CALIFORNIA FISH AND GAME
California Fish and Game 87(2):51-60 2001

ASSOCIATION OF FALL-RUN CHINOOK SALMON REDDS WITH WOODY DEBRIS IN THE LOWER MOKELUMNE RIVER, CALIFORNIA

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Surveys in the lower Mokelumne River during 1994–1995 indicated that fall-run chinook salmon, *Oncorhynchus tshawytscha*, redds associated with woody debris (WD) had smaller substrate and greater mean depths. Also, the proportion of redds associated with WD was negatively related to stream gradient. Female chinook salmon selected spawning sites containing WD in some instances. Woody debris may make less desirable habitats more suitable for spawning and may allow greater concentrations of redds on suitable sites.

INTRODUCTION

Over the past 2 centuries, human activity has greatly altered the inland waterways of the Pacific West. Development on aquatic systems and excessive harvest of natural resources, including gravel, timber, and fish, have depleted native salmonids. Habitat condition is a key factor regulating salmonid production and can limit the carrying capacity of these streams for fish (House and Boehne 1985). Thus, management programs are aimed at increasing naturally spawning wild stocks through rehabilitation of severely altered habitats.

The presence of woody debris (WD) in streams is a potential source of log jams that could block river flow, impede navigation, reduce flood-control capacity, destabilize levees, and impair passage of migrating adult salmonids. As a consequence of these concerns, many maintenance programs are aimed at the removal of WD from stream channels, even though WD may play an important role in the creation and maintenance of fish habitat throughout entire river systems (Bisson et al. 1987).

Few studies have explored the importance of WD to spawning salmonids, although the influences of instream structure on juvenile salmonids has been extensively discussed in the literature (Ward and Slaney[1] 1979, Ward and Slaney 1981, House and Boehne 1985, Fuller 1990). Woody debris is also an important energy source for benthic invertebrates (Anderson et al. 1978, Bisson et al. 1987), a principal food of juvenile salmonids (Mundie 1974). Woody debris provides cover for adult

[1] Ward, B.R. and P.A. Slaney. 1979. Evaluation of instream enhancement structures for the production of juvenile steelhead trout and coho salmon in the Keogh River: Progress 1977 and 1978. Fisheries Technical Circular 45, Ministry of the Environment, Fish and Wildlife Branch, Vancouver, British Columbia, Canada.

salmonids (Bjornn and Reiser 1991), and low gradient sediment deposits upstream of debris accumulation can provide suitable spawning substrate in sediment-poor drainages (Everest and Meehan 1981). Woody debris may create scour pools with tail-outs appropriate for redd construction in sediment-rich streams (Sedell et al. 1982). House and Boehne (1985) described the accumulation of superior salmon spawning material near gabion structures placed in East Fork Lobster Creek, Oregon to mimic large debris. House and Crispin (1990) evaluated the economic value of large WD in salmonid habitat, but only estimated numbers of adult salmonids from sampled juvenile populations.

Heavily wooded streams of the Pacific West have supported genetically and morphologically distinct strains of salmonids (Beacham and Murray 1987, Beacham et al. 1988). The amount and size of woody material that each forest contributes to stream habitats is directly linked to the vegetative composition of the riparian zone and, as some streams may lack the woody structure present in the old growth watersheds, they may also lack habitat structure for fish (Flebbe and Dolloff 1995).

The purpose of this study was to examine the association of fall-run chinook salmon, *Oncorhynchus tshawytscha,* redds with WD in the lower Mokelumne River below Camanche Dam. Specifically, I evaluated the association between WD and depth, stream velocity, gradient, and occurrence of salmon redds.

STUDY AREA

The lower Mokelumne River below Camanche Dam is characterized by alternating bar-complex and flatwater habitats, with a gradient of approximately 0.17 m/km. The drainage area below Camanche Dam consists of 87 km^2 of mostly agricultural and urbanized land (Fig. 1) (USGS 1977). Two reservoirs, Pardee and Camanche, are located 77 and 59 km upstream from the extension of tidewater influence. In 1964, the Mokelumne River Fish Hatchery was constructed at the base of Camanche Dam to mitigate loss of chinook spawning habitat above the dam. Lake Lodi, a 191.7-hectare reservoir, is formed by Woodbridge Dam, 40 km downstream from the hatchery. A fish ladder allows adult salmonids to pass above Woodbridge Dam to the section of river from Lake Lodi to Camanche Dam. Annual monitoring of adult chinook salmon passing Woodbridge Dam is conducted by trapping and video monitoring in the ladder from 1 October through 31 December (Marine and Vogel[2] 1996).

Annual chinook salmon redd surveys are also conducted from 1 October through 31 December (Hartwell[3] 1995). Primary spawning habitat is located in the 8-km river reach downstream from Camanche Dam to the town of Clements (Fig. 1). Riffles

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[2] Marine, K.R. and D.A. Vogel. 1996. Mokelumne River chinook salmon and steelhead monitoring program, 1994–1995. Natural Resource Scientists, Inc., Red Bluff, California, USA.

[3] Hartwell, R. 1995. Upstream migration and spawning of fall run chinook salmon in the Mokelumne River, 1994. East Bay Municipal Utility District, Orinda, California, USA.

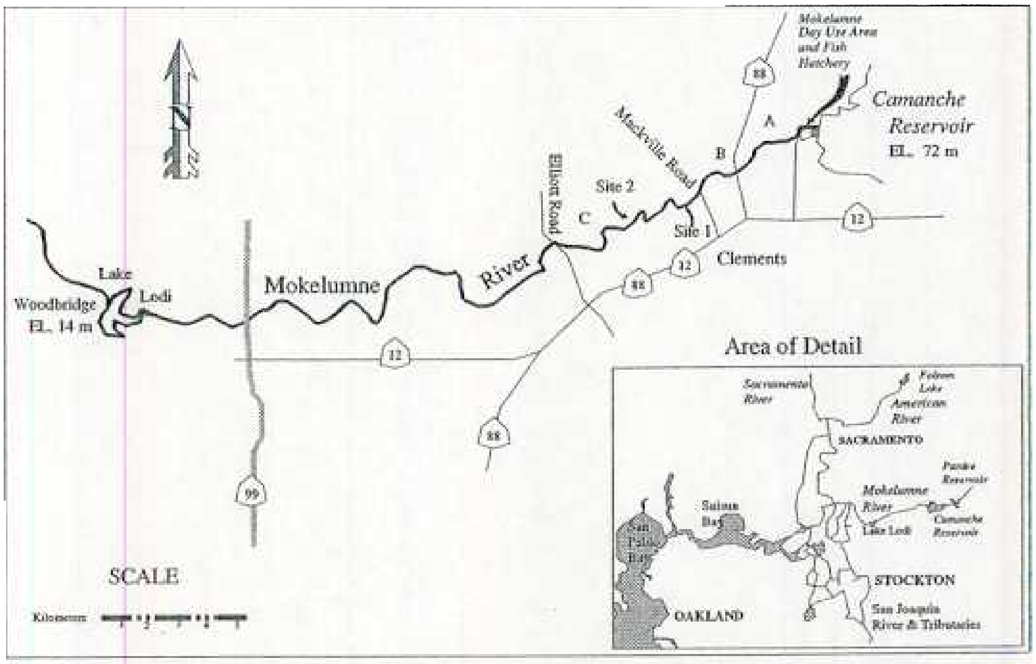

Figure 1. The lower Mokelumne River between Camanche and Woodbridge dams, San Joaquin County, California, showing chinook salmon redd sampling sections (A, B, C) and sites (1, 2).

and pools in this area are bordered by alternating strips of white alder, *Alnus rhombifolia*; Fremont cottonwood, *Populus fremontii*; valley oak, *Quercus lobata;* and sandbar willow, *Salix exigua*. Downstream of Clements, the river becomes a narrow, meandering stream confined by sparsely vegetated levees along both banks with few spawning riffles of poor quality.

Average water release from Camanche Dam during the 1994–1995 spawning season was 6.8 m^3/s. From 7 October to 31 December 1994, 3,221 adult chinook salmon were counted by trapping and video monitoring at the Woodbridge Dam fish ladder (Hartwell[3] 1995). The Mokelumne River Fish Hatchery recorded 1,920 adult salmon returning to the hatchery during the 1994–1995 season (Hartwell[3] 1995).

METHODS

The river was separated into 3 sections: Section A, the base of Camanche Dam to Highway 88; Section B, Highway 88 to Mackville Road; and Section C, Mackville Road to Elliott Road (Fig. 1). Chinook salmon redds were observed weekly by canoe and wading from Camanche Dam to Elliott Road from 25 October 1994 to 31 January 1995. Individual redds were marked by a numbered brick placed on the tail-spill of each identified redd. River flow, redd superimposition, presence or absence of gravel berms (naturally formed gravel ridges [see Huntington[4] 1985, Shirvell 1989,

[4] Huntington, C.W. 1985. Deschutes River spawning gravel study, volume I. Final Report. Project No. 83-423, Bonneville Power Administration, Portland, Oregon, USA.

Ferren et al.[5] 1996]) and association with WD was noted for each redd. Habitat units were identified and assigned to 1 of 4 habitats (modified from Bisson et al. 1981): pools (unbroken surface, slow velocity, deep water), glides (moderately shallow water with an even flow that lacked pronounced turbulence), runs (rippled surface, fast velocity, shallow water), and riffles (stream bed substrate protruding through water surface). Depth at the upstream edge of the redd (redd depth), water velocity at 6 cm above the upstream edge of the redd (nose velocity), stream velocity (average of 20% and 80% of depth below surface), and dominant substrate types were recorded. Dominant substrates were divided into 5 classes: 1) small gravel (4–32 mm), 2) medium gravel (33–50 mm), 3) large gravel (51–64 mm), 4) small cobble (65–130 mm), and 5) medium cobble (131–250 mm) (modified from Bovee and Milhous 1978).

For purposes of this study, any vegetative material with diameter >5 cm and length >30 cm was characterized as WD. This was the minimum size visible from aerial photographs. Any redd constructed in a site where its shape, depth, view from terrestrial predators, or associated turbulence was altered by the debris was considered associated with WD. Two or more observers were needed to arrive at the same conclusion to make this assessment.

Two sites (Site 1: 1,377m^2, Site 2: 1,044m^2) were used to evaluate specific location of WD and chinook salmon redds. These sites were selected based on their accessibility to foot surveys and aerial photography and consisted primarily of run and glide habitat. Both sites, located in Section C (Fig. 1), were mapped by aerial photography and ground crews. Woody debris and redds were noted for each site. Because the average area of a chinook salmon redd is approximately 9 m^2 (Bjornn and Reiser 1991, Hartwell[3] 1995), the sites were separated into grids of 9-m^2 squares. Each square was categorized as containing 1 or more redds within its boundaries and containing WD within its boundaries. If a redd was located in more than 1 square, it was counted in the square that contained the majority of the redd.

I used chi-square analysis to assess the relationship between 1) proportion of redds associated with WD and berms, 2) WD association and redd substrate size, 3) WD association and habitat types, and 4) the frequencies of redds and WD at Sites 1 and 2 (Zar 1974). I used simple linear regression to assess the relationship between 1) the proportion of redds associated with WD and average gradient in each reach and 2) proportion of newly constructed redds associated with WD and average weekly discharge from Camanche Dam (Gardner et al.[6] 1995). I also used Student's t to assess the relationship between redd association with WD and 1) redd nose velocity, 2) stream velocity, and 3) redd depth.

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[5] Ferren, W.R., P.L. Fiedler, and R.A. Leidy. 1996. Wetlands of the central and southern California coast and coastal watersheds. A methodology for their classification and description. Final report prepared for U.S. Environmental Protection Agency, Region IX, San Francisco, California, USA.

[6] Gardner, R.S., W.T. Harris, J. Weber, and R.E. Stein. 1995. East Bay Municipal Utility District Water Supply Section statistical report, fiscal year ending June 30, 1995. East Bay Municipal Utility District, Oakland, California, USA.

RESULTS

Of the 773 chinook salmon redds observed in the 3 sections, 223 (29%) were associated with WD. The proportion of redds associated with WD was negatively related to stream gradient ($F = 446.2$; df = 1, 1; $P = 0.03$) (Fig. 2). The proportion of redds associated with WD that were constructed on berms was not significantly different from those away from berms ($\chi^2 = 0.70$, df = 1, $P > 0.50$). A significant difference was observed in the proportion of redds associated with WD in different habitat types ($\chi^2 = 7.89$, df = 2, $P = 0.02$) (Table 1).

At both Sites 1 and 2, a disproportionate number of redds was associated with WD ($\chi^2 = 14.5$, df = 1, $P = 0.0001$; $\chi^2 = 10.8$, df = 1, $P = 0.001$). At Site 1 (43 redds) (Fig. 3), 44% of the plots with WD contained redds, whereas only 25% of the total plots contained redds. At Site 2 (40 redds) (Fig. 4), 60% of the plots with WD contained redds, but only 29% of the total plots contained redds.

Approximately 2 weeks into the study, a large cottonwood snag floated into Site 2, settling across the 1st berm and spanning over 50% of the channel. Undercutting

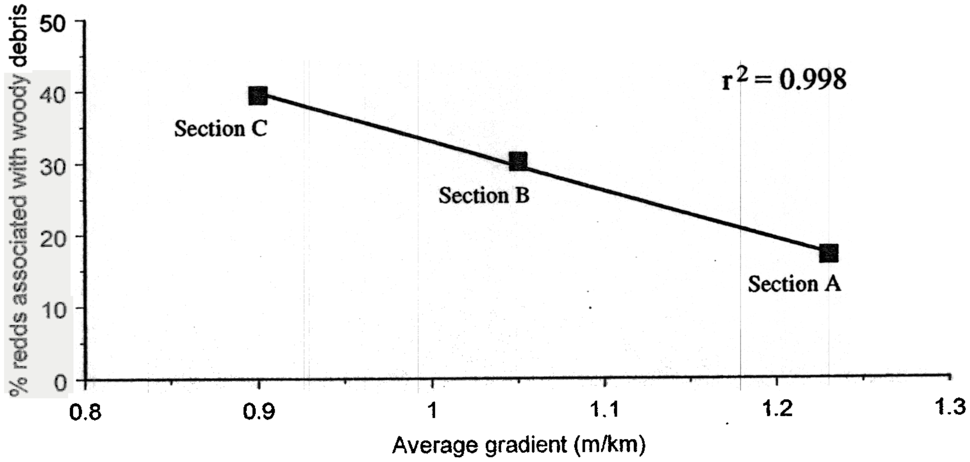

Figure 2. The relationship between percentage of chinook salmon redds associated with woody debris and mean river gradient at each section sampled on the lower Mokelumne River during the 1994–1995 spawning season.

Table 1. The association of chinook salmon redds with woody debris (WD) and several habitat variables in the lower Mokelumne River during the 1994–1995 spawning season.

Habitat Type	Redds associated with WD	Redds not associated with WD
Glide	105 (34%)	200 (66%)
Pools	No redds	No redds
Riffle	97 (25%)	295 (75%)
Run	21 (28%)	55 (72%)
On Berm	40 (26%)	115 (74%)
Off Berm	183 (30%)	435 (70%)

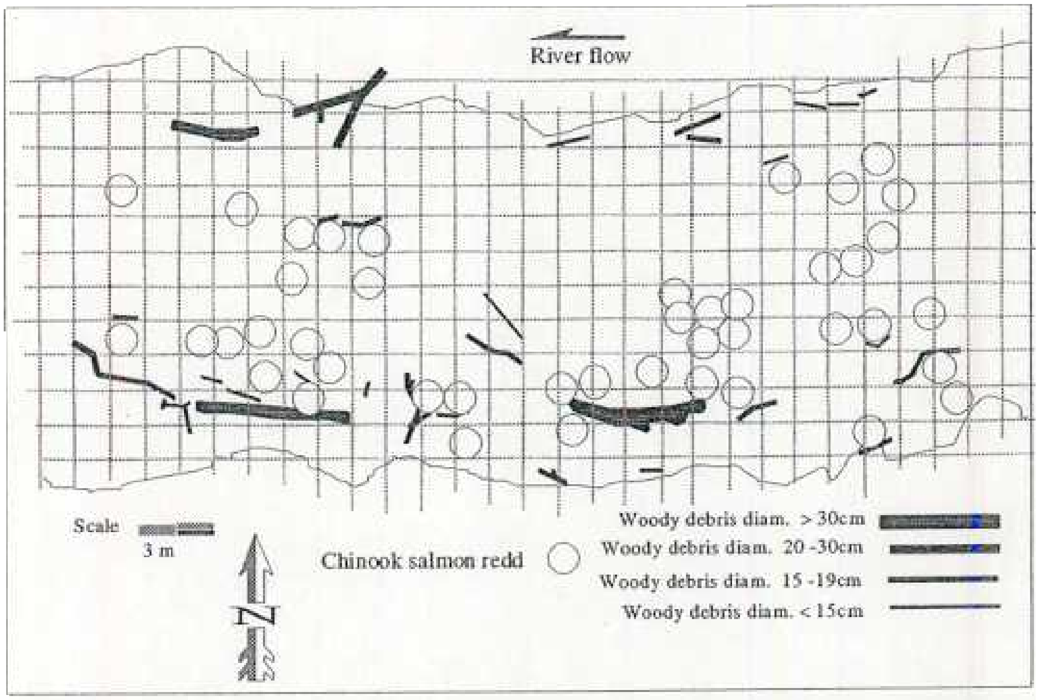

Figure 3. Location of chinook salmon redds and woody debris at Site 1, lower Mokelumne River, 1995.

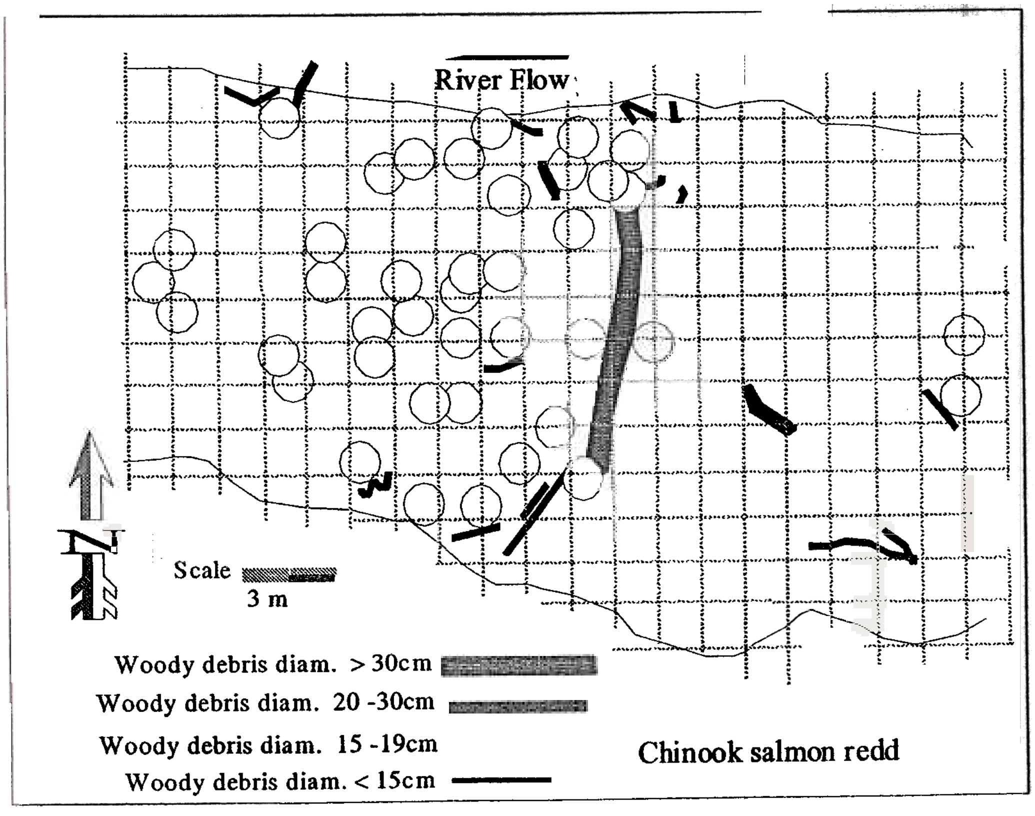

Figure 4. Location of chinook salmon redds and woody debris at Site 2, lower Mokelumne River, 1995.

occurred at this site, damaging or destroying 2 of the earliest redds. However, several other redds were constructed in front and in the 2 channels formed on either side of the snag.

Flows from Camanche Dam were gradually increased from approximately 5.7 m^3/s during the 1st week of sampling to approximately 6.8 m^3/s by the 3rd week. The proportion of newly constructed redds associated with WD was not related to mean weekly river flow ($F = 0.95$; df = 1, 8; $P = 0.36$). However, the percent of redds associated with WD peaked twice during the spawning season. These peaks appeared to lag 1 week behind peaks of weekly precipitation in the lower watershed (Fig. 5). A relationship was observed between weekly precipitation and the following week's proportion of redds associated with WD ($F = 10.82$; df = 1, 9; $P < 0.01$).

Mean depth of redds associated with WD (0.55 m) was significantly greater than for those not associated with WD (0.48 m) ($t = 2.10$, df = 87, $P = 0.04$). Stream or nose velocities were not significantly different at redd sites with and without WD ($t = 0.42$, df = 155, $P = 0.68$; $t = 0.10$, df = 156, $P = 0.92$).

Mean substrate size for redds associated with WD (50 mm) was significantly smaller than for redds not associated with WD (89 mm) ($t = 2.34$, df = 169, $P = 0.02$).

DISCUSSION

According to Bisson et al. (1987), when input of debris is from bank undercutting of living trees or the direct fall of dead trees, the debris tends to be spaced at fairly random intervals along small channels where flow is insufficient to carry the debris downstream. However, in most streams with strong flows, there is some degree of clumping and the magnitude and spacing of debris clumps generally increase in a

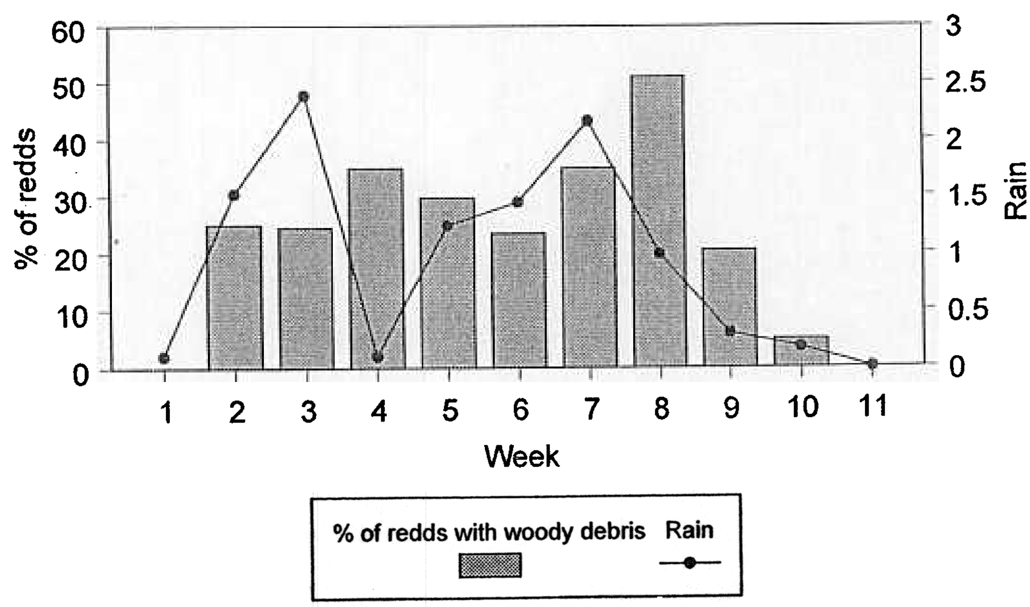

Figure 5. Comparison of the percent of chinook salmon redds associated with woody debris and weekly precipitation in the lower Mokelumne River Drainage, 25 October 1994–20 January 1995.

downstream direction. Other natural phenomena, such as beaver activity, can also affect this clumping. Previous studies indicate sediment deposits formed adjacent to WD provide suitable spawning substrate in sediment-poor drainages (Everest and Meehan 1981, House and Boehne 1985). The Mokelumne River data suggest that WD collects smaller gravel in deeper sections of the river as well. This may explain the increased association of redds with WD in a downstream direction (Fig. 2) and the disproportionate number of redds associated with WD in glide habitat (Table 1). Therefore, this clumping may be beneficial for spawning in less desirable habitats with slower, deeper water and small or fine substrate.

Whereas an increase in redd association with WD downstream may be a result of the increased amount of debris accumulation in the lower sections, selection by chinook salmon for specific sites containing WD was observed. The lack of difference between the proportion of redds associated with WD on berms and the proportion not on berms suggests that site selection is not a result of WD merely collecting at suitable sites.

During spawning, male and female chinook salmon aggressively defend the redd area (Barnhart 1986). Dolloff[7] (1983) suggested that visual isolation provided by the matrix of a root system reduces the frequency of aggressive encounters in other species of Pacific salmon. In the lower Mokelumne River, several instances were observed where thin branches 13–25 cm diameter were all that separated 2 female salmon simultaneously constructing redds. Furthermore, 4 females constructed redds simultaneously around a large piece of WD (>30 cm diameter) after it floated into Site 2 (Fig. 4). This debris appeared to provide visual segregation of spawning fish, although 2 of these redds, no longer occupied by the adults, were later re-used by other females. These observations suggest that WD may also be a factor in reducing aggressive behavior among spawning adults, allowing higher concentrations of redds on suitable sites.

While speculative, several other aspects of WD may also be attractive to spawning chinook salmon. In order for water to move around a large object, its velocity must increase. The water then slows after it passes the object and forms a back-eddy. This may be appealing to adult chinook salmon in several ways. First, increase in flow immediately adjacent to the structure may provide suitable velocities for spawning that otherwise would not be present. Second, decreased flows behind the structure may provide suitable resting habitat immediately adjacent to the redd. Third, large debris may provide cover in the form of turbulence produced by these structures (Bauer and Burton 1993). Last, this turbulence may provide increased oxygen for spawning adults and may increase intergravel water exchange through redds.

Woody debris may have an effect on the size, shape, depth, and distance between redds. On several occasions, I observed female chinook salmon constructing redds in, around, and adjacent to WD, creating redds that took on the shape and length of

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[7] Dolloff, C.A. 1983. The relationships of wood debris to juvenile salmonid production and microhabitat selection in small southeast Alaska streams. Ph.D. Dissertation, Montana State University, Bozeman, Montana, USA.

the adjacent structure. Often, it appeared that females attempted to dig underneath WD, which influenced redd depth also. Sedell and Swanson (1984) have suggested that such debris may create secondary currents that sweep fine sediment away from spawning beds and this may be a factor in redd site selection. In concurrence with Sedell and Swanson (1984), the increased association of redds with WD during increased periods of rain may be an attempt by the spawning female chinook to evade the increased sediment loads during these periods. However, increased WD from wind damage during storms may simply increase the chance for association. Further studies of specific WD effects on redds, such as intergravel flows, dissolved oxygen, and reduction of aggression among spawning adults are needed.

ACKNOWLEDGMENTS

I thank the Fish and Wildlife section of the East Bay Municipal Utility District, especially R. Hartwell and J. Setka, for providing significant information for this paper. I also thank C. Vanicek, P. Moyle, L. Brown, C. Hanson and 3 anonymous referees for critical reviews of the manuscript.

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Received: 5 June 2000
Accepted: 10 December 2000