry

200 Ali, I.F., D.B. Neale, and K.A. Marshall. 1991. Chloroplast DNA restriction fragment length polymorphism in *Sequoia sempervirens* (D. Don) Endl., *Pseudotsuga menziesii* (Mirb.) Franco, *Calocedrus decurrens* (Torr.), and *Pinus taeda* L. TAG 81: 83–89.

Genetic variation was studied in the chloroplasts of trees from four species representing three families of Coniferales. Variation was detected in coast redwood, incense-cedar, and Douglas-fir, but not in loblolly pine. Considering the sources of the sampled trees, the results suggest that there may be variation in chloroplast DNA among populations of the first three species.

201 Anekonda, T.S. 1992. A genetic architecture study of coast redwood. Ph.D. dissertation, University of California, Berkeley, California, 285 pp.

This study is based on morphological and physiological data collected from common-garden studies containing 174 coast redwood clones from 81 stands across the natural range of the species. A statistical adjustment that accounts for some of the microenvironmental effects was found to be beneficial and increased the estimates of clonal components of variance and heritability. Numerous traits were analyzed to determine the genetic architecture within this sample of the species: of the three-level hierarchy examined (i.e., clones within stands, stands within regions, regions), 11 to 21% of the genetic variation was among clones within stands, 7 to 13% among stands, and 4 to 6 % among regions. This suggests that there is only modest genetic differentiation among regions of coast redwood, with more variation among clones within the same stand. The physiological trait measured, metabolic heat rate, was found to be correlated with tree size and latitude. High metabolic heat rates were associated with the clones that had a more southerly origin and with large individual clone size.

202 Anekonda, T.S. and R.S. Criddle. 1993. Spatial and temporal relationships between growth traits and metabolic heat rates in coast redwood. Can. J. For. Res. 23: 1793–1798.

Metabolic heat rates (i.e., the heat rate of respiration measured in the dark) has been shown previously to be related to the rate of height growth in *Sequoia sempervirens*. In this study, the growth rates and metabolic heat rates are compared within the same redwood clones growing on different sites over a 17-week period. Results suggest a positive relationship between the average height growth rate and average metabolic heat rate over the sampling period. A value for the maintenance respiration rate is suggested based on the metabolic heat rate in trees which grew little or not at all.

203 Anekonda, T.S., R.S. Criddle, W.J. Libby, R.W. Breidenbach, and L.D. Hansen. 1994. Respiration rates predict differences in growth of coast redwood. Pl. Cell Env. 17: 197–203.

The inter-relationships among growth, photosynthesis, and respiration in plants are not well understood. Several growth characteristics of coast redwood (e.g., height, diameter) were measured on young, plantation-grown trees and compared with several measurements of respiration rate (i.e., metabolic heat rate, CO_2 production rate, and their ratio). On average, there were positive correlations among most of the measurements, indicating that respiration rate may be a useful indicator of growth rate in this species, and that rapidly growing trees (in this study) may be less 'efficient' than more slowly growing ones.

204 Anekonda, T.S. and W.J. Libby. 1996. Effectiveness of nearest-neighbor data adjustment in a clonal test of redwood. Sil. Gen. 45: 46–51.

Common-garden studies can be used to identify genetic differences among different individuals of a plant species. In this case, growth data from a common-garden study of *Sequoia sempervirens,* with samples from many parts of the species' range, were analyzed in such a way as to remove microenvironmental effects. Genetic differences, as measured by height, stem volume, branch size, and crown diameter, were greater among clones than among stands, and were more pronounced in both cases after adjustment for microenvironmental differences among the individuals.

205 Anekonda, T.S., R.S. Criddle, and W.J. Libby. 1994. Calorimetric evidence for site-adapted biosynthetic metabolism in coast redwood (*Sequoia sempervirens*). Can. J. For. Res. 24: 380–389.

Within a plant species, different plants may vary in the temperatures that are optimal for respiration and photosynthesis. Different clones of *Sequoia sempervirens*, originating from diverse regions of the species' range, were measured for dark metabolic heat rates under various temperatures. It is suggested that the differences observed among clones in the temperature of peak activity and the peak metabolic rate may reflect adaptive differences among the clones related to their geographic origin.

206 Bates, T.G. 1977. The energy content of specific tissues of *Sequoia sempervirens*. M.S. thesis, Humboldt State University, Arcata, California, 40 pp.

At the time this study was conducted, milling residue was often not being effectively utilized. The idea of constructing centralized electrical generating plants powered by wood waste created interest in knowing the range in heat values for redwood. The objective of the study was to quantify the energy per unit mass contained in the outerbark, innerbark, sapwood, and heartwood of old-growth coast redwood. In addition, energy variations within various positions (e.g., midcrown, midstem, top of stump, etc.) of the tree were compared. Energy variations between different trees were compared. Heartwood was found to have the highest energy content and innerbark the lowest.

207 Becking, R.W. 1970. Fasciation of coastal redwoods. Madr. 20(7): 382–383.

Fasciation, a flattening of the normally cylindrical stem, is an apparently rare phenomenon in coast redwoods. Two cases are reported here, one of which is described. The flattened growth is presumably due to the formation of a row of linked meristems, instead of a single one at the apex. Possible causes for this phenomenon — including virus infection, insect attack, hormone imbalance, and genetic origin — are discussed.

208 Blazková, A., B. Sotta, H. Tranvan, R. Maldiney, M. Bonnet, J. Einhorn, L. Kerhoas, and E. Miginiac. 1994. Hormonal regulation or rhizogenesis in young and mature clones of *Sequoia sempervirens in vitro*. Biol. Plant. (Suppl.) 36: S351.

Root development in cuttings from young and mature clones of coast redwood were compared. Some cuttings received treatment with a hormone, indole-3-butyric acid (IBA). Both clones rooted only in the presence of IBA but the treatment was more efficient with the young clone. The levels of some natural hormones were measured in the two clones and showed differing responses to the IBA treatment.

209 Crafts, A.S. 1943. Vascular differentiation in the shoot apex of *Sequoia sempervirens*. Am. J. Bot. 30: 110–121.

One of the earliest studies on tissue development in *Sequoia sempervirens*, this paper describes the appearance of numerous longitudinal and cross-sections of tissue taken from a young shoot tip. A reconstruction of the development of phloem, xylem, and cambium tissues is attempted. Differences between phloem and xylem differentiation are emphasized. For example, xylem differentiates both upwards and downwards; phloem follow a continuous upward differentiation. It is noted that, in redwood, the general form of the shoot apex varies according to its position within the tree. The apex of the dominant leader that forms the main stem of the tree is a large, broad, conical meristem, whereas that of a lateral stem is hemispherical and much smaller. Numerous photographs and diagrams illustrate the story of tissue differentiation in coast redwood.

210 Cauwels, C.A. 1996. Partial 18S RDNA sequences in Taxodiaceae and their potential in phylogenetics. M.S. thesis, San Jose State University, San Jose, California, 54 pp.

A 557 base-pair region of the 18S gene was analyzed in six genera of the Taxodiaceae (including *Sequoia sempervirens*). If variable, the gene could provide information regarding the evolutionary history of species within this family. However, with the exception of *Metasequoia*, the genera were found to be highly similar in this region of the 18S gene, precluding any taxonomic inferences. The author indicates that future work will focus on the ITS-1 region, a region that often shows variability.

211 Daniel, T.W. 1942. The comparative transpiration rates of several western conifers under controlled conditions. Ph.D. dissertation, University of California, Berkeley, California, 190 pp.

The transpiration (water loss) rates of several western conifers (coast redwood, giant sequoia, Lawson cypress, ponderosa pine, Monterey pine) were compared with those of lemon and sunflower. The measurements were taken under controlled conditions of constant temperature and controlled humidity between 30 and 90 per cent. Regardless of humidity level, the following ranking was observed, from high to low transpiration rate: sunflower, ponderosa pine, giant sequoia, Monterey pine or redwood, and Lawson cypress or lemon. The author concludes that, among these species, redwood is second only to sunflower in being poorly adapted to dry conditions.

212 Emanuel, C.F. 1961. Rare tumor in coast redwood, *Sequoia sempervirens*. Science 133: 1420–1422.

Tumors discovered on a tree of *Sequoia sempervirens* growing on the campus of the University of California at Berkeley were of interest as such tumors (of apparent developmental or genetic origin) are rare in gymnosperms. This occurrence is noted to be only the second reported case of such a tumor in this species. Tumor tissue was sampled and described. Evidence is presented which suggests that the tumors were not of fungal or bacterial origin.

213 Ewers, F. W. 1982. Secondary growth in needle leaves of *Pinus longaeva* (Bristlecone pine) and other conifers: Quantitative data. Am. J. Bot. 69(10): 1552–1559.

The focus of this study is bristlecone pine, whose needles can be accurately dated and remain alive on branches for 30 or more years. However, 11 coniferous species in total were studied, one of them being coast redwood. It was shown that the mature leaves of these species produce secondary phloem each year but no secondary xylem. There was an inverse correlation between maximum leaf longevity and rates of secondary phloem production in the leaves. The species with greater needle longevity are high elevation species, while those with shorter-lived needles were growing at lower elevation. It is interesting to note that coast redwood was somewhat unusual in this respect: with rates of secondary phloem production similar to high elevation species, but needle lifetimes closer to those of low elevation species.

214 Fink, S. 1984. Some cases of delayed or induced development of axillary buds from persisting detached meristems in conifers. Am. J. Bot. 71(1): 44–51.

With the exception of pines, where it was previously known that regenerative sprouting may occur from dormant axillary buds, most other conifers (including coast redwood) were assumed to develop buds only in the axils of a few leaves, whereas all other axils remain empty. The author investigated leaf axils in six coniferous species, including coast redwood. In the apparently ‘empty’ axils of the needles of all these species he found persisting detached meristems. In coast redwood (and several other species) the development of additional axilllary buds from these meristems was induced by natural frost damage or by artificial pruning and disbudding.

215 Finney, M.A. Effects of thermal wounding, shading and exogenous auxin on some sprouting responses of coast redwood seedlings. Tree Phys. 12: 301–309.

Various factors putatively affect vegetative sprouting in *Sequoia sempervirens*, including light, fire, and plant hormones. In this study, container-grown seedlings were subjected to various combinations of three light levels, four hormone concentrations (indole-3-acetic acid), and three thermal wounding treatments. Shading and hormone applications appeared to negatively affect sprout growth (number and size), while thermal wounding increased sprout length but decreased the number of sprouts.

216 Fozdar, B.S. and W.J. Libby. 1968. Chromosomes of *Sequoia sempervirens*; 8-Hydroxy-quinoline-castor oil pretreatment for improving preparation. St. Tech. 43(2): 97–100.

The somatic chromosomes of *Sequoia sempervirens* have characteristics which make them difficult to study. This paper reports a treatment that shortens and spreads out the chromosomes, thereby making them more suitable for counting and describing.

217 Gius, F. W. 1961. A contribution to the understanding of the low viability of redwood seed (*Sequoia sempervirens* (D. Don) Endl.). M. For. thesis, University of California, Berkeley, California, 21 pp., plus appendix.

The author reviews the current understanding of embryogeny of coast redwood. Literature relating to seed production and viability is analyzed: various results are put into appropriate context such that conflicting results are resolved and the understanding of factors affecting these processes in coast redwood is enhanced. The author reports on several experiments relating to seed viability in coast redwood. Observations suggest that tannin deposits within seeds are associated with lack of fertilization and that the maturity of the seed coat is related to its permeability to tannin. A schematic diagram illustrating the complex relationship of factors affecting the morphology and development of seed in coast redwood is provided.

218 Gregonis, D.E., R.D. Portwood, W.H. Davidson, D.A. Durfee, and A.S. Levinson. 1968. Volatile oils from foliage of coast redwood and big tree. Phytochem. 7: 975–981.

This is the first study in which leaf monoterpenes were identified in *Sequoia sempervirens* and *Sequoiadendron giganteum* by gas chromatography. In each species, the major component of the oils is α-pinene. The composition of the leaf oils in the two species is compared and contrasted.

219 Greguss, P. 1956. The phyllotaxy of Metasequoia, Sequoia, and Taxodium. Acta Biol. 2: 29–38.

Phyllotaxy, the pattern formed by leaves and branches around their central axis, is explored mainly in *Metasequoia* and compared with that of *Sequoia* and *Taxodium*. Some previous descriptions of the phyllotaxy of *Metasequoia* have emphasized the differences between this species and *Sequoia*, and even suggested that it is an intermediate link between Cupressaceae and Taxodiaceae. Greguss concludes that the phyllotaxy of Metasequoia is quite similar to that of *Taxodium* and *Sequoia*.

220 Hall, G.D. and J.H. Langenheim. 1986. Temporal changes in the leaf monoterpenes of *Sequoia sempervirens*. Biochem. Syst. Ecol. 14(1): 61–69.

Leaf monoterpenes in needles of *Sequoia sempervirens* showed significant quantitative changes over time when monitored from bud burst through (needle) maturity. When herbivory was simulated by needle removal, changes in monoterpene composition were noted.

221 Hansen, L.D., R.A. Woodward, R.W. Breidenbach, and R.S. Criddle. 1992. Dark metabolic heat rates and integrated growth rates of coast redwood clones are correlated. Therm. Acta 211: 21–32.

Growth rates and metabolic heat rates were measured on unrooted cuttings taken from several clones of *Sequoia sempervirens* growing in natural stands in northern California. Similar measurements were made on several 25-year-old cultivated redwoods. Results showed a positive correlation between metabolic heat rates and growth rates, and it is suggested that metabolic heat rate measurements may provide a means of early selection of coast redwood trees with genetic potential for rapid growth.

222 Harrison, R.G. and J.J. Doyle. 1990. Redwood break the rules. Nature 344: 295–296.

Sequoia sempervirens, like other plants, contains DNA not only in the nucleus of cells but in chloroplasts and mitochondria. The transmission of DNA from these latter 'organelles' may show a different pattern from that of the nuclear DNA. This report suggests that we know little about the transmission genetics of organelle DNA and that the rules that we assumed to hold across animal and plant taxa are in fact based on studies of only a few species. The unexpected paternal inheritance of mitochondrial DNA (see Neale et al. 1989) in *S. sempervirens* is highlighted as an example of the increasing body of exceptions to the rules.

223 Hashizume, H. 1966. On the development of gibberellin-induced flower buds in *Metasequoia glyptostroboides* and *Sequoia sempervirens*. Bull. Tottori Univ. For. 3: 1–8.

The effect of spraying a hormone (gibberellin) on a 6-year-old metasequoia and a 4-year-old coast redwood on flower bud development was studied. The hormone was applied three to four times from June through August. Unlike the metasequoia, which developed both male and female buds, the redwood developed only males buds. in Japanese, with an English abstract.

224 Hein, F. 1934. When does the redwood bear seeds? Madr. 2: 158.

Observations are made on the age at which planted redwoods can produce cones. The author planted redwoods in city parks and noted that some produced cones within ten years of planting. He observes that the cone production occurred much earlier than he expected, but doesn't indicate the age of the trees when planted.

225 Hellmers, H. 1963. Effects of soil and air temperatures on growth of redwood seedlings. Bot. Gaz. 124(3): 172–177.

Soil and air temperatures were varied independently so that their individual effects on root and shoot growth of coast redwood seedlings could be determined. Two age classes of seedlings were tested: 6- and 20-weeks-old. The age or size of the seedlings appeared to have a significant effect on the response to temperature. The younger seedlings were more responsive than the older ones. High air temperature stimulated shoot growth within each of the three soil temperatures tested. Low air temperature, in combination with warm soils, stimulated root growth.

226 Hellmers, J. 1966. Growth response of redwood seedlings to thermoperiodism. For. Sci. 12(3): 276–283.

Seedlings of *Sequoia sempervirens* grown under various controlled temperature regimes did not exhibit dependence on a marked day-night temperature change (i.e., ‘thermoperiod’) that is characteristic of other conifers. Height and diameter growth of seedlings at the end of 24 weeks were highest under conditions of a 19°C. day with a 15°C. night, but growth was not significantly different from a constant 19°C. day and night (i.e., no thermoperiod). A marked decrease in growth occurred when the night temperature was lowered from 15°C. to 11°C. — perhaps due to the inability of one or more enzymes to be activated at the lower temperature. The highest day temperature tested (35°C.) reduced height growth and drastically reduced survival of the seedlings.

227 Hellmers, H. and R.P. Pharis. 1968. Influence of photoperiod and photoperiodic cycles on the growth of coastal redwood seedlings. Bot. Gaz. 129(1): 53–57.

The growth response of redwood seedlings to differing durations of light delivered in two cycles (24- and 48-hour) were studied under controlled conditions for approximately six months. Seedlings grew best (i.e., tallest height growth, greatest dry-weight production, etc.) when grown under a 24-hour cycle of continuous or near-continuous (i.e., 20 hours of light and four hours of darkness) light conditions. It is concluded that redwood appears to grow best when the photoperiod is supplied on a circadian rhythm, and most efficiently when there is very little daily fluctuation in photoperiod.

228 Hellmers, H. and W.P. Sundahl. 1959. Response of *Sequoia sempervirens* (D. Don) Endl. and *Pseudotsuga menziesii* (Mirb.) Franco seedlings to temperature. Nature 184: 1247–1248.

This was a preliminary investigation of the growth response of seedlings of *Sequoia sempervirens* to variations in day and night temperatures. Shoot growth was highest under the maximum daytime temperature treatment — 23°C. — and was relatively unresponsive to changes in nighttime temperature. This lack of responsivenes to diurnal temperature variation in redwood was a sharp contrast to the situation with Douglas-fir seedlings grown under similar treatments. With the latter, the seedlings grew optimally with 10°C. diurnal variation.

229 Hirayoshi, I. and Y. Nakamura. 1943. Chromosome number of *Sequoia sempervirens*. Bot. Zool (Tokyo). 2: 73–75.

The chromosome number of *Sequoia sempervirens* was determined to be 66. Knowing that the other general of Taxodiacea have a basic number of 11, the authors suggest that *S. sempervirens* is a hexaploid: the first case of hexaploidy in conifers. In Japanese with English abstract.

230 Ho, R.H. and O. Sziklai. 1973. Fine structure of the pollen surface of some Taxodiaceae and Cupressaceae species. Rev. Palaeob. Palyn. 15(1): 17–26.

Living and fossil pollen grains have long been used as diagnostic characters for systematic and phylogenetic studies. The fine structure of the pollen surface of six species in the families Taxodiaceae (including coast redwood) and Cupressaceae were studied by scanning and transmission electron microscopy. All except one species, *Sciadopitys verticillata*, had a similar surface structure. The pollen surface of coast redwood very closely resembled that of *Cryptomeria japonica*.

231 Huang, L-C., and T. Murashige. 1994. mtDNA and phase change of *Sequoia sempervirens*. Pl. Physiol. (SUPPL.) 105(1): 27.

This brief report of (then) current research describes the relationship between mitochondrial DNA (mtDNA) and rejuvenation in coast redwood. Genetic (i.e., mtDNA) differences were noted between adult and juvenile shoots of the same clone, while juvenile and rejuvenated shoots showed identical mtDNA patterns. These differences and similarities were confirmed by other genetic tests. These tests results, and the relative stability of rejuvenation, are consistent with the idea that rejuvenation is regulated by nucleotide sequences contained in mtDNA.

232 Jay-Allemand, C., P. Doumas, B. Sotta, H. Tranvan, and E. Miginiac. 1995. Juvenility and physiology of rhizogenesis in two woody species (*Sequoia sempervirens* and *Juglans nigra* x *Juglans regia*). *In* Sanderman, H., Jr., and M. Bonnet-Masimbert (eds.). Colloques de l'INRA, No. 76. EUROSILVA: Contribution to forest tree physiology, International Conference, Dourdan, France, November 7–10, 1994, pp. 79–99.

The formation of a supporting root system is a critical step in vegetative propagation of plant species. Numerous genetic and physiological factors can affect root formation (i.e., rhizogenesis). Previous research had suggested that the factors governing root formation in coast redwood may differ from those in walnut trees. Thus, two different approaches were taken to investigate root formation in these species. In coast redwood, the relationship between rooting ability and auxins was investigated. In both juvenile and mature clones of coast redwood, no *in vitro* rooting was observed without supplying a source of auxin. This could be the result of low inherent levels of auxins in the base of cuttings. Alternatively, an auxin inhibitor could be induced by the 'wounding' during the act of taking a cutting.

233 Kirchgessner, K.A. and W.J. Libby. 1985. Inbreeding depression in selfs of redwood: Rooting. California Agricultural Experiment Station, No. 29, University of California, Berkeley, California, 2 pp.

Many conifers exhibit some level of inbreeding depression with respect to seed production, germination, early survival and/or growth. However, given the hexaploid nature of coast redwood, there has been speculation as to whether it exhibits inbreeding depression. In the study reported here, cuttings are taken from numerous young redwood that resulted from either selfing or outcrossing. After approximately six months in a rooting medium, the selfed cuttings had a higher mortality rate and a lower rooting percentage than the outcrosses. This study suggests that coast redwood exhibits inbreeding depression with respect to speed of rooting juvenile cuttings, and mortality of those cuttings, and under stress conditions.

234 Lewis, L. 1992. Germinative capacity of *Sequoia sempervirens* (D. Don) Endl. seed from full-sibling crosses. Unpublished data. Humboldt State University, Arcata, California, 10 pp.

In general, there is a low germination level in seeds of coast redwood in natural forests. It is desirable to know the genetic influence on germination. In this study, numerous seed families from known redwood parents (i.e., controlled pollination) were compared for germination rates under controlled environmental conditions. Germination capacity was found to be strongly influenced by the combination of parents used in the crosses that produced the seed.

235 Libby, W.J., B.G. McCutchan, and C.I. Millar. 1981. Inbreeding depression in selfs of redwood. Sil. Gen. 30(1): 15–25.

The results of selfing versus outcrossing in selected trees of *Sequoia sempervirens* were compared. Seed production was similar between the two groups, but selfed seedlings had a lower survival rate and slower growth rate than outcrossed seedlings when grown under stressful (i.e., disease and drought) conditions.

236 Looby, W.J. and J. Doyle. 1937. Fertilization and proembryo formation in *Sequoia*. Sci. Proc. Royal Dub.Soc. 21(44): 457–476.

The structure of male and female gametophytes and development of the proembryo are contrasted and compared in *Sequoia sempervirens* and *Sequoiadendron gigantea*. The authors conclude that the structure of the gametophytes and the mechanism of fertilization are similar in the two species, but differ in a number of features of proembryo development.

237 Millar, C.I., J.M. Dunlap, and N.K. Walker. 1985. Analysis of growth and specific gravity in a 20-year-old provenance test of *Sequoia sempervirens*. California Agricultural Experiment Station, No. 29, University of California, Berkeley, California, 7 pp.

Cones were collected from ten populations throughout the natural range of *Sequoia sempervirens* in 1961–62. The nursery-grown seedlings from this collection were later planted in three 'common garden' trials on three different sites in central and north-coastal California and measured for various traits at 20 years of age. Results suggested that much genetic variation exists *within* families for these traits, and relatively little genetic variation is *among* the tested populations.

238 Neale, D.B., K.A. Marshall, and R.R. Sederoff. 1989. Chloroplast and mitochondrial DNA are paternally inherited in *Sequoia sempervirens* D. Don Endl. Proc. Natl. Acad. Sci. 86: 9347–9349.

Using parents and offspring from controlled crosses of *Sequoia sempervirens*, evidence is presented that mitochondrial (mtDNA) and chloroplast DNA (cpDNA) are paternally inherited in this species. Paternal inheritance of cpDNA was expected as this is the case with various species of the Pinaceae that have been investigated. However, the results of paternal inheritance of mtDNA were surprising! This phenomenon had never before been reported in sexual crosses of a multicellular eukaryotic organism.

239 Okamoto, R.A., B.O. Ellison, and R.E. Kepner. 1981. Volatile terpenes in *Sequoia sempervirens* foliage. Changes in composition during maturation. J. Agric. Food Chem. 29: 324–326.

The volatile terpene composition of plants is associated with their degree of palatability to browsing animals. The volatile terpene composition in coast redwood was examined in both young and mature foliage of a naturally-occurring tree, and in mature trees growing in an arboretum. Foliage from the forest tree showed changes in chemical composition over the growing season, while foliage from the arboretum trees did not.

240 Pharis, R.P. and W. Morf. 1969. Precocious flowering of coastal and giant redwood with gibberellins A3, A4/7, and A13. Bioscience 19(8): 719–720.

Seedlings of coast redwood, 6 to 12 months old, were induced to flower when treated with large amounts of hormones (gibberellins) — generally, more than 1000 micrograms. In one instance, a seedling flowered after application of only 350 micrograms. There was little difference among the gibberellins (i.e., A3. A4/7, A13) in their effectiveness in inducing flowering.

241 Riffer, R., A.B. Anderson, and A. Wong. 1969. Terpenoid constituents of the pocket resin from coast redwood (*Sequoia sempervirens*). Phytochem. 8: 923–925.

This is believed to be the first report of the occurrence of resin acids in *Sequoia sempervirens*. Analysis of the resin taken from open pockets in redwood heartwood was found to contain terpenes, resin acids, and other constituents comparable to balsams and pine oleoresin. The major constituent was α-pinene, followed by limonene — both of which had been previously reported to be among the terpenes in the volatile oil from the foliage of coast redwood.

242 Rogers, D.L. 1994. Spatial patterns of allozyme variation and clonal structure in coast redwood (*Sequoia sempervirens*). Ph.D. dissertation, University of California, Berkeley, California, 171 pp.

This body of work is the first allozyme study of *Sequoia sempervirens*. Organized as three chapters, the first chapter presents the inheritance study that lays the foundation for the use of allozymes as genetic markers in this species and comments on allozyme evidence for the species' origin. The second chapter examines the resolving power of a specific set of allozymes to distinguish closely-related redwood clones. The final chapter presents results from an intensive field study in four old-growth stands in Humboldt Redwoods State Park, California. Clonal structure is described: most notably, ‘fairy rings’ are shown to be often nonclonal. Patterns of genetic variation show relationships with elevation on the upland sites and with distance from the river on lowland sites.

243 Rogers, D.L. 1997. Inheritance of allozymes from seed tissues of the hexaploid gymnosperm, coast redwood (*Sequoia sempervirens*). Hered. 78(2): 166–175.

In this first study of allozymes from seed tissues of *Sequoia sempervirens*, six enzyme systems were examined in the megagametophyte (i.e., maternal genetic contribution) tissues of nine control-pollinated families. This study provided evidence for genetic control of the enzymes studied and thus provided the basis for their use as genetic markers in future studies of this species. Patterns of inheritance were considered for evidence as to the origin of this species. While not definitive, observations do not refute the longstanding (as per Stebbins 1948) hypothesis of an autoallopolyploid origin.

244 Roy, D.F. 1972. Fasciation in redwood. Madr. 21: 7.

The author provides corrections to the information provided by Becking (1970). He cites previous reports (some occurring more than 70 years ago) of fasciation in redwood and challenges Becking's description of fasciation in the species as "very rare". He clarifies the comments made about the duration of fasciation; it usually being confined to one growing season. Furthermore, he objects to the speculations as to the causes of fasciation, indicating that this subject is not well researched and bacteria and nutritional causes are as likely as those suggested by Becking (i.e., wound stimulation, often caused by insect attack).

245 Ruddat, M. and R.P. Pharis. 1966. Participation of gibberellin in the control of apical dominance in soybean and redwood. Planta 71(3): 222–228.

Control of the elongation of axillary buds by the apex is called apical dominance. Redwood seedlings, growing under temperature- and light-controlled conditions, were treated with growth regulators for three months and then decapitated. The results suggested that gibberellin, along with auxins, is normally involved in apical dominance.

246 Saylor, L.C. and H.A. Simons. 1970. Karyology of *Sequoia sempervirens*: Karyotype and accessory chromosomes. Cytol. 35: 294–303.

A detailed description of the chromosomes of *Sequoia sempervirens* is presented. The authors suggest that their data support the autoalloploid origin of the species proposed by Stebbins. A surprising finding is that of accessory chromosomes: they are very rare in woody species, particularly gymnosperms.

247 Schlarbaum, S.E. and T. Tsuchiya. 1984. A chromosome study of coast redwood, *Sequoia sempervirens* ((D. Don) Endl.). Sil. Gen. 33: 56–62.

A detailed chromosome analysis of five seedlings of coast redwood confirms earlier observations that the species has 2n = 6x = 66 chromosomes. There were no notable differences in chromosome morphology among the five seedlings. Analysis of the size and structure of the chromosomes led to the tentative conclusion that coast redwood is a segmental allopolyploid.

248 Shintaku, D.A. 1984. Cone induction on redwood (*Sequoia sempervirens*) seedlings by exogenous applications of gibberellins A3 and A4/7. M.S. thesis, Humboldt State University, Arcata, California, 128 pp.

Within the context of tree breeding, it is desirable that trees flower earlier than in nature. Cone induction on one-year-old redwood seedlings was attempted by application of gibberellins (GA), 6-benzyladenine, and ALAR-85 in various combinations. Only the gibberellin applications were effective. The combination of GA4 and GA7 produced the greatest number of cones, GA3 the fewest. Neither the quantity of GA, nor the timing of application was found to alter the time of the year when male and female cones were produced. Seedlings treated with multi-month (i.e., greater quantities) applications produced approximately 4 times as many female cones as those treated with single-month applications. Shorter daylengths and cooler temperatures may be more conducive to female cone induction.

249 Simmons, N. 1973. Description of bud collars on redwood seedlings. M.S. thesis, Humboldt State University, Arcata, California, 55 pp.

Bud collars develop on seedlings of coast redwood forming a region at the base of the shoot with an abundance of buds. Data were collected on bud collar occurrence on approximately 800 seedlings in Humboldt County, California, and related to seedling age, size, and vigor. Also, bud collar ontogeny was studied. The results indicate that the bud collar is a normal feature of healthy, vigorous seedlings and that the buds arise within the axils of the cotyledons and subsequent bud scales. By six years of age, 74% of the studied seedlings had bud collars. The occurrence of bud collars increased with age. In fact, the absence of bud collars may indicate low vigor in seedlings six years of age or older.

250 Southworth, D. 1988. Isolation of exines from gymnosperm pollen. Am. J. Bot. 75(1): 15–21.

Exines are the outer cell walls of pollen and spores. Purified exines are of potential use in chemical analyses of sporopollenin (i.e., the organic polymer that is characteristic of exines) and in production of antibodies to exine. This study reports on a method used to isolate and purify exines from five conifers, including coast redwood.

251 Tsoumis, G. 1974. Anatomical characteristics of redwood (*Sequoia sempervirens* [D. Don] Endl.) of seed and sprout origin. IAWA Bull. 2: 11–14.

Growth patterns were compared in a tree of seed origin and one of sprout origin by measuring ring widths on 50-year-old cross-sections of each. The sprout-origin tree grew more quickly at first, but average ring widths over the 50-year period were similar for both trees. Significant differences between the two were noted in the proportion of latewood and amount of cell wall substance.

252 Wind, C. and K-P. Häger. 1996. Legumin encoding sequences from the Redwood family (Taxodiaceae) reveal precursors lacking the conserved Asn-Gly processing site. FEBS Let. 383: 46–50.

A section of DNA known to be involved in the production of legumins (i.e., seed storage proteins) was examined in various members of the Taxodiaceae family, including *Sequoia sempervirens* and *Cryptomeria japonica*. This section of DNA had been previously assumed to be 'highly conserved' (i.e., similar) among most, if not all, plant species. The significant differences noted in the Taxodiaceae sequences (as compared with the angiosperm species examined) require a new view of legumin gene evolution.

253 Zakharenko, G.S. and G.D. Yaroslavtsev. 1983. Reproductive development and sexual differentiation of *Sequoia sempervirens* on the south coast of the Crimea and the Black Sea coast of the Caucasus. Biologicheskie Nauki 8: 76–80.

The occurrence of male and female flowers was noted in redwoods growing in parks in the Crimera from 1971 to 1981. The trees varied in age from 10 to 90 years. It was noted that the relative number of male and female strobili varied from year to year, irrespective of tree age. A few normally monoecious (i.e., having both male and female strobili) trees became 'temporarily male' in certain years, but purely female trees were never observed. It is concluded that annual sexual differentiation is an important mechanism of determining the best adapted individuals in this introduced species. In Russian, with an English abstract.

254 Zakharenko, G.S. and G.D. Yaroslavtsev. 1985. Reproductive layer structure of the crown in *Sequoia sempervirens*. Byulleten' Glavnogo Botanicheskogo Sada 136: 32–36.

Crown structure (i.e., the pattern formed by the branches) and the distribution of male, female, and vegetative shoots was studied in coast redwood trees of seedling origin at Yalta in the Crimea. The proportion of male shoots decreased from the lower to the upper crown while that of female shoots increased. Consequently, it is suggested that both outbreeding and inbreeding occur in different parts of the crown. In Russian.

3. Ecology

300 Bacon, C. 1982. Plant reproduction in revegetating coastal redwood communities. M.S. thesis, Humboldt State University, Arcata, California, 54 pp.

This study explores the dispersal strategies of plant species in revegetating coast redwood ecosystems by analyzing the viable seeds in the soils and by a survey of the dispersal ecology of the component species. Six redwood stands were examined, all second-growth (4 to 45 years since logging) except for one old-growth stand. Larger seed pools were found in the younger stands. The majority of seeds were from non-woody genera (e.g., *Erectites* and *Gnaphalium*). Production of numerous, tiny, wind-dispersed seeds was the primary reproductive strategy of plant species in these stands, while vegetative regeneration and the formation of a buried seed pool were also important mechanisms in the revegetation of these sites.

301 Baker, H.G. 1965. The botany of California's coast and Sierra redwoods. University of California Extension Series on Redwood, 14 pp.

This is one of a series of five lectures on the California Redwood presented by Letters and Science Extension in cooperation with the School of Forestry, University of California. The paleohistory and the environmental conditions within the current range of giant sequoia and coast redwood are described. The history of European discovery and the subsequent naming of these species is related. Some comparative notes with metasequoia are made.

302 Bemis, W.A. 1967. Phenotypic variation in *Sequoia sempervirens* (D. Don) Endl. in Humboldt County, Arcata. M.S. thesis, Humboldt State University, Arcata, California, 121 pp.

Data were collected from ten areas of old-growth coast redwood forests to determine the range of phenotypic variation in various bark, foliage, and cone characteristics and to look for relationships with environmental variables such as elevation, soils, and latitude. No consistent relationships were noted between environmental variables and phenotypic characteristics. A positive correlation was noted between length of cone and number of scales per cone.

303 Bingham, B.B. 1984. Decaying logs as a substrate for conifer regeneration in an upland old-growth redwood forest. M.A. thesis, Humboldt State University, Arcata, California, 56 pp.

In considering the high content and stability of moisture and nutrients found in decaying logs, it appears that decaying logs, when present in large enough quantities, offer a suitable substrate for conifer seedling establishment and subsequent tree development in old-growth redwood forests. This study provides evidence that redwood and Douglas-fir logs provide important substrates for forest tree regeneration in mesic, upland, old-growth redwood forests.

304 Bingham, B.B. and J.O. Sawyer, Jr. 1988. volume and mass of decaying logs in an upland old-growth redwood forest. Can. J. For. Res. 18: 1649–1651.

The volume and mass of dead, naturally fallen, logs were determined for a 80-hectare upland old-growth redwood forest in Prairie Creek Redwoods State Park in northwestern California. Logs were identified by species and categorized by level of decay. Redwood logs in the middle decay class had the greatest volume and mass. The total volume and mass of decaying logs in this redwood forest were larger than averages typical of other conifer forests in the Douglas-fir region.

305 Bollen, W.B. and E. Wright. 1961. Microbes and nitrates in soils from virgin and young-growth forests. Can. J. Microbiol. 7:785–792.

Microflora and nitrates were investigated in soils of numerous old- and young-growth forests in California, Oregon, and Idaho. Sandy loam soils in a virgin coast redwood forest near Crescent City, California gave the lowest count of bacteria of all forest soils surveyed and also showed a low count of molds.

306 Bonar, L. 1971. A new Mycocalicium on scarred *Sequoia* in California. Madr. 21(2): 62–69.

A new (i.e., previously undescribed) fungus is described, *Mycocalicium sequoiae* Bonar, that grows on scarred trees of *Sequoiadendron giganteum* and *Sequoia sempervirens*. Surveys of the fungus on both tree species shows that the fungus is less frequently found and less profuse in growth on the coast redwood than on the giant sequoia. In natural conditions, the fungus was found on scarred trees only, growing on the exudate that flows from the surface of exposed heartwood of living trees.

307 Borchert, M., D. Segotta, and M.D. Purser. 1988. Coast redwood ecological types of southern Monterey County, California. USFS PSWF&RES General Technical Report PSW-107, 27 pp.

The classification of natural areas by vegetation type can provide a supportive context for both research and management of these areas. Reported here is a plot-based ecological classification of coast redwood forests of southern Monterey County, California. Six ecological types were recognized on the basis of vegetation, soils, and geomorphology. Four types occur between 100 and 800 feet elevation (e.g., the coast redwood/bracken fern-chain fern/streamsides ecological type), and two types above 800 feet (e.g., coast redwood-tanoak/round-fruited carex-Douglas's iris/Gamboa ecological type).

308 Brown, R.L. and J.A. Powell. 1991. Description of a new species of *Epiblema* (Lepidoptera: Tortricidae: Olethreutinae) from coastal redwood forests in California with an analysis of the forewing pattern. Pan-Pac. Entom. 67(2): 107–114.

An inventory of the Lepidoptera (i.e., moths and butterflies) at the Landels-Hill Big Creek Reserve, Monterey County, California, was conducted over a decade. This is the first attempt to census the entire group of moths and butterflies at any locality in western North America. During the census a new species of *Epiblema* was discovered at two sites on the reserve. Both sites are located in forests dominated by coast redwood.

309 Bull, R.A. 1951. A new gall disease of *Sequoia sempervirens*. Gard. Chron. 130: 110–11.

The abstract describes a gall disease of coast redwood not previously recorded in England. The galls seemed to have been formed at nodes and varied in size from about 1 cm. to 15 cm. in diameter. At the base of the tree severe galling had defoliated and killed the branches.

310 Bury, R.B. 1983. Differences in amphibian populations in logged and old growth redwood forest. N.W.Sci. 57(3): 167–178.

The is the first known study to examine the effect of clearcut logging on the amphibians of old growth redwood forests. Four study areas, each with both an old growth and clear-cut logged site, were established in or adjacent to the Redwoods National Park in northwestern California. Type of vegetation and amphibian species presence and abundance were surveyed on all sites in 1975. The old growth sites had slightly more species than did logged areas. Some species were found in old growth (e.g., tailed frog) or logged sites (e.g., Pacific treefrog), but not both. Amphibian populations had more individuals and greater biomass on the old growth sites than on logged plots. The author points out that forest management practice that may favor some (e.g., game) species of wildlife may be to the detriment of others.

311 Bury, R.B. and M. Martin. 1973. Comparative studies on the distribution and foods of Plethodontid salamanders in the Redwood Region of northern California. J. Herp. 7(4): 331–335.

Several species of plethodontine salamanders co-exist in areas of northwestern California, but it was unknown whether the apparent lack (or low level) of interspecific competition was due to low population sizes or due to differences in ecology or morphology of the species. This study compares distribution, food habits, and known ecological features of four species of salamanders in three areas (old-growth redwood, second-growth redwood, and open areas) near Pepperwood in Humboldt county, California. Results suggest that the co-existence is a function of many factors, including differences in local distribution, ecological and morphological specializations, and different prey preferences (although the range of prey is similar among the four species). Logging of redwood forests appears to alter the species composition of salamanders.

312 Carroll, G.C. and F.E. Carroll. 1978. Studies on the incidence of coniferous needle endophytes in the Pacific Northwest. Can. J. Bot. 56: 3034–3043.

The incidence of needle (endophytic) fungi was surveyed in 19 conifers of western Oregon and southwestern Washington states. Rate of infection, species (or genus) of fungi present, and location on the needle (i.e., blade or petiole) were noted. In *Sequoia sempervirens*, 100% of the needles sampled were infected, the most common endophyte being *Chloroscypha chloromela*.

313 Carroll, F.E., E. Müller, and B.C. Sutton. 1977. Preliminary studies on the incidence of needle endophytes in some European conifers. Syd. 29: 87–103.

The presence of endophytic fungi was investigated in needles of some native and introduced conifers to Europe. In needles of two trees of *Sequoia sempervirens*, standing in the Fontainebleau forest of France, several species of fungi were identified. It was noted that the frequency of occurrence of endophytes is higher in the winter than in spring (for coast redwood), and higher in older than in younger needles.

314 Carter, H.R. and S.G. Sealy. 1987. Inland records of downy young and fledgling marbled murrelets in North America. Murr. 68: 58–63.

At the time of this publication, only 13 nests of the Marbled Murrelet had been found, leaving much mystery about its nesting habits. This paper summarizes the records of hatching-year birds (i.e., downy young or fledglings, defined by being covered mostly with down, or in juvenile plumage, respectively) found at inland localities (i.e., land or freshwater lakes). Forty-one inland records are reported, with some from Big Basin Redwoods State Park (8), Humboldt Redwoods State Park (1), and Prairie Creek Redwoods State Park (1), California. Eight of the ten records of downy young and 20 of the 31 fledglings were obtained in old-growth forests: the remaining records were near old-growth forests. These data provide evidence of dependence upon old-growth, tree-nesting habitat in southern parts of the breeding range for the murrelet.

315 Cobb, F.W., Jr. and H.W. Barber, Jr. 1968. Susceptibility of freshly cut stumps of redwood, Douglas-fir, and ponderosa pine to *Fomes annosus*. Phytopath. 58(11): 1551–1557.

Fomes annosus is a fungal pathogen that can invade some forest tree species by spore contact with freshly cut stump surfaces. Prior to this study, it was well known that in California *F. annosus* causes widespread mortality of ponderosa pine, but its effects or potential effects on Douglas-fir or coast redwood were not known. Freshly cut stumps of coast redwood and Douglas-fir were treated with spores of *F. annosus* and rates of infection were compared with controls (natural infection rate). Sixty percent of redwood stumps and 11 percent of Douglas-fir stumps became infected, relative to 18 percent and 2 percent, respectively, in the controls. Length of time between cutting and inoculation appeared to influence susceptibility of all three species. The susceptibility of both coast redwood and ponderosa pine seemed to be highest during the first week after cutting. Additional studies compared seasonal variability in susceptibility of ponderosa pine and Douglas-fir, and the rate of stump colonization by *F. annosus*.

316 Combs, W.E. 1984. Stand structure and composition of the Little Lost Man Creek Research Natural Area, Redwood National Park. M.S. thesis, Humboldt State University, Arcata, California, 93 pp.

The stand structure of an old-growth redwood forest was examined to investigate age and diameter size-class distributions for redwood, Douglas-fir, western hemlock, and tanoak. Redwood, under both mesic and xeric conditions, showed evidence of an all-aged structure, suggesting a self-perpetuating replacement pattern. Implications for park management strategies are discussed.

317 Davidson, J.G.N. 1971. Pathological problems in redwood regeneration from seed. Ph.D. dissertation, University of California, Berkeley, California, 288 pp.

Under the premise that coast redwood produces seeds of low viability, short storage life, and low survival following germination, the pathological aspects of sexual reproduction were investigated. Fungal infection of cones and seeds was tracked over the developmental period from pollination to seed maturity. Most of the seeds developed disease symptoms, often due to fungi. Larvae of a cone moth were found to damage seeds. Laboratory tests established a relationship between pathological activity of fungi and both the soil temperature and soil depth. The lower activity of fungi at lower soil depths was consistent with the observation of natural occurrence of redwood (sexual) regeneration on disturbed soil only.

318 Diller, L.V. and R.L. Wallace. 1994. Distribution and habitat of *Plethodon elongatus* on managed, young growth forests in north coastal California. J. Herp. 28(3): 310–318.

The Del Norte salamander (*Plethodon elongatus*) lives in forests within a limited area of southwestern Oregon and northwestern California, and has been federally listed as threatened (1991) and as a “species of special concern” by the state of California (1991). The presence of this salamander and associated habitat was described for an area in northwestern California, west of the crest of the Coast Range in western Del Norte and Humboldt counties. Coast redwood and Douglas-fir are the co-dominant conifers in the study area, and much of the area had been clearcut at least once. The site condition most strongly associated with the salamander's presence in this area is talus. Earlier studies in more interior regions showed that the salamanders were tied to old-growth, undisturbed areas. The authors explain that the old-growth – salamander connection is probably indirect: in more mesic, coastal areas old-growth forests may play less of a role in creating suitable microhabitat for the salamanders than they do in the drier, interior regions. “This study indicates that mitigation measures for timber harvest or other disturbances must be area-specific for protecting [this salamander].”

319 Espinosa-Garcia, F.J. 1991. Studies of the relation of the fungal endophytic community and essential oils in the leaves of coastal redwood (*Sequoia sempervirens*). Ph.D. dissertation, University of California, Santa Cruz, California, 147 pp.

Relationships were explored between some (endophytic) fungal species occurring in the leaves of *Sequoia sempervirens* and essential oils also found in the leaves. Several separated leaf oils were shown to inhibit several selected endophytes in a dose- dependent fashion. Redwood leaf essential oils are suggested to have differential importance in influencing endophytes, depending on their total quantity and terpenoid composition, and on the nature of the specific endophyte-plant relationship.

320 Espinosa-Garcia, F.J. and J.H. Langenheim. 1990a. The endophytic fungal community in leaves of a coastal redwood population — diversity and spatial patterns. New Phytol. 116: 89–97.

The diversity of endophytic fungal species was studied in 1 to 12-year-old leaves of *Sequoia sempervirens* growing in central California. Numerous species were detected, with varying ecological roles from host generalists to specialists to putative pathogens. Differences in fungal patterns were noted between mature trees and their basal sprouts.

321 Espinosa-Garcia, F.J. and J. H. Langenheim. 1990b. Growth response of the leaf endophyte fungus Pleuroplaconema sp. exposed to different types of essential oils from coast redwood (*Sequoia sempervirens*). Bull. Eco. Soc. Supplement, 72(2): 148.

A relationship was determined between the types and relative levels of essential oils (mainly monoterpenes and sesquiterpenes) and the distribution of a type of endophytic fungus, *Pleuroplaconema* spp., in needles of *Sequoia sempervirens*. These results, plus those from related controlled exposure tests, suggest that particular suites of terpenes may be important in influencing the activity of *Pleuroplaconema* after it colonizes the leaf.

322 Espinosa-Garcia, F.J. and J.H. Langenheim. 1991a. Effect of some leaf essential oil phenotypes from coastal redwood on growth of its predominant endophytic fungus, *Pleuroplaconema* spp. J. Chem. Ecol. 17(9): 1837–1858.

Four essential oils from coast redwood were tested with fungal species (*Pleuroplaconema* spp.) that are ubiquitous on coast redwood. The oils were differentially inhibitory: two reduced fungal growth 70 to 80%, and the other two 50 to 60% at the dose tested. It was determined that two or more fungal genotypes per tree were represented in the study and that overall tolerance of individual fungal genotypes to the essential oils was low. The low tolerance of *Pleuroplaconema* species to redwood essential oils, in spite of its predominance and specialization in this conifer, is discussed.

323 Espinosa-Garcia, F.J. and J.H. Langenheim. 1991b. Effects of sabinene and gamma-terpinene from coastal redwood leaves acting singly or in mixtures on the growth of some of their fungus endophytes. Biochem. Syst. Ecol. 19(8): 643–650.

Two monoterpenes occurring naturally in coast redwood were tested both individually and in mixtures for their inhibitory effect on fungal species that occur in its leaves. Either acting singly or in combination, both monoterpenes were inhibitory to all endophytic fungal species tested, but their effect varied according to species. Results suggest that when the monoterpenes co-occur, they act additively on leaf endophytic fungi.

324 Espinosa-Garcia, F.J. and J.H. Langenheim. 1991c. Effect of some leaf essential oil phenotypes in coastal redwood on the growth of several fungi with endophytic stages. Biochem. Syst. Ecol. 19(8): 629–642.

Four essential oils extracted from leaves of coast redwood were tested for their inhibitory effect on six endophytic fungal species. One fungal species was an opportunistic generalist pathogen able to attack redwood, three were actual or potential conifer pathogens isolated from redwood, one was a common conifer endophyte with uncertain ecological status, and one was a mutualistic endophyte that was isolated from Douglas-fir. Susceptibility to the oils varied widely among the fungal species. The conifer-specific pathogens were the least susceptible and the Douglas-fir endophyte the most.

325 Espinosa-Garcia, F.J. P. Saldivar-Garcia, and J.H. Langenheim. 1991. Dose-dependent effects of volatile terpenoids as potential controllers of the activity of two endophytic fungi in coastal redwood *Sequoia sempervirens* leaves. Am. J. Bot. (SUPPL.) 78(6): 140–141.

Certain chemicals (volatile terpenes) in the leaves of *Sequoia sempervirens* are thought to play a role in controlling the activity of naturally-occurring leaf endophytes (i.e., fungi). To test this hypothesis, two known redwood endophytes, one a non-pathogenic and the other a pathogenic species, were tested with various doses of volatile terpenoids *in vitro*. At high doses, both species were inhibited. The pathogen showed an inhibition response at a lower dose than did the nonpathogen.

326 Florence, R.G. 1965. Decline of old-growth redwood forests in relation to some soil microbiological processes. Ecol. 46: 52–64.

A series of experiments was designed to examine the capacity of soils in old-growth redwood forests to support redwood seedlings. Seedlings grown in irradiated soil free from soil pathogens showed improved growth over the controls. Little nitrification was evident in the soils from old-growth stands. Low levels of respiration in old-growth soils suggested to the author that low levels of microbial activity might be limiting nutrient availability in these soils. The possible ameliorative role of a hardwood species phase is discussed.

327 Gardner, R.A. 1960. Soil-vegetation associations in the Redwood-Douglas-fir zone of California. *In* Proc. North American Forest Soils Conference, Sept. 9, 1958, East Lansing, Michigian, U.S.A., pp. 86–101.

The soils are described for an 8 million acre area of California in the western part of the northern Coast Range Mountains. Coniferous forests are the main vegetation type in this area, with redwood or Douglas-fir often dominating. This paper describes some of the soil series mapped in this area as a result of a cooperative soil-vegetation survey. Some of the soil series supporting coast redwood that are described here include the Caspar, Josephine, Hugo, and Larabee series. In the inland part of this zone, the Larabee series is one of the more extensive upland soils which often supports (or did support) almost pure stands of redwood.

328 Gellman, S.T. and W.J. Zielinski. 1996. Use of bats of old-growth redwood hollows on the north coast of California. J. Mammal. 77(1): 255–265.

Interior cavities of living old-growth redwoods in Del Norte County, California, were found to be used by several bat species throughout much of the year. The greater the internal volume of the cavity, the higher the use by bats as roosting sites. The availability of large cavities within trees may affect the abundance and diversity of bats in this area.

329 Hall, G.D. 1985. Leaf monoterpenes of coast redwood (*Sequoia sempervirens* [D. Don] Endl.). Ph.D. dissertation, University of California, Santa Cruz, California, 139 pp.

This work describes several aspects of leaf monoterpenes in *Sequoia sempervirens*, namely: variation in terpenes during leaf development, variation spatially within individual trees, variation in terpenes associated with geographic origin of trees throughout the natural range of *Sequoia sempervirens*, and assessment of these monoterpenes for antifungal properties. Significant changes occurred in leaf monoterpene composition during the first six months of leaf development. Little variation in monoterpenes was noted from samples taken at various canopy locations within the same clone. Significant differences in leaf monoterpene composition were found between trees from different geographic sources: the greatest disjunction was between those from the north, compared with those from the south, of San Francisco Bay. Four leaf monoterpenes were tested individually with four species of leaf pathogens: significant inhibition of fungal growth occurred, with evidence of specific monoterpene - pathogen interactions.

330 Hoekstra, J.M., R.T. Bell, A.E. Launer, and D.D. Murphy. 1995. Soil arthropod abundance in coast redwood forest: Effect of selective timber harvest. Env. Entom. 24(2): 246–252.

Soil arthropods are important in decomposition processes and nutrient cycles, and have been suggested as indicators of forest health. Soil arthropod diversity and abundance were measured in old-growth, second-growth (i.e., logged before 1920), and selectively harvested (14 years prior to study) areas in the Santa Cruz Mountains of central California. Results suggest that the short-rotation, selective harvest method disturbs arthropod abundance and diversity and does not allow sufficient time for arthropod recovery between harvests. The forests harvested 70 years prior showed similar arthropod structure as the old-growth forests.

331 Hughell, D.A. 1982. The adaptive strategy of coast redwood. M.S. thesis, Humboldt State University, Arcata, California, 35 pp.

The objectives of this study were to determine whether the inland edge of the natural distribution of coast redwood is advancing or receding, to determine if timber harvesting has altered the location of this edge, and to assess the role stump sprouting plays in regeneration in natural and harvested stands at this inland margin. Observations of second-growth redwood stands were interpreted to indicate that there has been no significant change in location of the inland edge of its distribution over the past 200 years. The inland limit is apparently neither advancing nor receding. In natural stands, all age classes of trees were well represented up to the inland edge of its distribution. The author concluded that the ability of redwood to sprout is probably the most important factor in explaining why the distribution of redwood is not changing.

332 Hunter, J.C. 1995. Architecture, understory light environments and stand dynamics in northern California's mixed evergreen forests. Ph.D. dissertation, University of California, Davis, California, 105 pp.

The first of four studies reported here describes the understory light environments and associated vegetation of an old-growth forested watershed. Regeneration level was associated with higher light levels for *Sequoia sempervirens* and several other tree species. The second and third studies investigated leaf structure and branch and crown architecture of several tree species in these forests (*Sequoia* was not studied). The fourth study examines the dynamics of an unlogged Douglas-fir/hardwood forest.

333 Jacobs, D.F. 1987. The ecology of redwood [*Sequoia sempervirens* (D. Don) Endl.] seedling establishment. Ph.D. dissertation, University of California, Berkeley, California, 137 pp.

Ecological factors affecting seedling establishment in *Sequoia sempervirens* were studied in both field and laboratory conditions. The field study was conducted at Muir Woods National Monument, California. In laboratory studies, the highest of three levels of light intensity tested resulted in the greatest seedling survival and growth. In the field, established seedlings were not found at the low light intensities found under redwood forest canopy, but were found under nurse trees on the forest edge, a brighter environment, yet lowest in soil moisture of all test sites. It is concluded that redwood is not able to reproduce by seed in undisturbed forests largely because extremely low light intensities predispose seedlings to damping-off.

334 Kimmey, J.W. 1958. The heart rots of redwood (*Sequoia sempervirens*). USDA Forest Service, Forest Pest Leaflet 25, 7 pp.

Two species of fungus, *Poria sequoiae* and *P. albipellucida*, are suspected to cause most of the heart rot that results in the culling of coast redwood lumber. This paper describes and illustrates with photographs the appearance and development of rot caused by the two fungal species. Fire scars are thought to be the main entrances for fungi to the tree tissues. Interestingly, the geographic distribution of the two species is implied by the relative cull percentages in commercial lumber along a latitudinal gradient in California: in old-growth redwood stands, the cull percentages increase with increased latitude.

335 Lenihan, J.M. 1983. The forest communities of the Little Lost Man Creek Research Natural Area, Redwood National Park, California. *In* van Riper, C., III, L.D. Whitting, and M.L. Murphy (eds.). Proc. First Biennial Conference of Research in California's National Parks, Sept. 9–10, 1982, Davis, CA, pp 139–169.

A 2,400-acre watershed inside the Redwood National Park in northern California was set aside by the National Park Service as a representative unit of virgin upland redwood forest for research and educational purposes. Lenihan intensively and systematically sampled the soils and described the plant species in this area — the Little Lost Man Creek Redwood Research Natural Area — for the purpose of describing and classifying the vegetation types found there. His methods, using the classification units of 'unions' and 'associations' were consistent with the majority of classification work in the Pacific Northwest, facilitating comparisons. He described three associations (occurring in moist, mesic, and xeric environments) and eight unions in this watershed area. Elevation, topography, and the fractional slope position were found to be the physiographic variables that best describe the associations. The information reported in this classification study is highly useful for other scientific research efforts in redwood forests and for guiding vegetation management within the Redwood National Park.

336 Maggenti, A.R. and D.R. Viglierchio. 1975. *Sequoia sempervirens* and *Sequoiadendron giganteum*: Hosts of common plant-parasitic nematodes of California. Pl. Dis. Rep. 59(2): 116–119.

Both giant sequoia and coast redwood are reported to be remarkably free of pests and diseases. However, the potential for pathogens has rarely been explored. This study investigates the ability of seven species of plant-parasitic nematodes to attack seedlings of both tree species. Five of the seven species of nematodes were able to attack coast redwood and six species were able to attack giant sequoia. The authors suggest that the ability of most of the nematode species to develop on coast redwood and giant sequoia and the occurrence of most of the nematodes within the natural range of one or both tree species may mean that nematodes could hinder the success of natural or artificial regeneration efforts.

337 Mandel, R.D. and D.W. Kitchen. 1979. The ecology of Roosevelt elk in and around Redwood National Park. Report prepared for the National Park Service, Redwood National Park, NO. PX8480-8-0045, 69 pp.

Roosevelt elk were “hunted out” early in the settlement of the area that is now Redwood National Park but are now a significant wildlife presence. This study reports the results of a one-year survey of Roosevelt elk in and around Redwood National Park, conducted from 1978 to 1979. The elk population in and around the Park was estimated at 580. The majority of elk habitat is in the southern portion of the Park. All age groups and both sexes were observed to be heavily dependent on prairie habitats in all seasons, presumably due to the forage availability. It was reported that much of the preferred habitat within the Park was near carrying capacity and that some herds were already showing signs of poor nutrition, high parasite loads, and a general lack of vigor. In two areas, elk appeared to rely heavily on the forage available in privately-owned pastures — creating a problem for some local ranchers. The authors explore management solutions, and recommend manipulating the habitat within the Park to make it more attractive for elk to stay within the Park. This has implications for forest management, as forest succession removes elk habitat.

338 Marshall, D.B. 1988. The marbled murrelet joins the old-growth forest conflict. Am. Birds 42(2): 202–212.

The North American subspecies of the marbled murrelet perplexed early ornithologists for, although a seabird, it has more recently been discovered to be an inland nester. This status report on the nesting habitats and behavior of the murrelet includes a history of various census activities. For example, we learn that the first North American tree nest of the marbled murrelet was discovered by Hoyt Foster, a tree surgeon, in a campground in big Basin Redwoods State Park in California's Santa Cruz Mountains, 10 km from the coast. Evidence of old-growth forest nesting and use is presented; factors affecting the bird's continued existence (i.e., old-growth habitat destruction, mortality from gill-net fisheries, and oil pollution) are described; and research, survey, and protection needs are identified.

339 Matthews, S.C. 1986. Old-growth forest associations of the Bull Creek Watershed, Humboldt Redwoods State Park, California. M.S. thesis, Humboldt State University, Arcata, California, 75 pp.

Classifying vegetation in natural areas is a means of finding patterns in a complex, interactive environment. If done well, this classification can provide an ecologically meaningful basis for vegetation management. Matthews described in detail the vegetation and several environmental factors (e.g., moisture, light, temperature, etc.) in the old-growth coast redwood forest of the Bull Creek watershed, Humboldt Redwoods State Park, California. Using statistical techniques, he defined a hierarchical classification consisting of four vegetation groups (called 'series') and five associations within these series. Coast redwood was the dominant component in four of the five associations. His study indicated that moisture was the primary environmental gradient controlling the distribution of vegetation in this region.

340 McBride, J. and D. Jacobs. 1978. Vegetation history of Muir Woods National Monument. Report prepared for the National Park Service, Contract no. CX 80000-6-0035, 39 pp. plus tables and figures.

Muir Woods National Monument is a mosaic of vegetation types, including redwood forest. It is located seventeen miles north of San Francisco and was established as a National Monument in 1908. Logging and hunting occurred prior to the creation of the park, and subsequent human activities within the park have included auto touring, camping, picnicking, hiking, trail construction, removal of fallen trees, inadvertent introduction of exotic plant species, and fire control. This report, both investigating the composition of vegetation in the park and the impacts of human activities, was prepared to provide a foundation for a vegetation management plan for Muir Woods. The vegetation was classified into fourteen types (e.g., redwood-alluvial, redwood-slope/old-growth, redwood/Douglas-fir, hardwoods, etc.) and mapped. The age structure of the different vegetation types was determined in an effort to predict successional change within the park. A history and description of each of the major human impacts (e.g., fire suppression activities, fallen log removal), and how these might be addressed in a park management plan are provided. For example, hand-clearing of some of the understory woody species and removal of downed fuel is suggested to remove the accumulating fire hazard. It was suggested that removal of some hardwoods in some of the redwood areas of the park might be indicated to increase light levels at the forest floor and improve the (largely deficient) redwood regeneration.

341 Mejstrík, V. and A.P. Kelly. 1979. Mycorrhizae in *Sequoia gigantea* Lindl. et Gard. and *Sequoia sempervirens* Endl. Ceska Myk. 33: 51–54.

Fine roots were collected from coast redwood and giant sequoia growing in natural conditions and examined for their anatomical structure. All investigated roots were infected with mycorrhizae (fungal associations). No root hairs were observed on the roots. The mycorrhizae are described. No external morphological changes were noted in roots infected with endomycorrhizal fungi.

342 Muelder, D.W. and J.H. Hansen. 1961. Biotic factors in natural regeneration of *Sequoia sempervirens*. *In* Proc. International Union of Forest Research Organizations, 13th Congress, Vienna. Part 2, volume 1 (21-4/1).

Seed formation, dispersal, germination, and seedling development are discussed in relation to natural regeneration in *Sequoia sempervirens*. Abiotic factors influencing these processes, such as soil composition and light availability, are also discussed.

343 Norris, D.H. 1987. Long-term results of cutting on the bryophytes of the *Sequoia sempervirens* forest in northern California. *In* Pocs, T., et al. (eds.), Symposia Biologica Hungarica, vol. 35. Proc. IAB Conference of Bryoecology, Parts A and B, Budapest-Vacratot, Hungary, August 5–10, 1985, pp. 467–473.

The presence of bryophytes (e.g., mosses, hepatics) was surveyed in virgin and second-growth mature redwood forests in northwestern California. Of the 128 species of bryophytes found in the virgin forest type, nine were completely absent from the old second-growth forest, 22 were reduced in abundance, and 28 showed increased abundance in old second-growth forest types. The author suggests that a single event of cutting in the old-growth redwood forest may have a longer term influence upon the bryophytes than upon the vascular plants. Some of the second-growth forests surveyed had been cut 100 years earlier.

344 Paton, P.W.C. and C.J. Ralph. 1990. Distribution of the marbled murrelet at inland sites in California. N.W. Nat. 71: 72–84.

Transect surveys were conducted from the Oregon border to Monterey County, California, in 1988 and 1989 to determine the distribution of marbled murrelets at inland sites. Although the seabird is well known to use coastal redwood forests, little was known of its distribution away from the ocean. Areas with high murrelet activity levels were primarily old-growth forests in state and national parks. The only private commercial timberlands with high detection rates were stands owned by the Pacific Lumber Company, southeast of Humboldt Bay. Areas with murrelet observations from the 1920s and 1930s that were subsequently logged had few or no birds detected during the study period.

345 Pelton, J. 1962. Factors influencing survival and growth of a seedling population of *Arbutus menziesii* in California. Madr. 16(8): 237–276.

This study followed seedling development in plots established on the forested northeast slopes of the Santa Cruz mountains. Although primarily following the survival and growth of Pacific Madrone, coast redwood seedlings were also included in the study. At the end of the six-month study period, there was 100% mortality of the redwood seedlings. Causes of death were varied: eaten by invertebrates (32%), succumbed to drought (6%), attacked by fungi (13%), died from a combination of factors (39%), and miscellaneous factors (10%).

346 Piirto, D.D., J.R. Parmeter, and W.W. Wilcox. 1984. Basidiomycete fungi reported on living or dead giant sequoia or coast redwood. Forestry and Forest Products, University of California, No. 55, 4 pp.

Seventy-four species of basidiomycete fungi, naturally occurring on coast redwood and/or giant sequoia, are listed alphabetically, along with synonyms.

347 Pillers, M.D. and J.D. Stuart. 1993. Leaf-litter accretion and decomposition in interior and coastal old-growth redwood stands. Can. J. For. Res. 23: 552–557.

This is the first known study of the decomposition rates of redwood leaf litter. Decomposition rates are important as they influence forest fire frequency and intensity, nutrient cycling, and productivity. Litter fall and litter decomposition rates were measured at upland and lowland sites, at inland (Humboldt Redwood State Park) and coastal (Prairie Creek State Park) locations in old-growth redwood forests in northwestern California. Redwood produced from 73% to 100% of the litter fall sampled at the four sites. Decomposition rates were higher at the coastal (Prairie Creek) sites, presumably because of the higher relative humidity there.

348 Prado Vera, I.C.D. 1982. Taxonomy, morphology, biology, and histopathology of *Rhizonema sequoiae* n. gen. n. sp. (Nemata: Heteroderidae) on coast redwood, *Sequoia sempervirens*. Ph.D. dissertation, University of California, Berkeley, California, 73 pp.

A previously undescribed nematode was discovered in the roots of *Sequoia sempervirens* growing near Lagunitas Lake, Marin County, California. The nematode, named *Rhizonema sequoiae*, induced uninucleate giant cells in the parenchyma cells of the xylem and phloem of redwood roots. Mature females of *R. sequoiae* were also found in the same locality on roots of other tree species including Pacific madrone, California laurel, and tanoak.

349 Rainey, W.E., E.D. Pierson, M. Colberg, and J.H. Barclay. 1992. Bats in hollow redwoods: Seasonal use and role in nutrient transfer into old growth communities. Bat Res. News 33(4): 71.

A survey of bat guano deposition over time revealed extensive use by bats of basal hollows in living fire-scarred coast redwoods along stream corridors near Carmel, California. Other observations suggested that several species of bat were present and that bats moved frequently among trees. It is suggested that bat guano deposition could enhance the nutrient status of regularly occupied living trees.

350 Rollinger, J.L. and J.H. Langenheim. 1993. Geographic survey of fungal endophyte community composition in leaves of coastal redwood. Mycol. 85(2): 149–156.

Endophytic fungi (i.e., those fungi that colonize the interior of plant tissues) were examined in needles of *Sequoia sempervirens* from six locations in its natural range. The species composition of endophytic fungi in redwood leaves was found to be remarkably consistent throughout the range of the tree species.

351 Stone, E.C. 1965. Ecology of the redwoods: inter-relationship of redwood and its environment. University of California Extension Series on Redwood, 21 pp.

This is one of a series of five lectures on the California Redwood presented by Letters and Science Extension in cooperation with the School of Forestry, University of California. The ecology of coast redwood is discussed in terms of the different ecosystems in which it occurs, the physiological characteristics of redwood that enable it to compete successfully in these environments, and its position within one environmental gradient — that of soil moisture. The challenges of preserving coast redwood are reviewed ... among them, the role of fire and the difficulty in being able to identify the ‘pseudospecialist’!

352 Strickland, W.B. 1969. The occurrence of *Aedes Sierrensis* larvae in stump cavities of the California coastal redwood, *Sequoia sempervirens*. California Vector Views 16(4): 33–34.

A survey conducted in 1968 near Orick, Humboldt County, California, revealed the presence of larvae of the western tree-hole mosquito in water that had accumulated in cavities of coast redwood. These cavities had been created by logging, with part of the core of the trunk being pulled out of the remaining stump. Water accumulating in the stumps provided suitable habitat for the larvae as the redwood regrowth shaded the cavities, slowing evaporation sufficiently to allow completion of the aquatic stages of this species of mosquito.

353 Toussoun, T.A., W. Menzinger, and R.S. Smith, Jr. Role of conifer litter in ecology of *Fusarium*: Stimulation of germination in soil. Phytopath. 59: 1396–1399.

Greater germination of spores of *Fusarium* species occurred in leachates from ponderosa pine, sugar pine, white fir, and coast redwood litter, individually, than in sugar solutions. However, in the conifer extracts, the germination generally resulted in the production of abnormal germ tubes. This result presents a partial explanation for the general absence of *Fusarium* species in conifer forest soils in California.

354 Vannatta, J.R. 1971. Ecological factors influencing reproduction in *Sequoia sempervirens* (D. Don) Endl. M.A. thesis, San Francisco State College, San Francisco, California, 134 pp.

This is an investigation of seed quality and seedling survival in terms of the seedbed-moisture relationship under natural and controlled condition to determine if these factors influence sexual reproduction in coast redwood. Field studies were conducted in Muir Woods National Monument. The study concluded that seedling survival, not seed production or germination, were limiting to natural regeneration via sexual reproduction. Seedlings survived the longest and developed best in watered seedbeds composed mainly of disturbed mineral soil (A_1 horizon) with small amounts of incorporated organic material. It is concluded that disturbance, such as fire or flooding, that will provide mineral soil for a seedbed, is necessary for redwood seedling survival.

355 Walls, S.C., A.R. Blaustein, and J.J. Beatty. 1992. Amphibian biodiversity of the Pacific Northwest with special reference to old-growth stands. N.W. Env. J. 8: 53–69.

An overview of amphibian biodiversity in the Pacific Northwest (including California) is provided. Habitat characteristics are described for the species, with emphasis on those inhabiting old-growth forests. Included are some species, such as the Del Norte salamander, that are associated with old-growth redwood forests. Ecological consequences of the loss of amphibian diversity are discussed. We are reminded that “amphibians are probably the most sensitive vertebrate bioindicators of environmental change because a complex life cycle characterizes many species, thus doubling their exposure to agents of mortality in both aquatic and terrestrial environments”.

356 Welsh, H.H., Jr. and A.J. Lind. 1988. Old growth forests and the distribution of the terrestrial herpetofauna. *In* Szaro, R.C., K.E. Sieverson, and D.R. Patton (eds.), Management of amphibians, reptiles and small mammals in North America. General Technical Report RM–166, USDA Forest Service, Rocky Mountain Station, Fort Collins, Colorado, pp 439–458.

Forty-two forest stands in northwestern California and southwestern Oregon spanning a range of ages (40 to 450 years), moisture classes, and inland to coastal locations were surveyed for species abundance and composition of reptiles and amphibians. Half of the coastal stands sampled contained coast redwood. Two survey methods are compared. This research indicated that salamanders comprise the majority of both species and individuals among the forests sampled. Species diversity among all reptiles and amphibians observed was greater in the older forest age classes. Amphibians, particularly salamanders, were significantly more abundant in older forests and significantly less abundant in drier forests. The authors support the view that greater species diversity and greater relative abundance in mature and old-growth stands may be related to greater structural complexity in older forests.

357 Westman, W.E. 1975. Edaphic climax pattern of the pygmy forest region of California. Ecol. Monogr. 45(2): 109–135.

The plant species distributions and soil types are analyzed on three forest types in the coastal area near Mendocino, California (pygmy forest, bishop pine forest, and coast redwood forest types). The study includes mosses and lichens, as well as vascular plants. Stand height and light extinction profiles (i.e., light loss at various levels in the forest, including tree height, shrub height, and herb height) are considered in the analysis. A primary classification of 14 forest types is suggested.

358 Whittaker, R.H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Monogr. 30(3): 279–338.

The Klamath Region, between the southern Cascade Range and the Pacific Ocean in southern Oregon and northern California, is an area of exceptional ecological interest. This paper describes an intensive vegetation study of this region, including description of the vegetation, classification of plant communities, interpretation of climax, and consideration of the species distributions in relation to four major environmental gradients — moisture, elevation, soils, and the east-west climatic gradient from the Pacific Coast inland. For the gradient analysis, observations were made along a transect from coastal redwood forests at the coast inland to an interior valley. The western end of the transect commenced in the Mill Creek State Park (*Sequoia sempervirens* forest). The second sampling point inland for this gradient analysis was near the inland edge of the *Sequoia* range, in the hills above the Smith River, about 14 km from the nearest point on the coast. Here, a few, widely scattered, large *Sequoia* occurred in stands strongly dominated in the upper tree stratum by Douglas-fir. Several trends are noted from this climatic transect, including the observation that stature and coverage of the coniferous high-tree stratum decreases progressively from the great *Sequoia* forests eastward. Both shrub and herb coverages decrease from the *Sequoia* forests to the middle of the transect, then increase again to the eastern end of the transect.

359 Wiant, H.V., Jr. 1964. The ecology of redwood. Report prepared for the National Park Service, Coast Redwood Study, Contract No. NPS–WASO–II–63–(4), 32 pp.

This report describes what was known at that time (1964) about the ecology of coast redwood, including its natural range, reproductive biology, seedling growing conditions, vegetative reproduction, and natural succession in redwood forests. Regeneration by sprouting is described in considerable detail and the contribution of sprouting to old-growth and second-growth stands is emphasized. The phenomenon of dead-topped or spike-topped redwoods in old-growth stands is discussed. Possible causes for this condition offered are moisture stress, carbohydrate stress, or mistletoe parasitism.

360 Wicklow, M.C. 1967. The microfungal flora of redwood forest soil. M.A. thesis, San Francisco State College, San Francisco, California, 42 pp.

Ninety species of soil fungi were identified across six coast redwood sites in California. While redwood soils appeared to support a wide variety of fungi, the abundance of each species was very limited. A characteristic fungal flora was identified for redwood forest soil.

361 Williamson, K. 1971. The breeding birds of century-old grove of coast and Sierra redwoods in Wales. Quart. J. For. 65(2): 109–121.

The bird populations in the Royal Forestry Society's coast redwood grove in Montgomeryshire, Wales, is compared with the bird populations surveyed in Big Basin Redwoods State Park, near Santa Cruz, California. The census shows many similarities (suggesting ecological replacements in the avifaunas of the two continents), but also some striking differences, such as the lack of woodpeckers in the Wales grove. It is suggested that the differences are due to the greater maturity of the California habitat.

362 Worrall, J.J. 1986. Pathogenicity and teleomorph-Anamorph connection of *Botryosphaeria dothidea* on *Sequoiadendron giganteum* and *Sequoia sempervirens*. Pl. Dis. Rep. 70: 757–759.

Some examples of stem cankers associated with branch mortality in coast redwood had previously been attributed to the fungus *Botryosphaeria dothidea* but the cause had not been proven. In greenhouse inoculation studies, the disease-induction potential of this fungus on coast redwood and giant sequoia was demonstrated. Results indicated that wounding is necessary for infection. There was no evidence of host specialization in fungal samples taken from either infected tree species.

363 Zucca, J.J. 1950. A study of acorns found buried in a redwood tree. Was. J. Biol. 8(3): 257–265.

Acorns of tanoak were found buried in the heartwood of coast redwood. The entrance holes were characteristic of the woodpecker, *Balanosphyra formicivora bairdi.* Analysis of the growth rings suggests that the acorns were deposited approximately 200 and 235 years ago. The bark of the tree also contain woodpecker holes, indicating recent activity.

4. Natural Disturbances and Abiotic Influences

400 Abbott, L.L. 1987. The effect of fire on subsequent growth of surviving trees in an old-growth redwood forest in Redwood National Park, California. M.S. thesis, Humboldt State University, Arcata, California, 90 pp.

Fire scarring, basal sprouts, and annual growth rates were examined in 1986 in an old-growth redwood forest to assess the effect of a 1974 surface fire on the subsequent growth of surviving trees. Fire scarring took place predominantly on the uphill side of trees. Basal sprouting was induced by the 1974 fire. Mean tree ring chronologies displayed an increase of ring width following two fires in 1894 and 1974, most likely due to a reduction in competition.

401 Ahlstrom, G.A. 1968. Soil moisture-vegetation relationships in the Redwood Region of Humboldt County. M.S. thesis, Humboldt State University, Arcata, California, 90 pp.

Soil moisture regimes, under extremes of vegetation and aspect in the redwood region of Humboldt County, California, were studied from July, 1966 to September, 1967. Soil moisture-vegetation relationships were monitored on grazed and ungrazed grassland, and on virgin and cutover redwood land, with each represented on both north and south slopes. The virgin forest plots (mainly redwood, Douglas-fir, and grand fir) had substantially less seasonal variation in soil moisture than the cutover plots, especially in the soil surface horizons. Such a relationship may be attributed to fog drip in the virgin stands adding moisture to the upper horizons during the summer months and offsetting the moisture utilization by the vegetation. Little difference was found between aspects on the virgin redwood plots, but for the cutover plots, the south slope showed a significantly greater depletion in soil moisture.

402 Azevedo, J. and D.L. Morgan. 1974. Fog precipitation in coastal California forests. Ecol. 55: 1135–1141.

Summer fog precipitation, a feature of much of the natural range of coast redwood, was measured at two forested sites on ridges bordering the Eel River Valley in northern California. One of the rain gauges was installed under a 70-meter redwood: during one 48-hour period this gauge recorded 8 cm of fog precipitation. Temporal fluctuations and chemical composition of the summer fog were measured. It is concluded that additions of ample amounts of nutrients to forests from fog precipitation throughout much of the growing season is at least as significant as those additions from rain.

403 Becking, R.W. 1971. The ecology of the coastal redwood forest and the impact of the 1964 floods upon redwood vegetation. Final report to the National Science Foundation, Grant NSF GB#6310, 158 pp.

This report is broad in scope, reviewing various aspects of the ecology of *Sequoia sempervirens* and investigating the impacts on redwood forests of the December, 1964 flood in Humboldt County, California. Flood impacts are measured in terms of abiotic factors such as air and soil temperatures, and biotic effects such as trends in seed germination, seed fall, and litter fall.

404 Brown, P.M. and T.W. Swetnam. 1994. A cross-dated fire history from coast redwood near Redwood National Park, California. Can. J. For. Res. 24: 21–31.

Cross-dating methods (i.e., the use of a master tree-ring history developed from numerous trees to act as a baseline or control for comparison with the fire-scarred tree samples) showed the mean fire interval in the study area to be 7.0 years, between the years of 1714 and 1762. These intervals are shorter than those reported in many previous fire-history studies and the authors suggest that fire frequency in redwood may have been underestimated in many past studies.

405 Busse, K.K. 1993. The potential change in range of *Sequoia sempervirens* (D. Don) Endl. with a 4º C. increase in mean annual temperature. M.S. thesis, Humboldt State University, Arcata, California, 100 pp.

Using a Geographic Information System (GIS), climate data from the current range of coast redwood, and information on the ecology and physiology of the species, the potential change in the range of coast redwood was simulated with an increase in temperature of 1 ºC., 2 ºC, 3 ºC, and 4 ºC. Precipitation was held at current levels. The overlap of the simulated range with the current range was reduced by 50 per cent at 1 ºC change, 85 per cent at 2 ºC, and 100 per cent at 3 ºC and 4 ºC. The results indicate that the combination of conditions suitable for redwood do not occur together after an increase in mean annual temperature of 4 ºC.

406 Finney, M.A. 1991. Ecological effects of prescribed and simulated fire on the coast redwood (*Sequoia sempervirens* (D. Don) Endl.). Ph. D. dissertation, University of California, Berkeley, California,194 pp.

Five papers are presented which describe studies on prescribed burning and fire effects on young- and old-growth coast redwood, simulated effects of fire on redwood trees and seedlings, and methods used for measuring flame characteristics and forest floor loading. In the prescribed burning study, both fireline intensity and surface fuel consumption were found to be related to the amount of young-growth redwood top-killing and basal sprouting responses one year after burning.

407 Finney, M.A. and R.E. Martin. 1989. Fire history in a *Sequoia sempervirens* forest at Salt Point State Park, California. Can. J. For. Res. 19: 1451–1457.

It is difficult to generalize about patterns of fire occurrence throughout the natural range of coast redwood. Part of the reason is due to the different methodologies employed in fire history studies. This study investigated historical fire occurrence in the (coast redwood and bishop pine) forests at Salt Point State Park, California, and compared the results from two techniques used to analyze fire history data. Mean fire intervals estimated from point data (20.5 to 29.0 years) were more than three times greater than mean intervals from composite data (6.1 to 9.3 years.)

408 Finney, M.A. and R.E. Martin. 1992. Short fire intervals recorded by redwoods at Annadel State Park, California. Madr. 39(4): 251–262.

This paper reports fire history evidence from fire scars recorded on coast redwood trees which grow in isolated groves within oak and mixed evergreen forests. All fire scars are believed to predate European settlement in the early 1800s, and the earliest scars date from the 14th century. During this period, mean fire intervals between 6.2 and 23.0 were found.

409 Finney, M.A. and R.E. Martin. 1993a. Modeling effects of prescribed fire on young-growth coast redwood trees. Can. J. For. Res. 23: 1125–1135.

Old-growth coast redwoods are very resistant and resilient to fire; young or small trees are more susceptible to fire damage or mortality. Using controlled fire treatments, models were developed relating fire characteristics, tree characteristics, and tree damage from fire. Tree diameter, surface fuel consumption, flame length, and crown scorch were significant predictors in all models of top killing and basal sprouting.

410 Finney, M.A. and R.E. Martin. 1993b. Fuel loading, bulk density, and depth of forest floor in coast redwood stands. For. Sci. 39(3): 617–622.

Fire characteristics, such as intensity and coverage, are influence by fuel loading on the forest floor. Measurements of fuel loading can be helpful in predicting the effects of fire on soils and plants. The depth and density of forest floor fuel were measured in two coast redwood sites in northern California. Results suggested that, for practical purposes of estimating fuel loading, a constant bulk density could be assumed.

411 Freeman, G.J. 1971. Summer fog drip in the coastal redwood forest. M.S. thesis, Humboldt State University, Arcata, California, 101 pp.

Fog drip was studied in the virgin redwood forest at Lady Bird Johnson Grove near Orick, California, during the period July 4 to Sept. 15, 1970. Four 1/4-acre plots were placed on a southwest aspect of the study area to sample fog drip. Results show that during that 10-week period, 0.12" of fog drip was collected at 1,200' elevation, trace amounts at 1,000', and none at the 800' elevation sample point. Fog drip was more frequent in August than July and none occurred in September. High relative humidity and reduced insolation as a result of fog appear to be more important than drip in reducing summer water losses in the coastal redwood forest.

412 Greenlee, J.M. and J.H. Langenheim. 1990. Historic fire regimes and their relation to vegetation patterns in the Monterey Bay Area of California. Am. Midl. Nat. 124: 239–253.

Fire history in the Monterey Bay area of California, concentrating on the area forested with coast redwood, was categorized into five fire regimes: prehuman (lightning-ignition), aboriginal, Spanish occupation, Anglo, and recent. Fire occurrence and coverage based on estimates (i.e., modeling fire behavior), natural records (e.g., fire scar dating), or human records (e.g., from newspapers, journals and fire records for Anglo and recent fire regimes) were compared for the five regimes. It is estimated that prehuman fire intervals in the redwood forest of this area were approximately 135 years. The frequency of fires apparently increased in the aboriginal (17–82 years), Spanish (82 years), and Anglo (20–50 years) fire regimes, and has decreased recently (130 years) due to limitation of human-caused fires. It is concluded that the present fire regime is similar in several respects to that which existed prior to the arrival of humans.

413 Griffin, J.R. 1978. The Marble-Cone fire ten months later. Frem. 8: 8–14.

A large fire burned in Los Padres National Forest in Monterey County, California, for three weeks, consuming chaparral, mixed hardwood forests (including Santa Lucia fir), mixed conifer forests (including ponderosa pine and incense-cedar), and some coast redwood groves. The author noted that many of the charred redwoods were sprouting from the base within a month of the fire. He suggests that redwood regrowth will probably be good, although a few redwood groves at higher elevations in the Big Sur drainage may have been killed as no sprouting was observed within a year of the fire.

414 Harris, S.A. 1987. Relationship of convection fog to characteristics of the vegetation of Redwood National Park. M.S. thesis, Humboldt State University, Arcata, California, 60 pp.

The relationship of redwood vegetation types (*Sequoia/Blechnum*, *Sequoia/Mahonia*, and *Sequoia/Arbutus*) in the Little Lost Man Creek Research Natural Area by fog cover frequencies was explored. Stratus/fog cover frequency observed in September (1969–1971) at 11:00 a.m. discriminated the *Sequoia/Blechnum* vegetation type (which represents the most fully developed redwood stands) from the other vegetation types. It is suggested that stratus/fog supports redwood development, and the redwoods subsequently control the environment of the site in which the vegetation community develops.

415 Hunter, J.C. and V.T. Parker. 1993. The disturbance regime of an old-growth forest in coastal California. J. Veg. Sci. 4(1): 19–24.

This study investigates the disturbance regime of an old-growth mixed-evergreen forest with a canopy composed of Pacific madrone, tanoak, canyon live oak, interior live oak, Douglas-fir, and coast redwood. The study area is located within Big Basin Redwoods State Park in the Santa Cruz Mountains of California's central coast. Eighty gaps in the canopy — caused by treefall, tree breakage, or slope failure — were examined within a 230-ha watershed. Although less than 10% of the gaps were created by slope failure, these accounted for 43% of the total land area within gaps. The largest gaps were created by the death of a Douglas-fir or coast redwood (averaging 119 and 111 square meters, respectively). Gaps formed by coast redwood were extremely long and narrow, and frequently a single fallen redwood formed more than one gap. The pattern of gaps and their characteristics are seen as complex — affected by the interactions of one or more disturbances, the tree species involved, and the topography.

416 Jacobs, D.F., D.W. Cole, and J.R. McBride. 1985. Fire history and perpetuation of natural coast redwood ecosystems. J. For. 83(8): 494–497.

Fire scars on stumps were used to determine the presettlement fire history of a coast redwood forest in Marin County, California, near Muir Woods National Monument. The mean interval between fires at one site was 27 years, while at a more inland site the interval was 22 years. The difference in fire intervals is attributed to a summer fog gradient.

417 LaMarche, V.C., Jr. and R.E. Wallace. 1972. Evaluation of effects on trees of past movements on the San Andreas Fault, northern California. Geol. Soc. Am. Bull. 83: 2665–2676.

Several coast redwood and Douglas-fir trees growing along the San Andreas fault in California were examined for evidence that could be useful in the extension of earthquake records. Fault movements can cause fracturing, twisting, and tilting of trees that grow on the surface break, and felling or topping of trees in a wider zone as a result of ground motion. Longterm effects may include changes in growth rate due to local hydrologic and topographic changes as well as biological release effects caused by the death of neighboring trees. Few trees were found that record multiple earthquakes. A redwood tree near Fort Ross was tilted between 1400 and 1650 A.D.: tilting is tentatively attributed by the authors to movement on the San Andreas fault. The same tree shows effects tentatively due to the 1906 earthquake. In contrast, a redwood tree that is 500 to 600 years old, growing only a few meters from the fault line, shows no effects from the 1906 quake.

418 Lang, J. and J. McBride. 1979. Impacts of fallen trees on coast redwood seedling regeneration on alluvial sites in Muir Woods National Monument. Report prepared for the National Park Service, Muir Woods Research Project, Technical Report No. 3.

Concern over the natural regeneration potential of *Sequoia sempervirens* on alluvial flats prompted this study. A survey of fallen tree sites in Muir Woods National Monument concluded that fallen trees did little to inhibit natural regeneration of redwood, and suggested that removal of fallen trees and debris would be ineffective in facilitating redwood seedling establishment.

419 Nives, S.L. 1989. Fire behavior on the forest floor in coastal redwood forest, Redwood National Park. M.S. thesis, Humboldt State University, Arcata, California, 73 pp.

Experimental fires, ignited during the summer and fall of 1986 in stands of redwood located in Redwood National Park, determined the fuel bed characteristics (i.e., fuel depth, load, and moisture) and local weather conditions (i.e., temperature and relative humidity) necessary to sustain a low intensity ground fire. Elevation and topographic position were found to be main factors to determine ease of fire ignition and rates of spread. Fuel depth and load appeared to affect the intensity and duration of the fires and rate of spread.

420 Oberlander, G.T. 1956. Summer fog precipitation on the San Francisco peninsula. Ecol. 37(4): 851–852.

Fog condensation was measured under three tree species, including coast redwood, along a three-mile transect of Cahill Ridge on the San Francisco Peninsula. Gauges measured condensation for a one-month period: 1.8 inches of fog drip was found under the coast redwood. It is suggested that the relatively cool and moist microsites provided by the fog drip from such trees adds to the flora biodiversity of the region.

421 Pillers, M.D. 1989. Fine fuel dynamics of old-growth redwood forests. M.S. thesis, Humboldt State University, Arcata, California, 61 pp.

Litterfall and litter decomposition were measured for two years at four sites in old-growth redwood forests in the Coast range of northern California. Sites were selected to represent sloped and flat areas at inland and coastal locations. Douglas-fir litter exhibited the fastest decomposition rates of the species tested, losing an average of 55 per cent of its original weight at the end of two years. Coast redwood lost 42 per cent. Results suggest that, for the two-year period, redwood litterfall at the sloped, inland site was significantly lighter than the other three sites.

422 Rains, M.T. 1971. Interception of rainfall by a redwood canopy in the north coast of California. M.S. thesis, Humboldt State University, Arcata, California, 100 pp.

Rainfall interception losses and net throughfall amounts were compared with gross rainfall in a redwood stand in fall, 1970. A total of 15 storms were studied. Since stemflow was shown to be insignificant, interception loss was the difference between gross rainfall and net throughfall. In five plots, each with six sample trees, net throughfall ranged from 60 to 83% of gross rainfall and is correlated with crown length. Average interception losses were found to range from 17 to 37% of gross rainfall. With small amounts of rain, net throughfall is low. Net throughfall varies with crown position in the canopy.

423 Stuart, J.D. 1987. Fire history of an old-growth forest of *Sequoia sempervirens* (Taxodiaceae) forest in Humboldt Redwood State Park, California. Madr. 34(2): 128–141.

The difficulties in using redwood stumps to determine fire histories prompted an exploration of an alternative method used in this study: dating redwood basal sprouts that presumably developed following fire. A sample of basal sprouts within the Bull Creek watershed of Humboldt Redwoods State Park was aged. Additional fire history information was obtained from fire scars on stumps found in an old clearcut and by determining the dates of establishment of Douglas-fir and grand fir in the area. Fire intervals were determined separately for the watershed and clearcut areas; and for three time periods: presettlement, settlement, and postsettlement. The smallest fire intervals (i.e., most frequent fires) were found in the postsettlement period; the largest, in the presettlement period. The size of fires was not found to be correlated with fire frequency.

424 Sugihara, N.G. 1994. Ecology of fallen trees and treefall gaps in alluvial flat coast redwood forests. Bull. Eco. Soc. 75(2), Part 2: 223.

This study was conducted to document the role of gaps in the canopy of flat, lowland coast redwood forests; gaps caused by the falling of individual trees. These gaps contribute to biodiversity by influencing light levels and structural composition in these redwood-dominated forests.

425 Vasey, R.B. 1970. Relative physiological capacity of coast redwood and Douglas-fir seedlings to tolerate saturated soil. Ph.D. dissertation, University of California, Berkeley, California, 84 pp.

This study explores some of the factors related to the apparent competitive advantage of *Sequoia sempervirens* over *Pseudotsuga menziesii* (Douglas-fir) on alluvial flats in the Eel River drainage of northern California. Response to controlled, saturated soil conditions was measured in seedlings of both species in terms of photosynthetic capacity, shoot respiration, transpiration, leaf moisture stress, and concentration of cytokinin in both root and shoot xylem sap. Results suggest that the overall vigor of Douglas-fir seedlings is much more adversely affected by brief periods in saturated soil than is the vigor of coast redwood seedlings.

426 Veirs, S.D., Jr. 1979. The role of fire in northern coast redwood forest vegetation dynamics. *In* Proc. Second Conference on Scientific Research in the National Parks, Nov. 26–30, 1979, San Francisco, CA. Vol. 10: Fire Ecology, National Park Service, Washington, D.C. pp. 190–209.

It is essential to understand the role of natural fires in forests dominated by *Sequoia sempervirens* to establish appropriate management policies in parks such as the Redwood National Park in California. The role of fire in the northern part of the species' range is studied and found to have a moderate ecological role. Light fires which do not open the canopy tend to maintain redwood dominance, while fires of higher intensity and greater frequency, as tend to occur on the hotter, drier inland sites, favor Douglas-fir over redwood.

427 Veirs, S.D., Jr. (ed.) 1985. Coastal redwood fire ecology and prescribed fire management. Proceedings of a workshop held October 15–16, 1984 in Arcata, California, 125 pp.

This workshop-derived document addresses a dilemma faced by many managers of parks and natural areas: how to perpetuate a natural ecosystem which is also a public display. The proceedings contains several presentations, including the natural role of fire in northern, central, and southern regions of the range of coast redwood. Much of the text is a transcription of discussions — and from these we learn about the interplay of fire research and redwood management, concerns and objectives related to prescribed burning, research needs, public perceptions about the role of fire and prescribed burning in redwood parks, and other related issues. Two conclusions reached during workshop discussions are:
1) The objective of any prescribed burning must be clearly defined, both with regard to agency policies and the desired effects of the prescribed fire; and
2) Prescriptions used in test fires, experimental fires, and management fires should be pooled among potential agency users to speed expansion of the database.

428 Waring, R.H. 1963. Vegetation of the California coast redwood region in relation to gradients of moisture, nutrients, light, and temperature. Ph.D. dissertation, University of California, Berkeley, California, 142 pp.

Thirty sites representing ten vegetation types in the north coastal region of California were analyzed for species composition and several environmental gradients, including temperature, moisture, nutrients, and light. It is suggested that the relationships noted between species prevalence and environmental variables can be useful for interpreting the significance of soil surveys and for forest research and management.

429 Zinke, P.J. 1983. Forest soil properties related to nutrient storage, and their change in the harvest of old-growth, and the regrowth and harvest of second-growth redwood forests. *In* New Forests for a Changing World: Proc. Convention of the Society of American Foresters, October 16–20, 1983, Portland, Oregon, pp. 210–215.

The transition from old-growth natural forests to second-growth and managed forests raises questions concerning the maintenance of soil productivity and fertility. Sites were selected in redwood forests in Humboldt County, California, representing: old-growth forest conditions before, and one year after, harvest; and second-growth forest conditions before, and one year after, harvest. Several soil properties changed significantly after harvest of old-growth stands, but had recovered to nearly original values by the time of the second harvest. Similar, but smaller, changes occurred after harvests in the second-growth stands. The main effect on soils of harvesting in both situations is to decrease some elements (e.g., nitrogen, phosphorus, potassium, etc.) near the soil surface, but to increase the amount in the entire soil profile. That is, harvesting changes the distribution of elements in the soil profile.

5. Managed Regeneration and Restoration

500 Adams, D.D. 1980. A case study of young-growth redwood management of a small non-industrial private forest in Santa Cruz County. M. For. thesis, University of California, Berkeley, California, 42 pp., plus appendices.

A case study is provided of a 100-acre property in Santa Cruz County, California, that was approximately 85% young-growth coast redwood, by area. An inventory of the area is provided and various management options are offered. While the report is mainly based on commercial objectives, biological considerations are taken into account and the need for more biological information to fortify and direct management decisions is emphasized.

501 Barrette, B.R. 1966. Redwood sprouts on Jackson State Forest. St. For. Notes 29, 8 pp.

Observations made on a logged *Sequoia sempervirens* site on the Jackson State Forest, east of Fort Bragg, California, suggest that over 80% of the stumps eventually sprout. No apparent reason for non-sprouting redwood stumps was discovered. Thinning sprouts to only those that were dominant and codominant seemed to favor growth only in open areas with plenty of light and little vegetative competition.

502 Barrett, M.M. 1988. A model of third growth coastal redwood sprout establishment and growth under various levels of overstory removal. M.S. thesis, Humboldt State University, Arcata, California, 92 pp.

Treatment plots, representing various levels of overstory removal, were established in second-growth redwood stands ranging from Fort Bragg to Crescent City, California. Stem analysis was performed to relate sprout height and diameter to age. Based on these data, a Fortran program was written to simulate sprout establishment and growth over time. The amount of residual overstory basal area appears to have a significant negative influence on annual sprout height and diameter growth. The author concludes that “the harvest system that provides the greatest sprout growth is the clearcut system.”

503 Belous, R. 1984. Restoration among the redwoods. Rest. Mgt. Notes 2(2): 57–65.

Seventy-five percent of the 48,000 acres of the Redwood Creek Basin added to Redwood National Park in 1978 had been previously logged. The past logging activities, together with the ongoing logging near the upper portion of the watershed that remained outside Park boundaries, contributed to severe erosion problems within the Park. This paper describes the scope and complexities of the rehabilitation plan, and the difficulties encountered in trying to stabilize the terrain and restore the natural vegetation, as well as to revive the streams and restore aquatic habitat. The guiding objective in this mission is "to restore a park environment—from redwoods in the creek bottom to ridgeline grasslands—that will resemble to the highest degree reasonably attainable the original undisturbed scene". Experiments to encourage survival and growth of planted coast redwood seedlings suggested that red alder is "the single most useful species of plant for purposes of redwood forest rehabilitation." Red alder is native to the area, readily invades logged terrain, and fixes nitrogen.

504 Bhaskar, V. 1995. Seed germination and seedling survivability of *Sequoia sempervirens* (Lamb.) Endl., and *Sequoiadendron giganteum* (Lindl.) Buch., in Bangalore, South India. Ind. For. 121: 749–753.

Seeds from *Sequoia sempervirens* and *Sequoiadendron giganteum* were obtained from the Institute of Forest Genetics, USDA Forest Service, in Placerville, California, and germinated at a forest nursery in North Bangalore, India. Comparing the two species, germination rates and early survival of seedlings were better for giant sequoia, but rate of growth of coast redwood seedlings was slightly higher.

505 Biryukov, V.I. and B.V. Mlokosevich. 1978. Plantations of exotic conifers in Abkhasia. Lesnoi-Zhurnal 1: 26–29.

Small plots of seven pine species and coast redwood were established in Abkhasia (on the Black Sea coast in the subtropical zone of the USSR) to determine their suitability for use in amenity planting and trial plantations in this region of the Caucasus. The plots had been established on river alluvial soil in 1961 to 1969: the trees were between 8 and 17 years of age when growth was measured for this report. The coast redwood trees, planted as both seedlings and rooted cuttings, grew more vigorously in height and diameter than most of the pine species.

506 Boe, K.N. 1961. Redwood seed dispersion in old-growth cutovers. USFS PSWF&RES Res. Note PSW–177, 7 pp.

Seed production and seed viability were measured over two years on the Redwood Experimental Forest in Del Norte County, California. Measurements were made in areas that had been harvested by: selection method, shelterwood method, and clearcutting. Based on these considerations only, results suggested that harvested areas less than 30 to 40 acres and circular in shape would still provide sufficient seed and dispersion for adequate natural regeneration.

507 Boe, K.N. 1965. Natural regeneration in old-growth redwood cuttings. USFS PSWF&RES Res. Note PSW–177, 7 pp.

Natural regeneration was measured in redwood stands at the Redwood Experimental Forest in Del Norte County, California. The study areas had each been harvested by one of three methods. Seed production, seedling survival, and stump sprouting were measured over five years in each of the three areas. In general, results showed rapid and abundant natural regeneration in all three areas over the study period.

508 Boe, K.N. 1968. Cone production, seed dispersal, germination in old-growth redwood cut and uncut stands. USFS PSWF&RES Res. Note PSW-184, 7 pp.

Observations on seed production and dispersal were made over a period of approximately five years at low to medium elevations in a redwood forest in Humboldt County, California. Results suggested that maximum seed dispersal occurred in winter and that germination was high (approximately 86%) in the sound seed. Implications for managing regeneration are discussed.

509 Boe, K.N. 1971. Growth of released redwood crop seedlings on the Redwood Experimental Forest. USFS PSWF&RES Res. Note PSW-229, 5 pp.

Shrubs and herbs were cleared away within a two-, three- or four-foot radius of young (3- and 4-year old) redwood seedlings. The expectation was that the reduction of competition would result in better growth in the redwoods. For the first three years after treatment, the treated seedlings grew more quickly than those that hadn't been freed from competition. By the end of the fourth growing season, however, the height growth rates of all seedlings, both treated and untreated, were similar.

510 Boe, K.N. 1974a. Growth and mortality after regeneration cuttings in old-growth redwood. USFS PSWF&RES Res. Paper PSW–104, 13 pp.

Areas in the Redwood Experimental Forest in Del Norte County, California, were harvested according to one of three methods: clearcutting, shelterwood, and selection cutting. Mortality, changes in crown volume, and growth of remaining trees, and growth of natural regeneration were monitored for the coast redwood and Douglas-fir on the sites after five and ten years. Results were variable, depending on harvest method, time of observation, and age-class of species considered. However, in general, the selection method caused high mortality to remaining trees.

511 Boe, K.N. 1974b. Thinning promotes growth of sprouts on old-growth redwood stumps. USFS PSWF&RES Res. Note PSW–290, 5 pp.

The effects of removing some sprouts from redwood stumps, four to five years after harvesting, were investigated in the Redwood Experimental Forests in Del Norte County, California. Different thinning intensities were employed and stump diameters were noted. Regardless of stump diameter, five years following thinning the remaining sprouts on thinned stumps showed greater diameter and volume than sprouts on stumps that had not been thinned.

512 Boe, K.N. 1975. Natural seedlings and sprouts after regeneration cuttings in old-growth redwood. USFS PSWF&RES Res. paper PSW–111, 17 pp.

Natural sexual regeneration was followed for ten years in experimental plots in areas harvested by different methods: clearcutting in small blocks, shelterwood, and selection cutting. The plots are located on the Redwood Experimental Forest, Del Norte County, California. High seedling mortality during the first growing season following the harvest was attributed to low levels of soil moisture and high surface temperatures. It is reported that adequate natural regeneration had occurred following all three harvest methods after ten years.

513 Bosch, C.A. 1971. Redwoods: A population model. Science 172: 345–349.

Using generalizations about reproductive rates and survival characteristics for various age classes of *Sequoia sempervirens*, a mathematical model is presented to predict population size over time. Even with considerable harvesting (but not of old trees) and with low seedling survival rates, the model suggests stable or increasing population size. However, ecological and genetic factors and environmental conditions are not considered in the model.

514 Brussard, P.F., S.A. Levin, L.N. Miller, and R.H. Whittaker. 1971. Redwoods: A population model debunked. Science 174: 435–436.

In a letter to the editor, the assumptions and conclusions in the population model developed by Bosch (1971; see 513) are criticized as invalid. Criticisms include the generalization across all redwood populations and ecological conditions; the failure to differentiate the population dynamics in natural, clearcut, and selectively cut redwood stands; and the assumption that the ages of trees within each age classes are evenly-distributed.

515 Buffi, R. 1987. Juvenile growth of various tree species in the Copera afforestation trial. Schweizerische Zeit schrift fur Forstwesen 138(2): 139–153.

In 1956, tests of exotic tree species were started in southern Switzerland with the goal of identifying species suitable to replace the sweet chestnut (*Castanea sativa*; also known as Spanish chestnut) which was declining from a canker infestation (*Endothia parasitica*). Of the 37 species of broadleaved trees and 34 species of conifers tested, only four species proved completely unsuitable: coast redwood was one of those. In German.

516 Burdon, R.D. 1975. Is coast redwood an answer to the Mangatu problem? N.Z For. 20(1): 148–152.

The East Coast-Gisborne region of the North Island, New Zealand, has some major erosion problems. The author explores the various characteristics of the most desirable tree species to be planted under these conditions. These characteristics include rapid early growth for quick stabilization, fire resistance, freedom from diseases and pests, windfirmness, and ability to coppice after logging. The suitability of coast redwood for this situation is considered. Many of its features are seen as well-suited to the role of erosion control in this area and its main disadvantage — that of early slow growth — could be offset with the establishment of a fast-growing nurse crop such as eucalypts.

517 Burgos, J.C. 1960. The climate of the Sequoias and the climatic possibility of their cultivation in Argentina. Rev. For. Argent. 4(1): 3–10.

Climatic data, particularly pertaining to temperature and precipitation, were collected from the natural range of coast redwood and giant sequoia and compared with regions of Argentina. On the basis of this comparison, regions of Argentina were selected as being potentially suitable for cultivation these species. For coast redwood, four zones appeared to have a suitable climate. It was speculated that in one of those four zones irrigation would not be required. In Spanish.

518 Cameron, D.M. 1960. Study on germination and early first year development of redwood (*Sequoia sempervirens* [D. Don] Endl.). M.S. thesis, University of California, Berkeley, California, 29 pp. (plus appendices).

Seed germination and seedling survival for two seed sources of *Sequoia sempervirens* — one near Pudding Creek, and the other near Ukiah, California — were studied under various nursery conditions. Several fungicide treatments and soil types were tested. The most effective treatments varied according to seed source.

519 Carr, S.B. 1958. Growth increase in young redwood stands after thinning. J. For. 56(7): 512.

The growth potential of coast redwood is one of its remarkable biological attributes. In 1923, Professor Emanuel Fritz made the first of a series of volume measurements on a one-acre plot of young (65-year-old) coast redwood growing on a fertile site. Subsequent measurements, according to the author of this note, showed an “almost unbelievable annual growth from 1923 to the present of more than three thousand board feet per acre”. The author continues with this investigation of growth in young redwood stands by establishing three plots near the Gualala River in northwestern California, consisting of an uncut, lightly cut, and heavily cut condition. He provides measurements on the growth in the three plots, six years after the harvest. The percent increase in volume in the plots over the six-year period was greatest in the heavily cut plot.

520 Cavallaro, J.I. 1989. Conceptualization and preliminary development of an organismal level process model. Ph.D. dissertation, University of California, Berkeley, California, 109 pp.

A model was developed for predicting tree and stand growth for both thinned and unthinned stands. Unlike other process models of ecosystem productivity, this model was developed at the organismal level rather than the cellular level, and a tree's growth rate was treated as the product of its leaf surface area and its net assimilation rate (i.e., growth per leaf surface area). A pilot study was carried out with coast redwood to ascertain that the values of the variables in the model can be determined from trees growing in natural stands.

521 Cole, D.W. 1982. Effects of thinning on redwood sprout growth. Cal. For. Note No. 84, 1–12.

An old-growth stand of *Sequoia sempervirens* was selectively logged in 1948 on the Jackson Demonstration State Forest in Mendocino County, California. Two years later, study plots were established to observe the effects of thinning stump sprouts under various light regimes. Thinning appeared to accelerate sprout growth on stumps in full-light areas, but had a negative impact in moderate-light areas. The interaction of light and soil moisture availability are discussed relative to the sprout growth.

522 Cole, D.W. 1983. Redwood sprout growth three decades after thinning. J. For. 3: 148–150.

Two years after an old-growth stand of *Sequoia sempervirens* was logged on the Jackson Demonstration Forest, east of Fort Bragg, California, a thinning experiment was initiated on the natural resprouting. Thirty-one years later, the thinned sprouts growing in full sunlight had grown the most, but unthinned sprouts in intermediate light levels were growing almost as well. Thinning sprouts that occurred in low-light conditions appeared to have had a detrimental effect on the sprouts.

523 Cooper, D.W. 1961. Influence of soil type on reforestation in Humboldt County. Cal. Agric. 15(2): 4.

Observations are presented on the capacity of different soil types in Humboldt county to support natural regeneration of tree species such as coast redwood and Douglas-fir following logging. It is noted that, in general, the red and reddish-yellow soil types (such as Mendocino, Sites and Josephine) support more rapid regeneration than the brown and gray soils (such as Masterson, Melbourne, or Hugo).

524 Diem, J.E., and J.L. McGregor. 1971. Redwoods: A population model debunked. Science 174: 436.

In a letter to the editor, some conceptual errors in the model developed by Bosch (1971; see 513) to describe redwood population dynamics are brought forward. One of the main errors is in the treatment of the age distribution of trees in a population. They further criticize the faulty assumptions: "it is inappropriate to compute the parameters for 50 percent harvesting by dividing natural environment parameters by two".

525 Fugimori, T. 1977. Stem biomass and structure of a mature *Sequoia sempervirens* stand on the Pacific coast of northern California. J. Jpn. For. Soc. 59(12): 435–441.

Height and diameter of individuals of *Sequoia sempervirens* were measured in a mature stand near Bull Creek, and a young, regenerated stand near the South Fork of the Eel River in northwestern California. Characteristics such as tree density, mean height, and (estimated) volume were compared across three height strata in the two stands. The number and size of redwood trees in the mature stand were compared with other tree species present. The amount of redwood biomass in the mature stand was found to be much greater than for estimates of any other natural forest type known by the author.

526 Gale, A.W. 1962. *Sequoia sempervirens*, its establishment and uses in Great Britain. Quart. J. For. 56: 126–137.

The author reviews the growth of redwoods in Britain, considering weather and soil conditions that appear to provide the best habitat. Characteristics such as its sexual and asexual means of reproduction, susceptibility to frost, and resistance to fire and insects are described. The south of England seems to provide the best habitat for coast redwood. Reasons for its lack of popularity as a plantation species there are explored.

527 Hadfield, M. 1964. The redwood in Britain. Quart. J. For. 58(4): 319–321.

Sequoia sempervirens has the potential to grow in some locations outside of its current natural range. One of these locations is the British Isles. This article traces the records of coast redwood growing in the British Isles and concludes that it was introduced to England in 1843 by Knight and Perry in the form of plants sent from St. Petersburgh, Russia.

528 Halbach, K. 1971. Redwoods: A population model debunked. Science 174: 436.

In a letter to the editor, errors in logic and execution in the population model developed by Bosch (1971; see 513) are exposed. A major criticism is that little ecological information is used in modelling population dynamics. An inconsistency in the mathematical formulation is also discussed. In his letter, Halbach states: "Although it is clearly worthwhile and possible to study the topic under discussion, it seems to me that publication of this particular paper can do great harm to the public, and also may well reduce the credibility of the scientific community."

529 Jager, D.J. 1965. Young-growth redwood site quality and the influences of certain environmental factors upon site quality of young-growth coast redwood. M.S. thesis, Humboldt State University, Arcata, California, 64 pp.

Site quality, derived from site index curves for young-growth coast redwood, was related to numerous environmental characteristics, including depth to subsoil, soil texture, latitude, elevation, miles from coast, and mean annual precipitation. No relationships were found that had good predictive value. It is concluded that greater sampling intensity may be required to discern the underlying relationships. Some generalizations are noted — such as the observation that some soil series tend to have higher site quality than others for coast redwood.

530 Kamakea, M.H. 1993. An adaptation of an eastern forest simulation model to coast redwood forest. M.S. thesis, Humboldt State University, Arcata, California, 98 pp.

The author modifies a pre-existing computer simulation model of forest development to account for some features of coast redwood forests — for example, vegetative sprouting. He also performed a sensitivity analysis of the species parameters to determine which processes were the most important in the longterm species composition. The results show that growth and canopy dynamics are the most important processes affecting the longterm species composition of the redwood forest.

531 Kuser, J.E. 1976. Potential site index of redwood as a function of climate. M.S. thesis, Rutgers University, New Brunswick, New Jersey, 99 pp.

Heights and ages of coast redwood growing in seven states in the United States and 12 other countries were determined and converted to site index, a measure of potential productivity. Site index was correlated with summer temperature, winter temperature, annual precipitation, and growing season temperature. The growing environments for redwood had temperatures in the warmest month of between 56 ºF. and 84 ºF., but growth was greatest where the mean temperature of the warmest month was approximately 64 ºF. In addition, redwood requires continual availability of moisture during the growing season. Growth was highest under 40 to 80 inches of precipitation annually, with 16 to 30 inches falling during the growing season. The author suggests that redwood requires a temperate, maritime regime of temperatures, but that well-distributed precipitation is as good as or better for it than the summer-dry Mediterranean climate of the west coast.

532 Kuser, J.E. 1981. Redwoods around the world. Am. Forests 87(2): 30–32, 60.

The actual range of a plant species is a product of many factors including its evolutionary history, genetic composition, and ecological attributes. The possible range is much greater, expanded by cultivation. Such is the case with coast redwood. In spite of its currently restricted natural range, it has been successfully planted and maintained in over 20 countries, spanning both the northern and southern hemispheres. The history of numerous redwoods in exotic locations (e.g., South Carolina, England, New Zealand, and the former Soviet Union) is described and a list of approximately 40 large redwoods (along with their planting dates and dimensions) from around the world is provided.

533 Kuser, J.E., A. Bailley, A. Franclet, W.J. Libby, J. Martin, J. Rydelius, R. Schoenike, and N. Vagle. 1995. Early results of a rangewide provenance test of *Sequoia sempervirens*. Forest Genetic Resources No. 23, Food and Agriculture Organization, Rome, pp. 21–25.

Clones sampled from 90 provenances (or populations) throughout the natural range of *Sequoia sempervirens* were vegetatively propagated and copies installed in field tests in various locations including Clemson, South Carolina; Lafayette, California; Pontevedra, Spain; Brookings, Oregon; and St. Fargeau and Etançon, France. After several years, differences in both growth and survival rates were apparent among test plantations and among clones within plantations. In general, clones from the northern part of the range survive and grow better than other clones in the more northern test plantations; clones from the southern part of the range grow better than the others on the warmer sites. This suggest differential adaptations among at least some of the sampled populations.

534 Libby, W.J. and K.A. Rodrigues. 1992. Revegetating the 1991 Oakland-Berkeley Hills burn. Frem. 20(1): 12–18.

Genetic considerations in revegetating the burned area in the Oakland-Berkeley Hills are discussed. Of particular interest is a situation involving *Sequoia sempervirens*: information and goodwill assured that genetically appropriate stock would be used in post-fire plantings.

535 Lindquist, J.L. 1974. Sampling redwood seedling and sprout regeneration: an improved technique. USFS PSWF&RES Res. Note PSW-294,6 pp.

Measuring natural regeneration in coast redwood forests is complicated by the two means of reproduction in this species: seed production and vegetative reproduction. The standard methods for measuring seedling abundance over an area are not appropriate for measuring vegetative reproduction due to the clustered nature of the latter. An appropriate method for measuring vegetative reproduction over an area is discussed.

536 Marden, M. 1993. The tolerance of *Sequoia sempervirens* to sedimentation, East Coast region, New Zealand. N.Z. For. Nov. 22–24.

Because the natural range of coast redwood includes flat areas prone to flooding and the species shows adaptations to periodic flooding, it was considered that planting coast redwood might be a longterm solution to erosion problems in the East Coast region of the North Island, New Zealand. The survival and health of 67-year-old redwoods was monitored after two severe storms in 1985 and 1988 which resulted in 60-90 cm sediment deposition. On the hillsides and in alluvial areas with less than 20 cm of sediment, the redwoods were unaffected. In alluvial areas with heavier sedimentation, many trees died. The contrast in survival in the two areas was attributed to the anaerobic conditions created by the fine-grained, clay-type soil in the alluvial areas versus the free-draining, coarser soils in the hillside plantations.

537 Millar, C.I. and W.J. Libby. 1989. Restoration: Disneyland or a native ecosystem? A question of genetics. Rest. Mgt. Notes 7: 18–24.

The importance of using not only native plant species, but appropriate genetic sources of these species, for restoration efforts is explained. Examples of management decisions, including some involving coast redwood planting in Redwood National Park, illustrate the social challenge of distinguishing between adapted populations and native species. Some of the potential consequences of using genetically inappropriate stock for restoration are discussed, and some recommendations on how to restore genetically viable plant populations are offered.

538 Namkoong, G. and J.H. Roberds. 1974. Extinction probabilities and the changing age structure of redwood forests. Am. Nat. 108: 355–368.

Population growth and survival are modeled for coast redwood under two regimes: 1) old-growth redwood stands with a complex age structure; and 2) young (less than 100 years old) even-aged stands. They assume that the development of stands results from both individual tree and population processes. They further assume different dynamics (e.g., different rates of survival and reproduction) in the two regimes. Results indicate that remaining areas of old-growth redwood have a small probability of extinction due to natural processes within populations. However, the survival and development of stands that have been clearcut or otherwise removed, is less certain. The authors explain that little is known of the life and reproductive characteristics of such young, even-aged stands, except that they are susceptible to heavy fire mortality and in general more uniformly susceptible to disasters. The probability of extinction of these artificially structured, young, even-aged stands is much higher than the relatively complex old-growth stands.

539 Neal, R.L., Jr. 1967. Sprouting of old-growth redwood stumps …first year after logging. USFS PSWF&RES Res. Note PSW-137, 8 pp.

The sprouting characteristics of stumps of mature redwoods, following harvest, were surveyed. Some observations were: the larger the stump diameter, the lower the probability that it would sprout; lower portions of stumps sprouted more often and produced more sprouts than did higher parts; and the more sprouts per stump, the higher the height of the tallest sprout, on average.

540 Oliver, W.W., J.L. Lindquist, and R.O. Strothmann. 1994. Young-growth redwood stands respond well to various thinning intensities. W.J. Appl. For. 9(4): 106–112.

While the goal of this study was to produce guidelines for commercial thinning in young (second-growth) redwood stands, the information on redwood growth rates, stump sprouting, and relationships between sprout growth and density of existing forest is of interest to biologists. The study was conducted at three locations in northwestern California. Second-growth redwood forests, regenerated from stump sprouts, were thinned to various densities by removing hardwoods and some of the conifers, including redwoods. Growth rates were measured over a 15-year period. Patterns of growth varied among treatments. Relationships between density of redwood (after thinning) and 15-year total growth are explored, and guidelines are provided for thinning second-growth redwood where volume production is an objective.

541 Powers, R.F. and H.V. Wiant, Jr. 1970. Sprouting of old-growth coastal redwood stumps on slopes. For. Sci. 16(3): 339–341.

To gain a better understanding of the principles that regulate sprout growth in old-growth redwood, stumps were studied in redwood sites in Humboldt and Del Norte counties, California, that had been logged five to ten years previously. Sprouting was most prolific on stumps in the 200- to 400-year age range, decreasing thereafter. Excessive logging damage reduced sprout production by one-half. Burning (from a slash-burn treatment of the site following logging) did not significantly affect the percentage of stumps that sprouted. On slopes, uphill segments of the stumps sprouted less often than downhill segments: this effect increased with slope gradient.

542 Rydelius, J.A. and W.J. Libby. 1993. Arguments for redwood clonal forestry. *In* Ahuja, M.R. and W.J. Libby (eds.), Clonal Forestry II — Conservation and Application. Springer-Verlag, Berlin, Germany, pp 158–168.

The article begins with a description of natural cloning or vegetative sprouting in stands of *Sequoia sempervirens*. The status of protocols and operational use of vegetative propagation of the species in reforestation efforts are described. The genetic consequences and potentials of using clonal versus seedling planting stock in restoration and reforestation are discussed.

543 Sesink, B.A. 1988. California redwood (*Sequoia sempervirens*): a possible species for timber production in South Africa. So. Afr. For. J.

Coast redwood can be successfully grown in most of the forestry regions of South Africa. On suitable sites, it can achieve growth rates in excess of 30 m^3 per hectare per year. The relatively fast growth rate, good form, and useful wood of this species suggest that it is worthy of further investigation as a commercial tree species in South Africa.

544 Stone, E.C., R.F. Grah, and P.J. Zinke. 1972a. Preservation of the primeval redwoods in the Redwood National Park, Part I. Am. Forests, April, 50–55.

The natural succession in forests dominated by *Sequoia sempervirens* is considered in relation to their status within park (in this case, Redwood National Park) boundaries. The role of natural phenomena such as fire and flooding in the health and succession of redwood is reviewed and appropriate management decisions are explored.

545 Stone, E.C., R.F. Grah, and P.J. Zinke. 1972b. Preservation of the primeval redwoods in the Redwood National Park, Part II. Am. Forests, May, 48–56.

The implications of private ownership of land bordering the Redwood National Park are considered. Large portions of the watersheds affecting the park are on private land. Harvesting practices outside the park can affect the park interior via changes in wind, contributions to stream-carried organic matter, and changes in flood patterns, among others. Appropriate management of the buffer area bordering the park is considered.

546 Stone, E.C. and R.B. Vasey. 1962. Redwood Physiology: Key to recreational management. Cal. Agric. 16(8): 2–3.

Soil compaction, from road building and recreational traffic in park situations, may damage the root system of coast redwood trees. A preliminary study is reported here of a technique (involving root pruning and soil replacement) that may have potential to revitalize redwood trees in areas that receive heavy recreational use.

547 Stone, E.C. and R.B. Vasey. 1968. Preservation of coast redwood on alluvial flats. Science 159: 157–161.

The adaptive characteristics of *Sequoia sempervirens* to fire and, particularly, flooding, are reviewed. The conditions under which the alluvial-flat redwoods have developed are described. The impact is predicted that flood control will have on the alluvial-flat redwood unless it is counterbalanced by techniques to preserve vegetation. The case is made for ‘active management’ to preserve coast redwood on alluvial (i.e., flood-prone) sites.

548 Tosta, N. 1977. A report on Cheatham Grove. Final report to the Management Advisory Committee for Cheatham Grove, 65 pp. plus appendices.

At the time of this report, the Cheatham Grove — a virgin redwood grove of approximately 160 acres in northwestern California — was owned by The Nature Conservancy and leased to the University of California, in conjunction with Humboldt State University, to be managed for scientific and educational purposes. This report documents the current and potential problems on this site, including erosion, windfall, and soil compaction. The history of the site's ownership is reviewed, and options for the University of California's future involvement in site management are considered.

549 Twight, P.A. 1973. Ecological forestry for the coast redwoods. National Parks and Conservation Association,14 pp.

Coast redwood forests are used here both as a specific case and a general model for the practice of ecology-based forestry, the author noting that "the redwood region contains the potential for the best and also the worst forestry on the Pacific coast". Some general information on the ecology of coast redwood forests is presented. Case studies on redwood forestry are presented from Georgia-Pacific ownership and a private forest — the Gazos Creek Tree Farm. The value of ecological forestry is reviewed and the need for planning is emphasized.

550 University of California at Berkeley, School of Forestry. 1966. Proceedings from a Symposium on Management for Park Preservation: A case study at Bull Creek, Humboldt Redwoods State Park. May 13–14, 1996, Scotia, California, 97 pp.

This symposium was organized to facilitate the use of science-based information in park management and to provide a forum for discussion of the problems concerning park preservation. The papers presented at this forum are contained in the proceedings without editorial review. Topics for the presentations include the physiography of the Bull Creek Watershed and its relation to redwood preservation, climate and hydrology of the watershed, past and present vegetation, land use history of the Bull Creek Basin, the 1955 and 1964 floods, ecology of the watershed, and Park System administrative aims and activities in the Bull Creek Basin. Fred Jones and John Zivnuska independently address the topic of 'The problem of choice in park and recreation management'.

551 Wiant, H.V., Jr. and R.F. Powers. 1967. Sprouting of old-growth redwood. *In* Proc. Soc. Amer. For., Sept. 12–15, 1966, University of Washington, Seattle, Washington, pp. 88–90.

Sprouting on redwood stumps was measured in two areas in Humboldt and Del Norte counties that had been logged within the past eleven years. Results suggested that older and/or larger stumps were less likely to sprout than younger or smaller stumps. Overall, more than 75% of the sampled stumps had sprouts.

552 Woodward, R.A. Early changes in coast redwood (*Sequoia sempervirens*) understory vegetation following harvest disturbances. Ph.D. dissertation, University of California, Davis, California, 145 pp.

Seven 70- to 90-year-old stands of *Sequoia sempervirens*, partially harvested since 1971, were sampled for understory vegetation species composition, frequency, and cover. The species with highest frequency and percentage cover were *Whipplea modesta* and *Polystichum munitum*. Natural regeneration of coast redwood, Douglas-fir, grand fir, and hemlock were studied. Coast redwood sprout clumps formed on approximately 100% of the cut trees. Redwood seedling establishment was relatively poor and was positively correlated with bare mineral soil. Introduced herbaceous vegetation hindered redwood seedling growth when compared with open-grown seedlings.

6. General

600 Adams, K. 1969. The Redwoods. Popular Library, New York.

This popular-style book is included here because of its rich description of some of the natural social history of *Sequoia sempervirens*, and the spirit of 'setting the record straight' with which it was written. Individual chapters explore the discovery of the species, its troubled history of classification, the growing conditions within its natural range, a comparison of the three 'redwoods', and provide insightful descriptions of the social and economic significance of the species.

601 Barbour, M., M. Borchert, S. Lydon, M. Popper, V. Whitworth, and J. Evarts. 1997. The Coast Redwood: A natural and cultural history. Cachuma Press, Los Olivos, California, 196 pp. In press.

The book's first four chapters examine the natural history of the species throughout its range. The origins, taxonomy, current distribution, and life history of coast redwood are discussed in the first two chapters; chapter three describes the ecology of coast redwood forests; chapter four introduces the wildlife associates of coast redwood. The final three chapters focus on humans and coast redwood, with one chapter devoted to each of the following: history of coast redwood utilization; history of coast redwood preservation; contemporary management of coast redwood parklands and timberlands.

602 Conservation Associates, 1966. A proposal for a Pacific Redwood National Park and Seashore in Humboldt County , California. Private-sector proposal, 66 pp. plus appendices.

This proposal, to establish the 'Pacific Redwood National Park and Seashore' in California, contains suggested legislation that aims "to save, restore, and preserve for the purposes of public inspiration and recreation benefit a region containing a superlative portion of the remaining undeveloped Pacific seashore, together with a succession of adjoining landscapes of notable variety and compelling scientific and scenic quality, supporting an unbroken redwood forest region of 56,246 acres of which 21,833 acres are of the finest virgin and old-growth redwoods in existence, and including an adjoining and accompanying system of earth, sea, and sky resources that are indispensable to the survival of the redwoods and to man's understanding of them ...". This proposal is an expansion of that proposed by the American Forestry Association in 1965. The proposal includes a description of other park proposals from the Federal Administration, the Save-the-Redwoods League, the Sierra Club, and a group of foresters and industrialists, among other proposals. The proposal includes a geological and botanical description of the Mattole Valley-King Range-Seashore area.

603 Cooper, D.W. 1965. Coast redwood (*Sequoia sempervirens*) and its ecology. University of California Agricultural Extension Service, Eureka, California, 20 pp.

This report was apparently written in response to media misinformation generated from various controversies concerning *Sequoia sempervirens* — including the proposal to create a Redwood National Park, the announcement of plans to reroute Highway 101 along the beach through Prairie Creek State Park, and the publication in the National Geographic magazine of "World's Tallest Tree". The report includes a botanical description of the species and its natural range, information on its natural reproduction, and a characterization of redwood forests, including the substrates.

604 Cornelius, C.J. 1969. An investigation of the current ecological situation of the *Sequoia sempervirens* community in Muir Woods National Monument. M.A. thesis, Sonoma State College, 149 pp.

This is a general investigation of ecological conditions in three selected areas within Muir Woods National Monument, a redwood preserve in southern Marin County, California. The species composition and age structure were studied over a two-year period. The author concludes that soil/moisture conditions and fire are the most influential natural processes in determining the ecological status here, and that exclusion of (most) fire from the preserve has "allowed for the development of community structure that would not otherwise have been realized." However, the author subsequently recommends the continued exclusion of fire in the preserve as a protective measure for the young redwood trees. The author concludes that "increasing visitor impact is by far the most serious threat facing the redwood community in Muir Woods today."

605 Daubenmire, R. 1975. The community status of the coastal redwood. Report prepared for the National Park Service, 17 pp.

The purpose of this report is to objectively evaluate some of the controversial issues regarding the ecology of coast redwood ... "as these might have a bearing on the future management of Redwood National Park". The author uses observations he made in the northern part of the redwood's range in 1975 as support for his analysis. "As early as 1889 it was stated that redwood was not reproducing and so is headed towards extinction." The author concludes that sprouts and seedlings are adequate to maintain current populations of redwood and that the shade tolerance of the species means that it won't be replaced by other species. The question of the origin of existing old trees is raised. The author opines that at least some of the huge trees in the old stands originated as basal sprouts. Is redwood windfirm? Based on observations near the edges of clearcuts, the author contends that redwood is fairly windfirm. He concludes that inconsistencies or controversies about redwood ecology may arise from generalizing across the diverse habitats it occupies.

606 Fritz, E. 1957. The life and habits of redwood the extraordinary. California Redwood Association, San Francisco, California. Section 1, File 1B1, Sheet 2, 4 pp.

An overview of the ecology and status of *Sequoia sempervirens* is provided. Information on its distribution, size, age, growth habits, and relationship with *Sequoiadendron giganteum* is presented. Harvesting practices and the status of the species in state parks are briefly discussed.

607 Gilligan, J.P. 1965. Man and the redwoods. University of California Extension Series on Redwood, 23 pp.

This is one of a series of five lectures on the California Redwood presented by Letters and Science Extension in cooperation with the School of Forestry, University of California. A chronological treatment of human interaction with the coast redwood is provided, commencing with native American use of the species, continuing with the development of the lumber industry, and examining the reasons for the change in public sentiment towards redwood logging. An overview of the history of coast redwood conservation efforts, including the establishment of the Save-the-Redwoods League and the Sempervirens Club, is presented. As a final note, the condition of the current redwood forests is contrasted with that of presettlement times.

608 Green, K. 1985. The old growth redwood resource: an historical review of harvesting and preservation. Report prepared for the United States Department of Justice, 32 pp. plus figures.

This document chronicles the changing acreages and volume of old-growth coast redwood since harvesting began. Differing figures from various sources are discussed: reasons for discrepancies include lack of information, changing criteria for inclusion, and lack of understanding about redwood growth and reproduction. A brief summary of preservation efforts and park establishment is provided.

609 Leblanc, J. (ed.) 1996. Proc. Conference on Coast Redwood Forest Ecology and Management. June 18–20, 1996, Humboldt State University, Arcata, California, 170 pp.

As explained in the Preface by Bill Baxter of the California Department of Forestry, the idea for this conference was first actively promoted in 1994, following a longterm and widely-felt sentiment that "the amount of published work on coast redwoods does not match the interest in this unique resource." Thus, one of the objectives of the workshop was to bring together not only the existing published literature pertaining to redwood ecology and management, but to provide a forum for a broader spectrum of information, including unpublished data, reports from various agencies, and information from interdisciplinary sources that might lie outside the traditional framework of 'redwood literature'. The plenary sessions were designed to present history and overviews of redwood conservation (e.g., Unity of Action, Saving the Redwoods!, by Mary Angle-Franzini), research on redwood forest health and dynamics (e.g., Ecology of the Coast Redwood, by Stephen Veirs, Jr.; Coast Redwood Forest Health, by John Stuart; Pattern and Process in Forests of *Sequoia Sempervirens* (D.Don) Endl., by Paul Zinke, Alan Stangenberger, and James Bertenshaw; etc.), the history of the human relationship with coast redwoods (The Use of Redwood (Keeth) by the Yurok People, by Roland Raymond and Walt Lara, Sr.; The History of Conflict over Managing Coast Redwoods; etc.), among other topics. The proceedings contains the plenary session presentations, as well as the technical papers that span a wide range of topics in redwood silviculture, ecology, forest management, park management, wildlife in redwood forests, effects of logging on watersheds, habitat restoration, and others. Abstracts from the poster session are also included.

610 Libby, W.J. 1990. Genetic conservation of radiata pine and coast redwood. For. Eco. Mgt. 35: 109–120.

Most of this paper is a personal history of Monterey pine genetic conservation efforts and fluctuations in their funding since 1962. A description of the more recent (i.e., initiated in 1985) genetic conservation collections of *Sequoia sempervirens* is provided. The 'endowed project' approach taken with the redwood collections is hoped to provide more stability for this redwood (*ex situ*) genetic conservation effort than has been experienced with the Monterey pine collections.

611 McBride, J. and D. Jacobs. 1977. The ecology of redwood [*Sequoia sempervirens* (D. Don) Endl.] and the impact of man's use of the redwood forest as a site for recreational activities. Report prepared for the United States National Park Service, 39 pp.

This report is broad in scope — briefly describing many aspects of *Sequoia sempervirens*, including the taxonomic history, evolution, botanical characteristics, geographic range, environmental conditions of the current natural range, and reproductive characteristics. Some aspects of human impacts on coast redwood in parks are described. These include soil compaction from heavy foot traffic, vehicular traffic, and road building; and the impacts of controlling fire and floods — both natural disturbances within the natural range of coast redwood.

612 Roy, D.F. 1966. Silvical characteristics of redwood (*Sequoia sempervirens* [D. Don] Endl.). USFS PSWF&RES Res. Paper PSW-28, 20 pp.

This general and often-quoted reference on coast redwood describes the climatic, edaphic, physiographic, and biotic conditions of the species natural range; its life history characteristics including seeding habits, vegetative reproduction, seedling development, and growth; and several other features such as use by wildlife, production of burls, and formation of 'varieties' with unusual foliar characteristics.

613 Simmons, I.G. and T.R. Vale. 1975. Conservation of the California coast redwood and its environment. Env. Cons. 2(1): 29–38.

The authors review the presettlement distribution of coast redwood and characteristics of its natural environment such as fire and flooding events. The history and impact of commercial utilization of the species are briefly reviewed. The history of the creation of redwood parks, including the Redwood National Park, is explored. Issues are raised and discussed such as the impact of activities outside park boundaries (e.g., logging and impacts on watersheds) on the redwoods that are within parks.

614 Snyder, J.A. 1992. The ecology of *Sequoia sempervirens*: An addendum to 'On the edge: Nature's last stand for coast redwoods'. M.A. thesis, San Jose State University, San Jose, California, 135 pp.

The ecology of coast redwood is examined with an emphasis on the climatic, physiographic, edaphic, and hydrologic factors responsible for its present distribution. Detailed appendices include a botanical comparison of the three redwood species, and an annotated register of the tallest coast redwoods.

Abbreviations

Acta Biol.	Acta Biologia
Acta Bot. Yun.	Acta Botanica Yunnanica
Acta Hort.	Acta Horticulturae
Acta Phyto. Sin.	Acta Phytotaxonomica Sinica
Am. Birds	American Birds
Am. Forests	American Forests
Am. J. Bot.	American Journal of Botany
Am. Midl. Nat	American Midland Naturalist
Am. Nat.	American Naturalist
Ann. Rech. Sylv.	Annales de Recherche Sylvicoles
Ann. Sci. For.	Annales des Sciences forestieres
Bat Res. News	Bat Research News
Biochem. Syst. Ecol.	Biochemical Systematics and Ecology
Biol. Plant.	Biologia Plantarum (Prague)
Bot. Gaz.	Botanical Gazette
Bot. Rev.	The Botanical Review
Bot. Zool. (Tokyo)	Botany and Zoology (Tokyo)
Bot. J. Linn.	Botanical Journal of the Linnean Society
Bull. Eco. Soc.	Bulletin of the Ecological Society of America
Bull. Tottori Univ. For.	Bulletin of the Tottori University Forests
Cal. Agric.	California Agriculture

Cal. For. Note	California Forestry Note
Can. J. Bot.	Canadian Journal of Botany
Can. J. For. Res.	Canadian Journal of Forest Research
Can. J. Microbiol.	Canadian Journal of Microbiology
Ceska Myk.	Ceska Mykologie
Cytol.	Cytologia
Dissert. Abstr.	Dissertation Abstracts
Ecol.	Ecology
Ecol. Monogr.	Ecological Monographs
Env. Cons.	Environmental Conservation
Env. Entom.	Environmental Entomology
Evol.	Evolution
FEBS Let.	Federation of European Biochemical Societies Letters
For. Eco. Mgt.	Forest Ecology and Management
For. Sci.	Forest Science
Frem.	Fremontia
Gard. Chron.	Gardeners' Chronicle (London)
Geol. Soc. Am. Bull.	Geological Society of America Bulletin
Hered.	Heredity
HortSci.	HortScience
Ind. For.	Indian Forester
In vitro Cell. Dev. Biol.	In vitro Cellular and Developmental Biology

Jap. J. Gen.	Japanese Journal of Genetics
J. Agric. Food Chem.	Journal of Agricultural and Food Chemistry
J. Arn. Arb.	Journal of the Arnold Arboretum
J. Chem. Ecol.	Journal of Chemical Ecology
J. Ecol.	Journal of Ecology
J. For.	Journal of Forestry
J. Herp.	Journal of Herpetology
J. Jpn. Bot.	Journal of Japanese Botany
J. Jpn. For. Soc.	Journal of the Japanese Forestry Society
J. Mammal.	Journal of Mammalogy
J. Pl. Physiol.	Journal of Plant Physiology
J. Pl. Res.	Journal of Plant Research
J. Res. U.S. Geol. Survey	Journal of Research of the U.S. Geological Society
J. Veg. Sci.	Journal of Vegetation Science
J. Wash. Aca. Sci.	Journal of the Washington Academy of Sciences
Kromo.	Kromosomo (Tokyo)
Madr.	Madroño
Murr.	The Murrelet
Mycol.	Mycologia
Natl. Geog.	National Geographic
New Phytol.	New Phytologist
N.W. Env. J.	The Northwest Environmental Journal

N.W. Nat.	Northwestern Naturalist
N.W. Sci.	Northwest Science
N.Z. For.	New Zealand Forestry (also, New Zealand Journal of Forestry)
N.Z. J. For. Sci.	New Zealand Journal of Forest Science
Pan-Pac. Entom.	Pan-Pacific Entomologist
Phys. Plant.	Physiologia Plantarum
Phytochem.	Phytochemistry
Phytomorph.	Phytomorphology
Phytopath.	Phytopathology
Pl. Cell Env.	Plant, Cell, and Environment
Pl. Cell Physiol.	Plant Cell Physiology
Pl. Cell Rep.	Plant Cell Reports
Pl. Dis. Rep.	Plant Disease Reporter
Pl. Physiol	Plant Physiology
Pl. Syst. Evol.	Plant Systematics and Evolution
Proc. Natl. Acad. Sci.	Proceedings of the National Academy of Science
Quart. J. For.	Quarterly Journal of Forestry
Rest. Mgt. Notes	Restoration and Management Notes
Rev. For. Argent.	Revista Forestal Argentina
Rev. Palaeob. Palyn.	Review of Palaeobotany and Palynology
Sci. Proc. Royal Dub. Soc.	Scientific Proceedings of the Royal Dublin Society

Sil. Gen.	Silvae Genetica
So. Afr. For. J.	South African Forestry Journal
St. Tech.	Stain Technology
St. For. Notes	State Forest Notes, California Division of Forestry, Department of Conservation
Syd.	Sydowia
Syst. Bot.	Systematic Botany
TAG	Theoretical and Applied Genetics
Therm. Acta	Thermochimica Acta
Trees	Trees—Structure and Function
Tree Phys.	Tree Physiology
Tree Pl. Notes	Tree Planter's Notes
USFS PSW F&RES Res. Note	United States Forest Service, Pacific Southwest Forest and Range Experiment Station Research Note
USFS PSW F&RES Res. Paper	United States Forest Service, Pacific Southwest Forest and Range Experiment Station Research Paper
W.J. Appl. For.	Western Journal of Applied Forestry
Was. J. Biol.	Wasmann Journal of Biology
Wood Res.	Wood Research (Kyoto University)

Author list