

Effects of Timber Harvest on Fog Drip and Streamflow, Caspar Creek Experimental Watersheds, Mendocino County, California¹

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Abstract

Within the second-growth redwood forest of the Caspar Creek watershed, fog drip was measured in 1998 at 12 sites where heavy fog drip was expected. The following year, two one-ha plots were each instrumented with six randomly sited 1.35 m² fog-drip collectors and one additional collector in a nearby clearcut. Fog-drip totals were highly variable, ranging from zero to 18 mm per event (mean = eight mm) and 0.2 to 99 mm (mean = 39 mm) during the 1999 season. Within the one-ha plots, fog drip under the canopy was only three mm greater than accumulations in the clearcut at one site and not significantly different at the other. Given the annual average precipitation of 1170 mm, fog drip does not appear to strongly influence groundwater recharge and baseflow processes at Caspar Creek. These results are consistent with streamflow measurements. From 1971 to 1973, 65 percent of the timber volume in the South Fork was selectively cut, and from 1985 to 1992, 50 percent of the North Fork basin was clearcut. Annual water yield and summer flows increased following both timber harvests, indicating that the effects of reduced rainfall interception and transpiration exceed that from the loss of fog drip.

Key words: fog drip, hydrologic processes, streamflow, timber harvest

Introduction

The summer fog that blankets California's north coast is an ecologically important characteristic of the region as it moderates temperatures and brings water to the plants and animals occupying this seasonally arid landscape. The coast redwood is limited to a narrow belt between central California and southern Oregon in large part because of the prevalence of summer fog. Advection fog forms when westerly winds move warm moist Pacific air over cooler coastal waters, causing air temperatures to drop and condensation to occur. This stratus layer may travel onshore and far inland, depending on the strength and direction of the prevailing breeze and local topography. Eventually, fog dissipates due to the warmer temperatures of the drier inland air mass. Foliage intercepts and absorbs some of this fog water while some droplets coalesce and are delivered to the ground as fog drip. This process is not unique to the north coast. Perhaps the earliest fog drip accounts date back to the legendary magic "rain tree" of the Canary Islands, an endemic laurel uprooted in 1610 that has inspired both legend and popular tradition (Gioda and others 1995). Scientists have measured fog drip at a variety of locations around the world,

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including both coasts of South America, Mexico, Canada’s maritime coast, northern Kenya, Australia, and northwestern United States (Azevedo and Morgan 1974; Dawson 1996, 1998; Harr 1982; Huntley and others 1997; Ingraham and Matthews 1988, 1995; Jacobs and others 1985; Kittredge 1948; Oberlander 1956; O’Connell 1975; Vogelmann 1973; Yin 1994).

In the redwood region, published values dating back more than 50 years vary greatly (*table 1*). More recently, researchers have used isotopic analyses of rain and fog water in comparison to groundwater and plant water to quantify the relative contributions of each source (Dawson 1996, 1998; Ingraham and Matthews 1995). According to Dawson (1998), fog inputs may account for as much as 10 to 45 percent of total water input to California’s coastal redwood forest. Ingraham and Matthews (1995) found evidence of groundwater recharge due to fog drip at their most coastal site on the Point Reyes Peninsula. Other studies suggest fog is hydrologically significant, as well. Reduced summer streamflows following timber harvest in western Oregon have been attributed to the loss of fog drip (Harr 1982, Hicks and others 1991, Ingwerson 1985). On the basis of such studies, a Sonoma County judge recently banned logging on a 13-acre parcel because the removal of the tall redwoods might reduce groundwater recharge, thereby impacting domestic well water yields (Benfell 2003).

Table 1—Fog-drip measurements in the redwood region.

Region	Fog drip (mm/day)	Study duration (days)	Source
Coastal Oregon	2.3	126	Kittredge 1948
San Francisco Peninsula	1.2 to 37.4	40	Oberlander 1956
Orick, Humboldt Co.	0 to 2	70	Freeman 1971
Eel River Valley	0.1 to 9.2	46	Azevedo and Morgan 1974
Muir Woods	0 to 1	56	Jacobs and others 1985
Klamath River	5*	1095	Dawson 1998

* 3-yr average annual fog drip of 447 mm occurring on average 88.2 fog-days per year.

In view of the potential influence of fog drip on the water budget, a study was instituted at the Caspar Creek Experimental Watersheds on the Jackson Demonstration State Forest, Mendocino County, to assess the importance of the process in this watershed.

Methods

The Caspar Creek Experimental Watersheds are located approximately seven km from the Pacific Ocean and about 10 km south of Fort Bragg at 39°21'N 123°44'W (*fig. 1*). Elevation ranges from 37 to 320 m. Climate is wet and mild, with an average annual precipitation of 1170 mm and mean monthly air temperatures ranging from 6.7 to 15.6 °C. Stratus fog frequently inundates the watersheds during the summer when rainfall is scarce.

In 1998, a pilot study was initiated to determine if fog drip was measurable beneath the forest canopy of the Caspar Creek watersheds. Sampling sites were established where field observations suggested fog drip was likely at locations 4 to 9 km from the ocean and across a range of topographic conditions. Eleven sites were selected under second-growth trees and one under an old-growth redwood. Between

four and seven four-inch diameter one-liter cylindrical collectors were mounted on stakes approximately 18 inches above the ground surface at each site. Five sites were located along exposed ridges, four were near-ridge, and the remaining three were at lower elevations near the channel (*fig. 1*). No attempt was made to randomly sample the entire topography. During the months of June through September, fog-drip accumulations were measured volumetrically on those days when night or morning fog was observed along the coast. Measurements were delayed until the first workday following weekends and holidays. A recording rain gauge documented the onset and duration of fog drip at a single location.

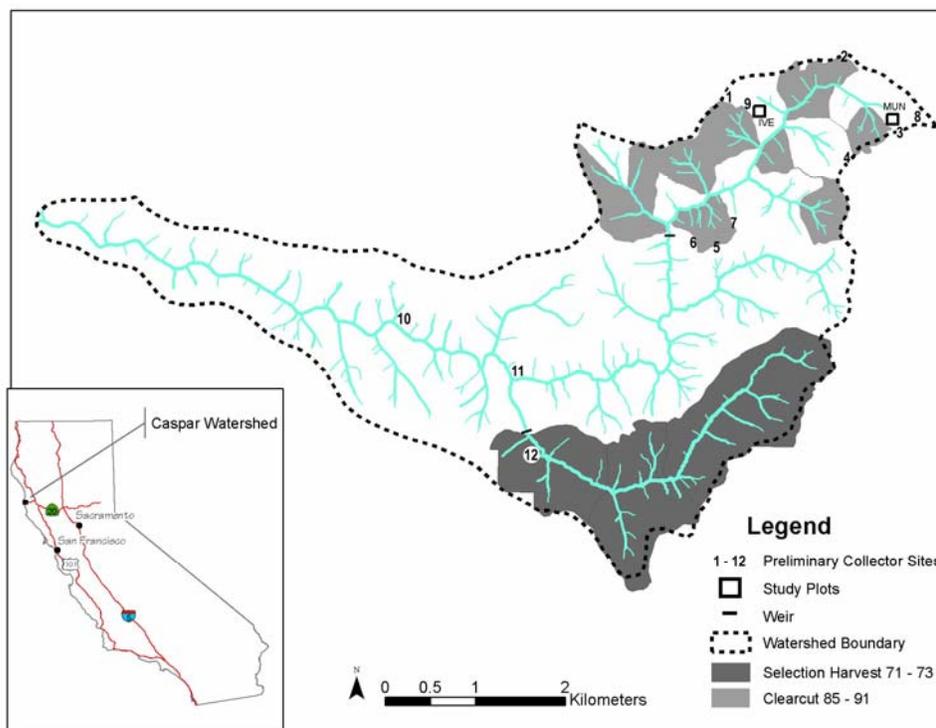


Figure 1—Caspar Creek watersheds, harvest areas, and fog-drip sampling sites.

In early August, 12 of these collectors were replaced with square platform collectors constructed of painted plywood. These were installed at a 25° angle to facilitate drainage, producing an effective area of 1.35m². Yields from these platforms were collected in a covered bucket. Two additional platform collectors were installed in nearby clearcuts.

After measurable fog drip was documented and the efficiency of the platform collectors confirmed during 1998, a sampling plan for determining the within-stand variation in fog drip was designed and implemented at two one-ha plots as part of a larger study to assess the role of foliage interception within the North Fork of the Caspar Creek watershed (Reid and Lewis 2006). The plots were established within 120-yr-old second-growth stands dominated by coast redwood (*Sequoia sempervirens* (D. Don) Endl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Sites were selected to span the range of stand class and density conditions within the North Fork while facilitating the instrumentation of a sample site in an adjacent clearcut. The IVE plot is located on a southeast-facing slope at an elevation

of 220 m and supports a forest stand having a basal area of 240 m²/ha. The other, MUN, is on a north-facing slope located 1.5 km to the east at an elevation of 270 m and has a basal area of 268 m²/ha (*fig. 2*).

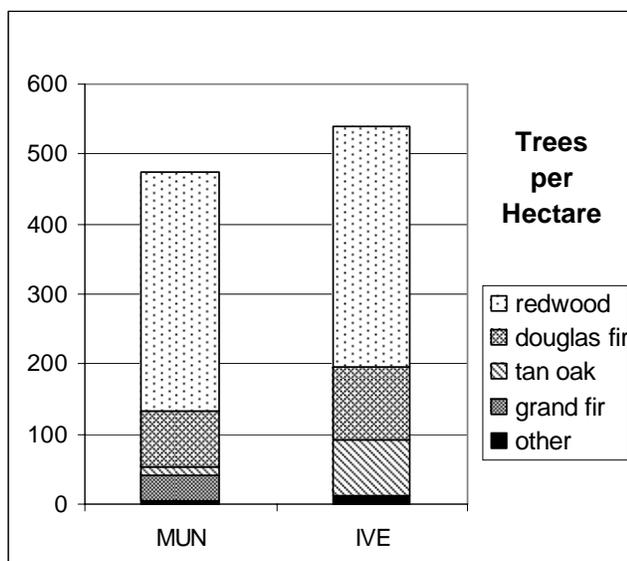


Figure 2—Stand composition in two North Fork sampling plots.

Six platform collectors were randomly located in each plot while two additional collectors (each paired with a standard eight-inch tipping bucket rain gauge) were situated in a nearby clearcut. Drainage from each platform collector was routed to a plastic barrel suspended from a load cell wired to a data logger recording at five-minute intervals. In addition, manual measurements were continued at five of the 1998 fog-drip sites and, on a less frequent schedule, at the platform collectors. Twenty-four-hour totals (noon to noon) were calculated for each collector and compared to rain gauge records. Equipment problems with two load cells eliminated one canopy collector at both IVE and MUN from this analysis. The Students *t*-test ($p < 0.05$) was used to detect a difference in fog-drip event yields between the open collectors and the mean of the five under-canopy collectors at each plot.

Results

Climatic observations indicate the presence of fog during one third of days during June through September of 1998 and 1999. After eliminating events for which rainfall was detected at the three standard rain gauge sites, 24 events were determined to have produced fog drip in 1998 and 29 in 1999. Typically, fog drip began after 1800 pst, peaking around 0600 pst and ending before noon (*fig. 3*). In 1998, site-specific fog-drip yields varied from zero to 13 mm per single 24-hr event and were as high as 91 mm for the season. Similarly, in 1999 the maximum yields were 18 mm for a single event and 99 mm for the season. Differences among gauges suggest that fog drip is greatest at ridge locations most exposed to fog-laden westerly winds (*fig. 4*).

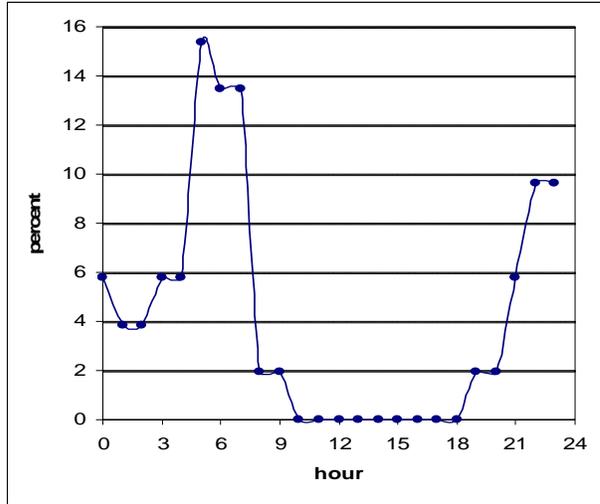


Figure 3—Temporal distribution of fog drip at one site during a three-week period in August 1998.

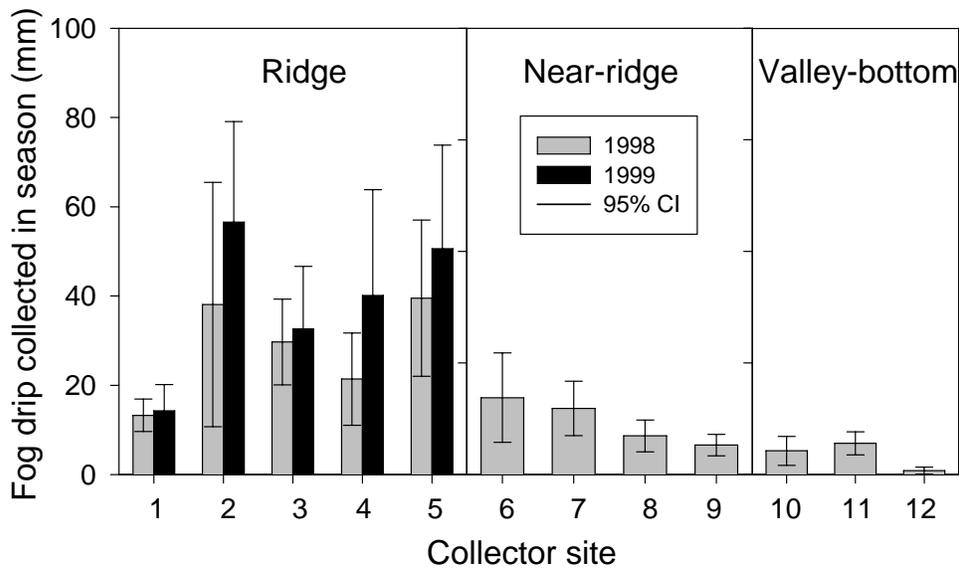


Figure 4—Seasonal fog-drip yields from 12 sites (61 sampling points). The mean value and 95 percent confidence interval for each site is shown.

Plot data from MUN and IVE produced far less dramatic results. Comparing the mean accumulation under the canopy to that in the nearby opening (*fig. 5*), fog-drip yields were greater under the canopy than in the opening at MUN, but not significantly different at IVE ($p < 0.05$; Students *t*-test). At MUN, fog drip enhanced moisture input by about 3 mm during the 29 fog-drip events of 1999. When the four days of summer rain are included in the analysis, no significant difference between water inputs in the forest and the open were detected ($p < 0.05$; Students *t*-test).

Discussion

Clearly, results from ridge-top fog collectors and casual observations of heavy drip trickling down the forest ridge roads suggest that fog drip can be appreciable in certain locations under certain conditions. Just as clearly, the absence of significant drip at other locations—including the two heavily-instrumented plots—indicates that other portions of the watershed are not strongly influenced by the process. These results confirm the occurrence and variability of fog drip in the Caspar Creek drainage and contrast to Dawson’s data documenting much greater fog-drip accumulations directly under large redwoods along the much foggier Klamath coast. In addition to differences in site proximity to the ocean, collector type and stand versus tree sampling are important factors affecting these disparate results.

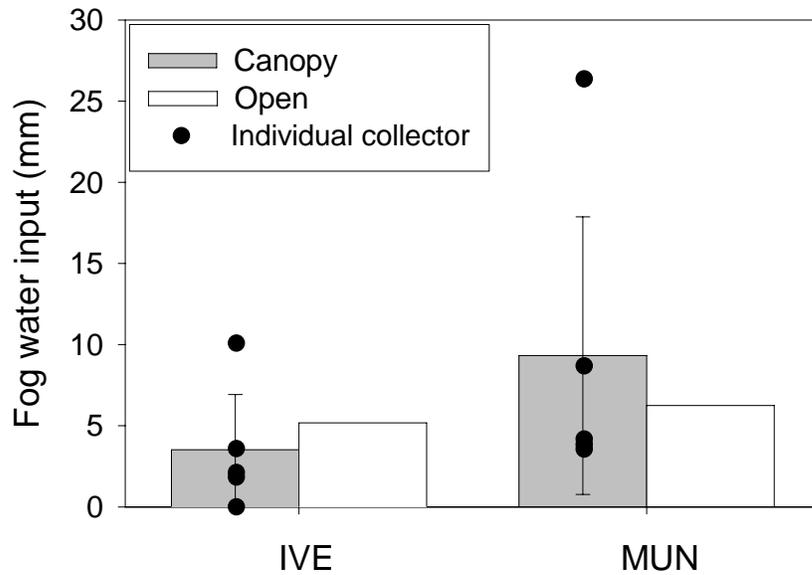


Figure 5—Fog water inputs (mm) for June to September 1999 beneath the canopy and in the open. The mean (shaded bar), individual collector values, and 95 percent confidence limits are shown.

The ridge-top gauges provide a non-statistical indication of probable maximum fog-drip rates for the experimental watershed. The mean values for the five ridge-top sites averaged 39 mm per year during the four month sampling period. This value is only three percent of the mean annual precipitation (1170 mm) at Caspar Creek, and so would represent only a minor influence on the annual water budget. However, only five percent of the annual rainfall (62 mm) occurs between May and September, so the average fog drip at ridge-top sites would augment dry-season precipitation by 63 percent. Water budget calculations described by Reid and Lewis (2006) suggest that transpiration over this period averages 162 mm under forested conditions, while runoff accounts for 27 mm. Even on ridge-top sites, where measured fog-drip rates are highest, a decrease in summer water input of 39 mm due to loss of fog drip would be over-balanced by a decrease in transpiration of 162 mm. At sites farther from the ridge, the relative influence of decreased transpiration would be even greater.

At Caspar Creek, research focuses primarily on investigating the effects of timber harvest on streamflow processes. Data from long-term streamflow monitoring

at Caspar Creek can be used to test the validity of these results. Two major investigations of logging effects on Caspar Creek streamflow have been completed in the past several decades. Both of these conclude that streamflow increases after logging. The first evaluated changes in streamflow following selection harvest of 65 percent of the South Fork watershed timber volume. Annual yield increases averaged 838 m³/ha (1973 to 1982) and minimum flows increased 38 percent (1972 to 1978). The second evaluated the effects of clearcutting 50 percent of the North Fork basin. Again, annual yields increased 730 m³/ha (1993 to 1997) and minimum flows by 148 percent (1990 to 1997). Additional instrumentation in the North Fork further indicated increased soil pipe flow, increased groundwater levels, and reduced soil moisture tensions within the cut units during the summer season (Keppeler 1998).

Streamflow increases are explained by reduced transpiration and interception in the logged areas. Reid and Lewis (2006) suggest clearcut logging in the North Fork watershed resulted in a 28.7 percent increase in effective precipitation at the forest floor (in other words, the forest would have intercepted 22.3 percent of the rainfall recorded at the rain gauge) and transpiration reductions estimated at 325 mm per year. Using these estimates, and assuming that all slash is burned and regrowth is not yet significant, one can calculate the expected average annual change in water availability to the North Fork watershed in the years immediately following logging:

$$\Delta W = L[0.223(PPT) + ET - FOG]$$

where

ΔW = additional available water (mm) for a year,

L = watershed area clearcut (percent),

PPT = annual precipitation,

ET = annual evapotranspiration from a mature second-growth stand,

FOG = annual fog water input to a mature second-growth stand.

Using the average annual rainfall from two North Fork gauges between 1993 and 1997 (1314 mm), a percentage cut of 37 percent, assuming no recovery of vegetation, and not including the loss of fog drip, the annual water balance of the North Fork was theoretically enhanced by as much as 229 mm (or 17 percent of average annual precipitation) during this five-year post-harvest period. In comparison, monitoring data indicate that increases in North Fork annual yield averaged 73 mm for five years after partial clearcutting. This equates to a *net* increase of 197 mm (73/.37) per year in streamflow from the clearcuts during this five-year post-harvest period—the net effect of reduced transpiration, interception, fog drip, and changes in soil moisture and groundwater storage. Differences between expected and observed changes are attributable to changes in soil moisture and groundwater storage, progressive hydrologic recovery from revegetation over the five-year period, annual variations in weather, and, especially near the ridges, some decrease in fog drip.

Reid and Lewis (in preparation) estimate post-drip canopy storage to be about one mm. A similar value is expected for potential storage of condensed fog before drip is significant. The effect of this wetting of the canopy is important in ameliorating moisture stress by direct foliar absorption and reduced transpiration losses. In 1999, fog drip occurred during 29 days, but solar radiation data collected at Caspar Creek indicate the presence of fog or cloud cover during more than a third of

days in the study period. Although the canopy may not have been saturated to the point of drip by every fog event, enhanced humidity and reduced insolation and air temperatures moderated actual evapotranspiration rates.

Conclusions

Direct measurements of fog-drip inputs to the Caspar Creek watersheds indicate it is a highly variable, but minor component of the annual water balance at this site. Although this result contrasts with a few studies that have shown fog water to be a significant portion of the water balance, it does not contradict other results. The climatic and topographic conditions that influence the distribution and frequency of fog along the California coast vary considerably, so fog drip is expected to be more significant at some sites than others. Certainly, fog has a pervasive effect on redwood ecology, but the indirect effects of reduced evapotranspiration are probably larger than the direct effects of fog-drip inputs to soil moisture and groundwater at all but the most coastal locations. Only by a more comprehensive research effort might the spatial and temporal variations of fog water inputs in this region be more fully defined.

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