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The influence of timber harvest on the structure and composition of riparian forests in the Coastal Redwood region

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ABSTRACT

The composition and structure of riparian forests in the coast redwood region were analyzed in relation to the length of time since timber harvest, and the width of riparian buffer zone. Ten sites were sampled in the central range of the coast redwood forest type within a variety of post-harvest age groups and riparian buffer zone widths. Data was collected using randomly selected sample plots adjacent to perennial coastal steams. Correlation Fisher's *r* to *z* tests and two-tailed *t*-test were used to examine the relationship between the sample variables and the experimental parameters "years since harvest", and "width of buffer." Results indicate that canopy cover was negatively correlated to "years since harvest" with the highest level of canopy cover found on the youngest sites and the lowest level found on the old-growth sites. The hardwood to conifer dominance ratio and the basal area of *Alnus rubra* (red alder) were correlated negatively to both "years since harvest" and "buffer width" indicating that timber harvest favored hardwood species. Late seral associates such as *Oxalis oregana* (redwood sorrel), *Anthyrium filix-femina* (lady fern), and *Vaccinium parviflorum* (billberry) were found preferentially in older forests and sites with wider buffer zones, while non-native species such as *Hedera helix* (English ivy), *Pampas cortedaria* (pampas grass), and *Myosotis latifolia* (forget-me-not) were found preferentially in younger forests and areas with smaller buffer zones.

1. Introduction

Forests dominated by coast redwood (*Sequoia sempervirens*) are limited to a narrow band (8–75 km wide) along the coast of northern California and southern Oregon in North America. These forests provide habitat for a variety of threatened and endangered species including salmonids such as coho salmon (*Oncorhynchus kisutch*), chinook (*Oncorhynchus tshawytscha*), and steelhead (*Oncorhynchus mykiss*). Extensive harvesting began in these forests in the middle of the 19th century and has continued to the present. Early logging took place using hand tools and oxen, later replaced by stream technology, and finally modern tractor logging. Prior to 1973, and the passage of the California Forest Practices Act, timber harvest operations impacted stream corridors directly. Since that time harvesting has been limited within riparian forests, and logging equipment no long operates within stream channels. The legacy of timber harvest within riparian areas is complex, however, and must be understood more thoroughly if current restoration and management goals are to be achieved.

The effects of timber harvest on forest stand structure and composition can be both profound and prolonged (Bergstedt and Milberg, 2001; McDonald et al., 2008). In coast redwood forests, canopy cover, basal area, species richness, and the dominance of *S. sempervirens* (coast redwood), exhibited significant impacts from logging as much as 100 years following harvest (DiGiovanni, 1971; Hageseth, 2008). In addition to the direct effects of logging on forest stands that have been harvested, adjacent stands can be affected as well. In coast redwood forests, timber harvest can affect stand density, species composition, and tree height in adjacent stands to a depth of 200 m (Russell and Jones, 2002). Timber harvest increases solar radiation and exposure of trees to evaporative stress resulting in changes to species composition and forest structure in neighboring stands (Chen et al., 1992).

The influence of logging on neighboring stands is of particular interest when harvesting takes place in, or adjacent to, a riparian zone. Riparian communities within coast redwood forests differ from their upland counterparts with regard to species composition and management history. Though *S. sempervirens* out-competes other coniferous species on sites with strong riparian influence, hardwoods such as *A. rubra* (red alder) and *Salix* sp. (willow) are common on stream banks, and can contribute significantly to the total basal area of a stand (Frazey and Wilzbach, 2007). The relatively high dominance of hardwood species versus coniferous species in riparian communities is due, primarily, to their adaptation to recurrent flood and sandy saturated soils (Russell

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et al., 2003; Russell and McBride, 2001). However, management inputs such as timber harvest may also favor their presence in a stand. The proliferation of hardwood species following logging is common resulting both from the adaptation of those species to disturbance, and the preferential harvesting of coniferous species (Mollot et al., 2007).

The management of riparian forests is of concern not only because of their distinct character in relation to their upland counterparts, but also because of the aquatic systems that depend on them. In recent years the direct and indirect effects of timber harvest on riparian systems within coast redwood forests have become an increasingly important management issue. A perceived correlation between logging activities and declining anadromous fish populations has led to a debate on the possibility of increasing the current width of stream side protection zones as described in section six of the California Forest Practice Rules (California Department of Forestry and Fire Protection, 1999). The relationship between salmonid populations and dominance of *Alnus* versus *Sequoia* is unclear (Frazey and Wilzbach, 2007). However, increases in temperature, seasonal streamflow, subsurface flow, erosion, and suspended sediment within streams have been noted following logging on a number of sites (Lewis, 1998; Lisle and Napolitano, 1998). Habitat for aquatic wildlife may also be affected by timber harvest operations through the simplification of stream channels and changes in large woody debris (LWD) inputs (Bisson, 1987). In riparian buffer strips adjacent to timber harvest edges logging significantly influences the availability of LWD, as well as tree fall rates which in turn affect the rate of LWD input into streams (Benda et al., 2002; Webster et al., 2008). In addition, timber harvest adjacent to riparian forests increases solar radiation thereby influencing steam temperature (Dignan and Bren, 2003).

Because riparian forests are distinct in their structure and composition, and because they function as an interface between aquatic and terrestrial communities, an in-depth study of timber harvest effects in this forest type was essential. The study was conducted to test the hypothesis that terrestrial habitat features related to the habitat of threatened salmonid species including forest composition and structure, solar radiation, and the occurrence of LWD were significantly effected for an extended period of time both within and adjacent to timber harvest areas. In order to address this hypothesis variables associated with the factors listed above were correlated to the period of time since the last timber harvest, and the width of existing riparian buffer zones.

2. Methods

Data was collected on 10 sites along perennial streams in the coast redwood forest in order to better understand the direct and indirect impacts of timber harvest on riparian vegetation. The effects of harvest on forest composition and structure within riparian zones were analyzed to determine if the length of time since timber harvest and the width of the riparian buffer zone were correlated with canopy cover, solar radiation, the ratio of hardwood to conifer dominance, the occurrence of individual species, and the recruitment of LWD into stream channels.

Data was gathered on 10 study sites adjacent to perennial streams in order to measure the influence of post-harvest regeneration time "years since harvest" and the width of riparian buffer zones "buffer width" on forest structure and composition following timber harvest. Ten sites were selected so that the physical and ecological features were as similar as possible. All sampling was conducted on class-2 streams (Strahler, 1952) with bank full width between 1 and 3 m and surrounding vegetation dominated by *S. sempervirens* (coast redwood) in Northern California, United States.

Table 1
Study site characteristics.

Study site	Years since harvest	Buffer width (meters)
North Fork Caspar (1991)	10	60
North Fork Caspar (1990)	11	60
South Fork Caspar	29	60
Brewery Creek	110	30
Little River	100	0
North Fork Caspar (1900)	100	0
Russian Gulch	100	0
Redwood Creek	NA	NA
Wadell Creek	NA	NA
Montgomery Creek	NA	NA

Study sites were located in the central part of the range of the coast redwood forest between Mendocino County in the north and Santa Cruz County in the south (Table 1). Sites were selected to create the broadest range of post-harvest age groups and buffer width. Because of the abundant data available on the history of timber harvest in Jackson Demonstration State Forest the Caspar Creek drainage in Mendocino County was selected for four of these sites. Four of the remaining six sample areas were also located in Mendocino County on lands managed by the California Department of Parks and Recreation. Two of these, Little River and Russian Gulch, were harvested in the 1890s. All marketable trees were removed on these sites down to the stream bank as timber harvest rules regulating harvesting in riparian areas had not yet been established. In contrast, the Brewery Creek drainage, though harvested in the same era, was only partially harvested due to the difficulty in removing timber on steep slopes with limited equipment resulting in a strip of old-growth trees 50–200 m wide along both sides of the creek. Montgomery Creek was never harvested and represents one of the best examples of an old-growth redwood forest in Mendocino County. The two final sites, Redwood Creek and Wadell Creek, were selected as old-growth reference sites. Redwood Creek is the main drainage in Muir Woods National Monument in Marin County, and Wadell Creek flows through Big Basin State Park in Santa Cruz County. It was necessary to choose these geographically distinct reference sites due to the lack of any other old-growth coast redwood stands in Mendocino County.

Thirty $10\ \text{m} \times 10\ \text{m}$ (0.01 ha) square sample plots were randomly selected for each study site and located using a handheld GPS receiver. Sample plots were located with the center 5 m from the stream adjacent to stream channel perpendicular to the direction of stream flow (Fig. 1). Data was collected on each plot to describe the composition and structure of the existing stand as well as physical characteristics of the site. Slope, aspect, tree canopy cover (estimated with a spherical crown densiometer), and solar radiation (measured with a solar pathfinder) were recorded at the center of each plot. The occurrence and abundance of each tree species was recorded within each sample plot, as well as the dbh (diameter at breast height) of all individuals greater than 1 m in height. Trees less that 1 m in height we identified and counted as seedlings. Percent cover was determined for all understory species, including shrubs and herbs, using ocular estimates. In addition, LWD (woody material greater than 10 cm in maximum diameter, and 1 m in length) within the stream channel, adjacent to the plot, was measured and recorded.

The data gathered using these procedures was used to compare sample variables between sites and between groups of sites based on timber harvest history "years since harvest" and width of the riparian buffer area "buffer width". A Fisher's r to z test was used for an initial correlation test. This test was conducted with data from the seven sites that had experienced timber harvest at some point in their history including four Casper Creek sites, Brewery