THE ROLE OF DROUGHT IN THE HYDROLOGIC RESPONSE OF A MANAGED COAST REDWOOD WATERSHED

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Extended Abstract— In California, projections of intensifying wet-dry extremes and shifts in precipitation seasonality suggest that hydrologic droughts may become more frequent in the coast redwood region. An increase in hydrologic drought frequency may be particularly problematic for aquatic species that rely on flow in headwater streams during the region's June-October dry season.

We used a 55-year record of precipitation and streamflow to explore the relationship between meteorological drought and hydrologic drought in the Caspar Creek Experimental Watersheds in north coastal California. The 4.24-km^2 South Fork (SF) and 4.73-km^2 North Fork (NF) watersheds are managed for research and timber production. Originally clearcut and burned prior to 1904, second-cycle selection-harvest occurred on the SF from 1967 to 1973 and partial-clearcutting on the NF from 1985 to 1992.

The only significant trend in annual precipitation and precipitation-adjusted runoff over the period of record was for SF runoff (*p=0.02*). It is not yet clear whether the decline in SF runoff is a response to forest regrowth, climatic variation, or a combination of both.

Time series of the standardized precipitation index (SPI) (McKee and others, 1993), the standardized runoff index (SRI) (Shukla and Wood, 2008), and monthly anomalies of precipitation and streamflow were derived from long-term monthly precipitation and runoff records. Using the 12- and 24- month SPI time series, we defined severe drought as a period of negative SPI where the drought index value was less than -1.5 for 12 months or more. Two severe drought events were identified: 1976-1978 (D77) and 2013-2014 (D14). For each drought, we calculated the drought duration as the number of consecutive months with SPI less than zero, severity as the cumulative SPI for that duration, and intensity as the mean SPI for that duration (Mishra and Singh, 2010). We defined the extreme as the minimum SPI for the duration and persistence as the length of time the SRI remained less than the SPI following the end of drought.

For both droughts, the maximum cumulative precipitation deficit exceeded mean annual precipitation and required more than five years of rainfall surpluses to be ameliorated. SPI values declined to more than two standard deviations below the mean, indicating "extreme" drought conditions during each event. Although the two droughts were meteorologically comparable, D14 was more severe and more persistent than D77. Accumulated monthly runoff anomalies, as percent of annual mean, were larger than those of precipitation and larger in D14 than D77 (Table 1). We identified an apparent lag in baseflow recovery of less than two years following the cessation of meteorological drought (Figure 1). Also, we found that hydrologic drought developed in the absence of severe meteorological drought as a result of an 8-year period of below-normal rainfall suggesting even mild multi-year precipitation deficits may propagate to amplify hydrologic extremes.

Our analyses suggest timber harvest may have ameliorated the hydrologic drought in the first five years after the SF selection harvest, but, four decades later, intensified the second hydrologic drought during subsequent forest regeneration and expected increased transpiration. The largest increases in post-harvest streamflows were observed on the SF in 1978 as D77 ended. In contrast, D14 occurred during a period of regrowth and recovering transpiration rates after the NF had been partially-clearcut and broadcast burned (1985-1992), and pre-commercially thinned (1993-2001). Thus, this hydrologic drought was more severe on both recovering watersheds.

These droughts produced variations in the magnitude and timing of fall flows that may have impacted the spawning success of the state- and federally-listed coho salmon (*Oncorhynchus kisutch*). Multiple regression analyses using the prior water year's SPI suggest that antecedent conditions from the previous one to two years influenced early-season runoff response (expressed as the initial 10 percent exceedance flow of the season, Q10, an approximation of the lower flow threshold for salmonid passage). For water years preceded by relatively dry conditions a mean of 327

mm was required to generate the Q10. When prior year conditions were wetter, Q10 was generally exceeded with significantly less rainfall. Harvest intensity and age were also significant factors ($p=0.05$). In 1978, the NF reference watershed did not attain Q10 until cumulative rainfall reached 484 mm, while the recently logged SF watershed attained Q10 after just 170 mm of precipitation. In 2014, it was not until March, after 444 mm of precipitation had occurred, that this threshold was exceeded—too late in the year for the fall-run coho to spawn in this coastal stream.

These results suggest that forest management treatments and climatic variations interact to influence hydrologic responses to meteorological droughts. Questions remain regarding the relative importance of various mechanisms.

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Literature Cited

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Table 1—Drought characteristics of the 1977 and 2014 droughts: 12-month and 24-month Standardized Precipitation Index (SPI12, SPI24) and Standardized Runoff Index for North Fork Caspar Creek (SRI12NF and SRI24NF) and South Fork Caspar Creek (SRI12SF and SRI24SF), the accumulated monthly anomaly of precipitation and North and South Fork streamflow (percent of mean annual) and the month and year the maximum anomaly occurred for each variable and drought.

a.	1977 Drought: JAN 1976-JAN 1978			2014 Drought: JAN 2013-NOV 2014		
Index	SPI12	SRI12NF	SRI12SF	SPI12	SRI12NF	SRI12SF
Duration, months	25	24	23	23	38	38
Severity	-45.3	-45.0	-35.4	-32.2	-44.0	-47.0
Intensity	-1.8	-1.9	-1.5	-1.4	-1.2	-1.2
Extreme	-3.19	-3.38	-2.83	-3.54	-3.22	-3.46
Persistence, months		10	0		19	19

b.	1977 Drought: MAR76-JAN79			2014 Drought: SEP12-DEC15		
Index	SPI24	SRI24NF	SRI24SF	SPI24	SRI24NF	SRI24SF
Duration, months	35	43	25	40	50	57
Severity	-47.1	-41.6	-26.3	-51.9	-56.6	-63.3
Intensity	-1.3	-1.0	-1.1	-1.3	-1.1	-1.1
Extreme	-2.72	-2.38	-1.99	-2.17	-2.22	-2.26
Persistence, months		7	0		21	21

c.	Precipitation	NF	SF	Precipitation	NF	SF
Accumulated Monthly Anomaly, %	-102	-173	-149	-113	-206	-211
month-yr	Nov-1977	Dec-1977	Nov-1977	Nov-2015	Nov-2015	Nov-2015

Figure 1—Variations in drought indices for precipitation (SPI12) and runoff (NF-SRI12 and SF-SRI12) and accumulated monthly precipitation anomaly (AMPA, % of monthly mean) during two droughts: D77 and D14.