Management Practices Related to the Restoration of Old Forest Characteristics in Coast Redwood Forests

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Abstract

A standardized, interactive, interview process was used with practicing Registered Professional Foresters asking a suite of questions to ascertain their management approaches to coast redwood (*Sequoia sempervirens* [D. Don] Endl.) stands that could best be transferred to other projects and lands interested in recruiting older forest characteristics. The assimilated results provided management insights that provide comparisons of similarities and vagrancies between properties, management styles and approaches. The survey included the properties and practitioners along the north-south geographic axis of coast redwoods to account for the diversity and range of physical and edaphic heterogeneity that is expressed within the forest type.

Forest managers generally agreed that uneven-age management provided the basis from which to begin the discussion further recognizing that a fully stocked stand was equally important and may require a "transitional" period depending on the initial condition of the stand in question. Furthermore, it was generally recognized that a positive financial return for the forestland owner was vital in order to secure their support throughout the period of restoration while advancing the stands to incorporate and retain larger size class cohorts and other structural elements associated with older forests.

In all cases the desire to increase the distribution of tree sizes classes (the inverse "J" curve) while simultaneously retaining existing conditions peculiar to older forests (i.e. tree trunk hollows, broken tops, reiterative branches, and others), affords the forest manager the ability to set the stand on a particular management pathway while affording the flexibility to adjust management decisions over time and capture market opportunities. Existing, archived datasets of unaltered old growth stands are used for comparisons in order to assist those interested in recreating old forest conditions.

Key words: *Sequoia sempervirens*, coast redwood, restoration, old forest characteristics, management practices

Introduction

The management for old forest characteristics in coastal redwood forests is a topic of interest among conservation interests and policy leaders in California. Unfortunately, a limited knowledge base regarding the structure and composition of older forests is available to land managers to assist them in making management decisions to achieve a specified future desired condition. Much of the scientific inquiry investigating the characteristics of redwood forests is relatively new and promises to provide useful and enlightening information in the years to come (Giusti 2004, Sillet and Van Pelt 2000).

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Historic and contemporary forestry practices have simplified the structural components of coast redwood forests (O'Dell 1996). Recruiting the structural elements commonly found in older forests is recognized as an important management objective in younger forest stands to address issues of biological diversity and forest integrity (Mladenoff 1993, Spies 2002). Simply stated, older forest characteristics are a function of time and chaotic events such as storms, wind, fire, and landslides whose legacies shape forest structure and composition and which may be difficult to mimic through traditional management practices. Interest in recruiting old forest characteristics is not limited to the redwood region and has been document for other forest regions (National Research Council 2000). As land ownership patterns and objectives continue to shift away from corporate ownership it is generally expected that this interest will continue to grow and find application in other forest types throughout the West.

Redwood characteristics through its range

The coast redwood forest, being dispersed along a north-south axis, has characteristics affected by geographic location and localized climate and edaphic conditions (Sawyer et al. 2000). Any comparison between redwood stands from differing geographic locations should be viewed as reference points for guidance purposes. Furthermore, numerical comparison between stands should recognize that differences exist in structural attributes between trees growing on upland sites vs. trees growing on alluvial flats and that comparisons should be limited to similar site characteristics. As illustrated in table 1 stands growing on alluvial deposits generally have higher tree densities then those stands on adjacent upland sites. This illustrates the need to recognize that no one description will define or articulate the structural elements of any particular site and any reference data should be used conservatively in management discussions.

Table 1—*Stand density comparison between old growth coastal redwood stands from different geographic locations with differing climatic and edaphic conditions (Giusti 2004).*

Stand Age	Old Growth	Old Growth	Old Growth	Old Growth
Location	Redwood Creek	Little Lost Man Creek	Bull Creek	Montgomery Woods State Reserve
County	Humboldt	Humboldt	Humboldt	Mendocino
Tree Size	TPA	TPA	TPA	TPA
> 24" dbh	No data	20	40	16
> 32" dbh	No data	15.7	40	------
> 40" dbh	11.3	12	35	15

Redwood forest characteristics vary greatly throughout the range. In general, the presence of hardwoods increases with distance from the coast. Zinke (1988) demonstrated how moisture gradients affect species associates from Sitka spruce-

grand fir-hemlock in moist areas, redwood mixed with other conifers, redwood mixed with hardwoods, to Douglas-fir- hardwoods, to grassland-oak woodlands in the driest locations. The northern limit of the redwood forest is determined by winter conditions, particularly from frost damage to young trees (Baker 1965).

Generally older forests in the northern part of the range are the largest, most continuous due to the higher amounts of winter rainfall and summer fog which help to moderate the effect of the rainless summers (Veirs 1996). As the sites become hotter and drier and elevation increases, a more favorable environment is created for Douglas-fir, and it can be found sharing the upper canopy with redwoods.

Dagley and O'Hara (2003) report that near its southern extent redwood can be found 5 to 19 km inland with Douglas-fir, tanoak, and madrone (Zinke 1988). Moving inland it can be found in isolated patches up to 32 km from the coast while further south redwood is found only in very moist canyon bottoms, such as along the Big Sur River. Both Baker (1965) and Zinke (1988) have written that the limit to the southern range seems to be restrained by soil moisture. However, high summer temperatures may also help determine redwood's southern boundary (Barbour et al. 2001).

There does exist some limited descriptive fieldwork for non-tree attributes of older redwood forests. Sholars (in Sawyer 2000) has cataloged 47 species of lichens as part of the Bryophytic component for an old growth forest. Similarly, Largent (in Sawyer 2000) has identified over 323 species of fungi associated with old growth redwoods. Others (Thornberg, personal communication) have taken their leads and are now pursuing field studies to determine the opportunities to inoculate previously logged stands that are missing these non-vascular botanical components as a means of recruiting missing botanical elements to mimic older forest stands.

Structural characteristics of older forests in the northern tier of the redwood range

Baseline conditions for coast redwoods are found in limited quantities. In 1969 the U.S. Department of Interior initiated a project to identify and purchase what is now known as Redwood National Park in the northwestern corner of California. As a result, stand structure data was collected in old growth redwood stands proposed for acquisition (Hammon, Jensen & Wallen, 1969 a, b, c, d). The synthesized information from the surveyed sites provides an opportunity to compare size class distributions in un-logged forests (*fig. 1*) and represents one of the few existing data sets for unaltered stands.

The resultant data from the approximately 9,000 aggregated acres cruised demonstrates a relatively similar size class distribution over the surveyed area. Given the acreages of the cruised parcels, one can surmise that both upland and riparian sites were sampled. The average tree density of the three ownerships was 32 trees per ac, with tree sizes below 50 in dbh dominating. In each case, trees >50 in dbh were common and averaged >2 trees/ac. Similarly, each property averaged approximately one tree >90 in dbh per ac.

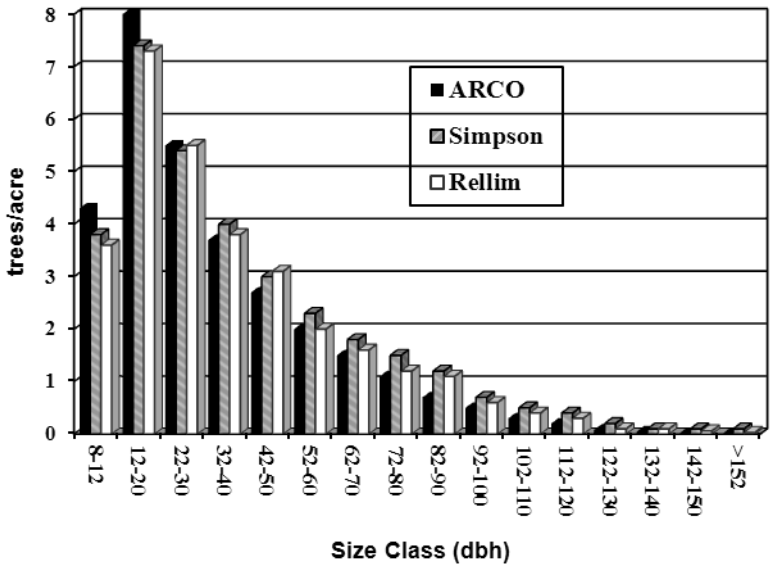

Figure 1—Size class distribution of old growth redwood trees; ARCO, Simpson and Rellim timber companies. Del Norte County. 9,378 acres. ≈ 32 trees/acre. Source: HJW 1969 a, b, c, d.

Though each property shared similar traits when comparing size class distribution, they had strikingly different conifer composition. Of the properties surveyed by HJW in 1969 the Rellim property had the least percent by volume of redwood and the highest percent by volume of Douglas-fir (*fig. 2*).

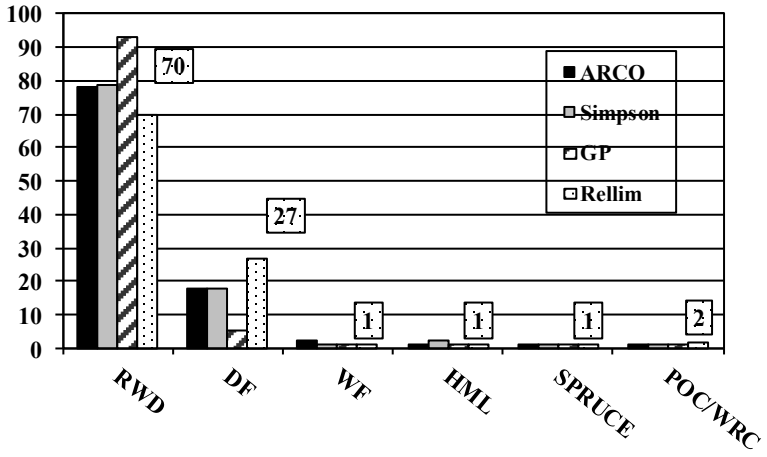

Figure 2—Relative percent by volume of tree species on ARCO, Simpson, Georgia-Pacific and Rellim Redwood Companies. Source: HJW 1969 a, b, c, d.

Combined, these data demonstrate the need to recognize that not all redwood stands within the range are created equal. Understanding the location along the north-south axis in addition to proximity to the coast with its influences is an important consideration when attempting to identify redwood associates and approximate species composition ratios.

Methods

Objective

This project was designed to "identify and articulate the applied knowledge that exists from practitioners who have experience with silvicultural operations that might affect forest restoration efforts." This was accomplished by identifying knowledgeable individuals widely recognized by their peers and others who have been part of an on-going discussion regarding recruitment of old forest characteristics or who have successfully or are attempting to retain or recruit old forest characteristics into their managed stands. Those interviewed represented managers of non-industrial, industrial and public lands.

Survey design

The project conducted range-wide surveys of managers with various management experiences in order to capture and synthesize their collective experiences at restoring old-forest characteristics in coast redwoods. The preliminary management survey review included identification of public and private landowners and land managers either (a) managing ancient coast redwood forests, or (b) conducting silviculture directed towards restoration of old-forest (or at least older) characteristics in coast redwood forests.

The survey was predicated on four main premise "themes" that were designed to serve as the basis for a number of questions asked to each practitioner. The thematic premises where used to help focus the scope of the questions and responses to better compare and identify "key findings" – similarities in approaches.

Results

Results of the survey are presented by premise. Each of the four premises is stated, followed by questions and key findings for each premise.

Premise 1

Statement: Silviculture is widely viewed as the management option that holds the greatest potential to accelerate and restore old forest characteristics. The following questions are intended to identify those practices that best accomplish this objective.

Question 1a

Do you have an existing stand of older trees? How are you managing that stand to maintain old forest characteristics? Do you manage older stands of trees differently than any other?

Key findings

In every case where older trees still exist they are identified by the owner/manager as an important component of the ownership that has High Conservation Values "HCV". In all cases, the owner/manager recognizes the older trees as "old growth" delineated as either whole stands or residual trees left from past harvest activities. In every case, stands that have not yet been harvested will not be entered and are being preserved. Where partial harvesting has occurred and residual trees remain, future harvest activities will focus on the trees within the matrix surrounding the residual old trees. In specific instances (MRC, SDSF, JDSF) policy language has been developed that 1) articulates the qualitative description of the stands/trees to be protected, 2) identifies the stands of old trees to be reserved, and 3) describes the management options available for the conservation of their values.

Question 1b

What are your management goals, monitoring techniques etc. toward redwood regeneration?

Key findings

In every case, the properties visited are being managed for the long-term production of timber and sawlogs. Hence, regeneration is a key component of the property's management objectives. Shared management objectives regarding regeneration included:

1) Stump sprouting is promoted since it is a unique attribute of coastal redwood and it avoids genetic contamination of the stand.
2) Harvest activities focus on the dominant and co-dominant trees within a sprout clump retaining the smaller size cohorts for future harvests. Thus retaining the genetic architecture of the redwood component of the stand. Harvest trees within clumps are selected on the basis of achieving both spacing and regeneration criteria.
3) Timber volume data are collected and monitored using conventional field plots in combination with growth and yield models. Standing timber volumes and recruitment estimates across all size and age classes are commonly collected to ensure that regeneration and future harvest objectives will be assured.

Question 1c

What are the most commonly applied silvicultural treatments on the properties you manage?

Key findings

1) Commercial thinning of redwood is the most widely applied silvicultural practice. In all cases, the RFP is selecting trees "from below" selecting co-dominant trees while retaining dominant individuals. This prescription concurrently achieves spacing, growth and volume objectives while maintaining contiguous canopy cover (*fig. 3*). *Figure 3* illustrates the concept of harvesting while continually increasing volume over time and space. The

incremental volume is achieved through selection of large tree retention as well as recruitment of younger cohorts.

2) To a lesser degree single-tree selection was the second most applied silvicultural practice. This selection approach was utilized to achieve specific site or ownership objectives regarding growth or volume.

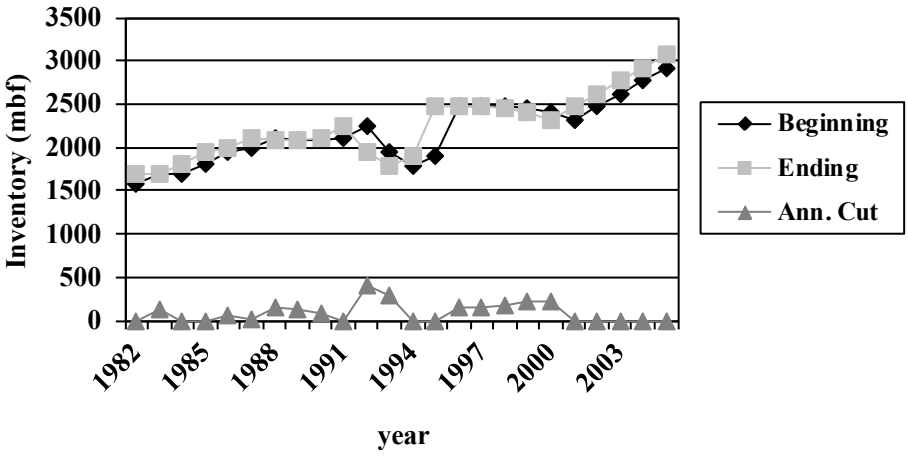

Figure 3—Humboldt Co. commercial thinning 1982- 2000. Site II. 70 acres. Birth of Stand 1915-1925. First commercial thin 1976. (Source: Able Forestry).

Question 1d

What is your philosophy regarding early spacing treatments (pre-commercial thinning) and when is it best applied (if ever)?

Key findings

Pre-commercial thinning (PCT) is virtually ignored as a management approach on most of the sites visited. Those individuals who practice PCT consider the optimum stand age to achieve desirable stand characteristics to be between 8 and 18 years (JDSF & MRC). This is based on their field experience for optimal release of remaining redwoods.

Question1e

What is your philosophy about the relationship between commercial (mid-rotation) thinning and redwood regeneration? When is it best applied?

Key findings

Commercial thinning is the most widely utilized silvicultural practice of the sites visited. In all cases, the approach is similar. The RPF chooses the harvest trees after assessing dominant and co-dominant trees. Generally, dominant trees are retained in the stand to increase stand volume through release. Volume is increased from both increased diameter and height. Additionally, commercial thinning initiate's gap phase

successional processes allowing for natural recruitment of future crop trees from stump sprouting.

The amount of wood volume harvested during each entry is dependent on the forester and the site. In some cases, RPF's concentrate on removing 30 percent of the volume per entry, while other RPFs remove 1/3 of the trees. *Figure 4* demonstrates the intent of this silvicultural approach. Here the "inverse J" curve is adjusted to move trees to the right of the "x" axis (harvestable trees) while addressing recruitment concerns along the "y" axis.

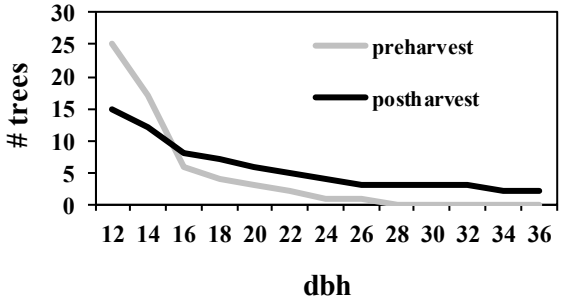

Figure 4—Desired outcome over time from commercial thinning. Source: Blencowe Forestry.

Question 1f

What experiences relative to recruiting old forest characteristics can you share regarding those treatments?

Key findings

1) By design or happenstance the use of mid-rotation selection cutting has resulted in the gradual increase in both average tree girth and height while maintaining dense forest canopy.
2) Mid-rotation thinning further allows the forester to identify and retain distinctive habitat elements that are present in the stand prior to harvest.
3) Furthermore, selection cutting allows for development of multiple age stands that address both old forest characteristic retention and future crop tree recruitment.
4) When recruitment goals are not being met, mid-rotation thinning allows the RPF to select appropriate sites for group selection harvest units. This combination of silvicultural treatments allows for increased regeneration while minimizing canopy disturbance and retaining old forest characteristics in the remainder of the stand.

Question 1g

Does your approach to regeneration require active vegetation control for undesirable species?

Key findings

The majority of interviewees have no need to consider vegetation management scenarios in established stands. They are achieving control of unwanted plant species either through the use of shade and/or the direct impacts of logging which are targeting the removal of undesirable species.

Question 1h

Is pruning a viable option for improving tree vigor, stand characteristics, and economic returns?

Key findings

Pruning is not generally being applied at the sites visited to improve tree vigor. The consensus by those interviewed is that pruning is an activity to promote "clean log production" and the cost of pruning is not justified under the silvicultural methods being used. Furthermore, few saw the utility of pruning in recruiting older forest characteristics.

Question 1i

What has experience taught you about the type of un-even age prescriptions that may have the greatest potential to provide information useful in old forest restoration?

Key findings

This question represents the primary purpose for undertaking this project. The guidance provided by the interviewees can inform future management decisions with regard to stand manipulations intended to achieve old forest characteristics. Key points are:

1) Un-even age prescriptions allow the forester to identify and retain old forest characteristics already present in the stand while designing a system to ensure adequate stand regeneration to meet financial objectives.
2) Managers are exploring and evaluating the harvest of all stems within a stump sprout to achieve both volume and regeneration objectives while creating canopy gaps.
3) Stump sprout harvesting most likely mimic the natural disturbance pattern for individual tree replacement in coast redwood.
4) Silvicultural prescriptions should be viewed as a mechanism that achieves both volume production and initiates a stand response to set the path of growth and development into the future.
5) Un-even age management does not commit the entire stand to a predetermined path of growth and habitat development. It allows the forester to make adjustments at any point in the development of the stand.
6) Through the use of uneven-age management the forester is able to maintain continuous forest canopy thereby positively affecting ambient conditions in the stand i.e. shade, humidly, temperature, forest floor cover, mid-level canopy characteristics.

Premise 2

Statement: Natural disturbances are widely viewed as playing a key role in defining old forest characteristics. Many of those features include peculiar traits exploited by various species of terrestrial wildlife and flora.

Question 2a

What specific habitat elements do you view as being uniquely characteristic to coastal redwood forests?

Key findings

The respondents each identified several habitat characteristics of coastal redwood that they are mindful of during their management decisions. These generally can be categorized into biotic and abiotic characteristics.

Biotic Elements	Abiotic Elements
Trunk hollows (goose pens) the result of multiple burns. Not unique to coast redwood but difficult to recruit under current fire suppression regimes.	Soil types, depth, slope and aspect of management unit and how these conditions affect species composition and tree growth.
Broken tops, deformed trunks, large woody debris caused by lighting, wind, disease and pests (in hardwoods) etc.	Rock outcroppings and shallow soils in the middle and southern portions of the range. Steep slopes and numerous 1st order streams common throughout the region.
Reiterative branching unique of older trees and difficult to recruit using modern silvicultural time frames.	Influences of past fire events (natural and induced) on stand composition and structure.
Multiple layered canopy with redwood and Douglas-fir being dominant.	
Ability to sprout, a unique characteristic for a North American conifer.	
Longevity, compared to other species found in the redwood region.	

Question 2b

What specific management practices (if any) have you applied or come to recognize that best create specific wildlife habitat feature(s)?

Key findings

1) Timber harvesting allows for the creation of canopy gaps of any desired size and shape. This freedom allows for canopy management using timber harvest to achieve regeneration goals as well as meeting wildlife management objectives.
2) White woods are most likely to provide the greatest opportunity for rapid nest cavity recruitment. Recognizing the role of white woods, in addition to hardwoods, for habitat element maintenance and recruitment can assist a manager achieve desired wildlife habitat goals.
3) Timber harvesting provides for a source of down and dead wood of any desired size and soundness.

Question 2c

From your experiences, are there any habitat elements that are easily recruited through silvicultural practices?

Key findings

A number of habitat elements are widely recognized as being relatively easy to recruit. These elements include:

1) Dead and down wood;
2) Large trees can easily be retained;
3) White woods are easily regenerated and retained;
4) Timber harvesting creates soil disturbance which aids in the germination of many botanical species;
5) Slash and litter are easily recruited which provides for nutrient cycling and erosion prevention in addition to cover for small mammals and herps.

Question 2d

From your experiences, are there any particular habitat elements that are particularly difficult to recruit through silvicultural practices?

Key findings

1) All respondents recognize the difficulty in recruiting trunk hollows (goose pens) associated with repetitive fire scarring. Subsequently, they further acknowledged the importance of trunk hollows as a habitat element and expressed a desire to see applied research projects designed to address this question.
2) Each of the interviewees recognized the difficulty in recruiting and maintaining phenotypically inferior trees in the stand. This paradigm is entrenched namely that retaining any inferior tree will be viewed as "high-grading". Though an important consideration, overly aggressive sanitation policies can inhibit the recruitment of habitat elements often associated with less thrifty trees.
3) The other most notable characteristic not readily recruited through management are those elements directly associated with age i.e. reiterative branches, bryophyte colonization, and rotten logs. Most recognize the importance of allowing these conditions to develop over time.

Premise 3

Statement: Some natural disturbance patterns may not be easily mimicked by silvicultural practices i.e. fire, landslides. (These questions were designed to explore the practitioner's management approaches in light of the fact that some variables may be out of their control.)

Question 3a

In this time of aggressive fire suppression, how do you manage forest fuels? Can silviculture affect fuel loads? If so, how?

Key findings

There is strong agreement that silviculture should not be viewed as a surrogate practice that can always be substituted for fire. It is further recognized that fire serves as a catalyst in many forest processes such as nutrient cycling and the formation of key habitat elements as well as potentially depletion of forest nutrients and downstream eutrophication. However, there was strong consensus among those interviewed that silvicultural practices can be used to mitigate fuel loading in the absence of fire. Specifically, silviculture and timber harvest activities are often aimed at reducing wildland fire fuels:

1) Lopping of slash is a common practice among RPFs working in areas where aesthetics and fuel suppression are equally important.
2) Tractor crush. As the name implies, the machinery used in timber harvest is used specifically to reduce the height of slash and other residual vegetative materials generated by harvesting.
3) Harvest activities that reduce ladder fuels are widely viewed as a positive activity associated with active silvicultural manipulations.
4) Windthrow. All of those interviewed recognize the positive relationship between silviculture and tree spacing as a means of inhibiting the spread of fire into the crowns. Additionally, several individuals further recognize the importance of incorporating naturally occurring fuel breaks into their silvicultural designs. Windthrow and other naturally occurring breaks in the vegetation across the landscape are generally viewed as opportunities that should be incorporated into management designs to maximize their effectiveness to limit the spread and impact of wildland fires.

Question 3b

How do you discourage the recruitment of less desirable tree species using silvicultural practices in absence of other natural disturbance regimes?

Key findings

Respondents viewed this question more broadly to include all less desirable species, not just trees.

1) Canopy management to maintain shade. Since all of the participants for this project are utilizing un-even aged management they acknowledged the relationship between canopy management and the role of shade on the forest floor to inhibit the recruitment of some less desirable species into the forest canopy i.e. tanoak (*Notholithocarpus (Lithocarpus) densiflorus*). Subsequently, respondents further acknowledged that maintaining high shade component creates a greater chance of recruiting other less desirable species that are more shade tolerant i.e., grand fir (*Abies grandis*).
2) Species management using market conditions. Where applicable, particularly in the management of less desired conifers, positive market conditions often provide an opportunity to mark a stand to reduce the number of undesired trees and thus reduce potential seed sources for future recruitment.
3) Neighbor awareness program. The Arcata Community Forest has initiated a neighbor awareness program aimed at increasing public consciousness to reduce the planting and introduction of exotic and noxious plant species on

properties adjacent to the forest. By involving broader community participation, the managers of the forest hope they have been effective in slowing the recruitment of many less desirable species from the surrounding urbanized area.

Question 3c

Is fire a useful tool? Is it realistic to assume that fire can be used effectively?

Key findings

Yes. Fire was unanimously viewed as a useful tool. Cited as the "missing piece" in modern forestry practices, fire is seen as a key element in shaping the structure and composition of coastal redwood forests by all of the respondents. There was further consensus that serendipitous fire occurrences i.e. lightning strikes, are generally viewed favorably if conditions allow for low-intensity burns.

Premise 4

Statement: There may be differences in social preferences vs. scientific data for desirable characteristics of old forests. It is important to identify obstacles that exist that serve as an impediment to improving active management practices aimed at maintaining or recruiting old forest characteristics in redwood stands.

Question 4a

Are there treatments or other considerations that we have not discussed that may be important in recruiting old forest characteristics and function while meeting landowner expectations?

Key findings

Several pragmatic factors were identified by the respondents that regularly affect how the best intentions of an RPF can be negatively influenced. They include:

1) Logging contractor decisions.
2) Cable yarding considerations.
3) Harvesting techniques and landowner expectations.
4) Roads, landings and yarding corridors.
5) Mill Infrastructure and availability
6) Disincentive to produce large logs.
7) Newly introduced pests and pathogens (SOD).

Question 4b

Have you identified/delineated areas with High Conservation Values or other old forest characteristics? Have you articulated your management treatments in these areas in a management plan or some other document?

Key findings

In every case, interviewees have identified areas or elements of High Conservation Value (HCV). Generally, the larger ownerships/parcels tended to have their HCV areas/elements delineated in landscape plans, while smaller, non-industrial ownerships used the NTMP as the vehicle to identify HCV components. The most commonly identified and/or delineated HCV areas or elements included:

- Old growth trees & stands.
- Riparian areas.
- Wet areas.
- Threatened and endangered (T&E) species sites.
- Special project areas i.e. arbon sequestration sites.
- Scenic corridors.

Discussion

Little is known about how old redwood forests developed over time. Information on the development of redwood stands is important for determining if second-growth forests can develop old forest characteristics. The results of the survey suggest that periodic entries into a stand can place the stand on a pathway toward achieving some of the aspects of an older forest. This is supported by Hunter and Parker (1993) who wrote old forests experience intervals of repeated small-scale disturbance events rather than a single disturbance event. They were able to illustrate the episodic nature of gap formation, the links between canopy tree biology and gap properties, and the relationship between topography and disturbance regime. They found half of the 80 canopy gaps in an old redwood forest to have resulted from more than one disturbance event. It appears that for redwood forests, the gaps created by small-scale disturbances contribute to the overall structural complexity of the forest, but do not affect the long-term composition of the overstory layer (i.e., redwood remains the dominant overstory species) (Sugihara 1996).

Fire is considered a primary factor in shaping the structure and composition of old growth forests. The exclusion of fire is viewed by all interviewed as a principle constraint in our ability to recruit certain components found in older forests.

Older forests are more complex than metrics that are limited to tree size, basal area and volume growth can accurately describe. Subtleties such as bark configurations, limb and branch configurations, epiphytic plant communities, trunk hollows (both conifers and hardwoods), persistent, large down woody materials (redwoods), mid and sub-canopy plant communities, and soil deposition and recruitment create a synergy that is very difficult to mimic in time frames comfortable for human acceptance. The best we can hope to accomplish is to retain and recruit (when possible) any of the remaining older forest characteristics lost during the period of intense timber harvesting of the 19th and 20th century under the constraints of the 21st century regulations.

The properties visited are not uniquely challenged when trying to address restorative actions similar to many other projects on the north coast who are concurrently wrestling with the condition of their lands. Collectively the lands and the practitioners surveyed believe that restoration and economic return on investments is a positive approach to addressing environmental and ecological issues associated with recruitment of old forest characteristics over time.

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