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The Effectiveness of Riparian Restoration for Improving Instream Fish Habitat in Four Hardwood-Dominated California Streams

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Abstract.—Recent reviews of salmonid habitat restoration programs have recommended that managers emphasize strategies that restore natural habitat-forming processes, such as restoring riparian vegetation, over placement of instream structures. In addition to the direct benefits of shading and providing a source for large woody debris (LWD), riparian restoration is often implemented to improve channel morphology for purposes of restoring fish habitat. However, multiple studies provide equivocal evidence that restored vegetation can lead to improved channel form within a period of years to decades. In this study, we examined the effectiveness of riparian restoration for improving channel morphology and fish habitat in four hardwood-dominated streams in Mendocino County, California. These streams support populations of steelhead *Oncorhynchus mykiss* and contain reaches with riparian corridors that were restored through exclusionary fencing implemented 10–20 years earlier. We compared channel morphology, LWD, and late-summer water temperature between the restored exclosure reaches and geomorphically similar control reaches within the same properties. Channels within exclosures were significantly narrower and had greater heterogeneity in long profile elevation than control reaches. Frequencies of LWD and debris jams were considerably greater in exclosure reaches than control reaches and were comparable to values from similar streams with mature forests. Late-summer water temperature in exclosures was within the acceptable range for steelhead, whereas water temperature in control reaches was warmer and potentially detrimental to steelhead. Riparian restoration in exclosures has resulted in quantitatively improved habitat characteristics and qualitatively different channel morphologies as compared with control reaches. The ability of vegetation to improve channel morphology in this region is probably due to frequent overbank flooding and high sediment loads. Through a comparative analysis of the cost and performance of exclusionary fencing versus those of instream structures, we propose that riparian restoration can produce instream salmonid habitat benefits that are more comprehensive, sustainable, and cost-effective than the benefits generated by instream structures.

Stocks of anadromous fish on the U.S. Pacific coast have declined significantly in the past century due to overharvesting, dams, and degradation of freshwater habitats (Nehlsen et al. 1991; National Research Council 1996; Stouder et al. 1997). To reverse declines in freshwater habitat quantity and quality, resources devoted to stream restoration have greatly increased, and millions of dollars are currently being spent on restoration projects (National Research Council 1996; Roper et al. 1997; Roni et al. 2002). Restoration strategies range from attempts to increase instream habitat functionality by placing spawning gravels or physical structures in rivers, to broader strategies focused on repairing riparian and watershed processes. Reviews of strategies to restore instream habitat through emplacement of structures have generally found little evidence that these techniques are effective or sustainable over a period of decades (Frissell and Nawa 1992; Beschta et al. 1994; Roper et al. 1994; Lassetre 1997; Miles 1998; Pretty et al. 2003). Consequently, recent reviews have suggested that restoration efforts should adopt a watershed-scale approach addressing linkages among hillslopes, roads, and the channel network, and promoting interactions between

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healthy riparian corridors and stream channels (Kauffman et al. 1997; Roper et al. 1997; Beechie and Bolton 1999; Kondolf 2000).

Intact riparian vegetation provides numerous benefits to instream fish habitat, including shading, bank stabilization, and inputs of fine organic matter and large woody debris (LWD) (Gregory et al. 1991). Because of the widespread losses of riparian vegetation (Armour et al. 1994; Kondolf et al. 1996) and the multiple benefits it provides, riparian restoration has been promoted as a key strategy for restoring the critical processes that create and maintain fish habitat (Roper et al. 1997; Beechie and Bolton 1999; Roni et al. 2002). Riparian restoration can frequently be achieved by passive methods, which entail the removal of ongoing stressors that limit natural regeneration (Briggs et al. 1994; Kauffman et al. 1995; Briggs 1997). Numerous studies and projects have demonstrated that exclosure fencing to reduce grazing and browsing pressure can result in rapid and impressive recovery of riparian vegetation (Platts 1981; Knapp and Mathews 1996; Kauffman et al. 1997; Opperman and Merenlender 2000).

Both theoretical (Ikeda and Izumi 1990) and empirical (Andrews 1984) studies of geomorphology have concluded that channels with vegetated banks are narrower and deeper than channels lacking bank vegetation. Numerous studies have reported that removal of riparian vegetation results in wider, shallower, less-complex channels (Gunderson 1968; Platts 1981). Thus, one of the common objectives for riparian restoration is the promotion of narrower and deeper channels.

Although the ability of exclusionary fencing to promote vegetative recovery has been clearly established, evidence that this recovery is followed by improvements in channel form is more equivocal (Sarr 2002). Many restoration projects report the narrowing of channels following riparian restoration, but vigorous vegetative growth can create the appearance of a narrower channel, even if channel form remains unchanged (Kondolf 1993). Therefore, qualitative assessments of channel form may produce inaccurate conclusions of recovery. Kondolf (1993) suggested that monitoring for channel recovery should involve direct measurement of channel form through cross-sections and long profiles.

Studies that include direct measures of channel dimensions following restoration have reported diverse results. Keller et al. (1978) and Duff (1977), both working on small streams in the intermountain West, asserted that restored vegetation resulted in narrower channels after 3 and 6 years, respectively. Clifton (1989) also reported channel narrowing within a 50-year-old exclosure on a second-order stream in central Oregon. Conversely, Hubert et al. (1985) found little change in channel form within a 4-year-old exclosure in central Wyoming. Myers and Swanson (1995) also found no narrowing of the channel on a Nevada stream after grazing was halted for 6 years (however, nearby grazed streams continued to widen). Working in the White Mountains of California, Kondolf (1993) reported that channel form within a 24-year-old exclosure was not different from that of grazed areas, but did observe vegetation recovery within the exclosure. In Utah, Platts and Nelson (1985) found little difference in channel widths between grazed areas and an 11-year-old exclosure; however, the channel in the exclosure had superior bank conditions and more pools, which resulted in a greater channel depth.

The diversity of results in these prior studies indicates that channel responses to restored vegetation likely vary with geographic context. In this paper, we explore the effectiveness of improving instream fish habitat through riparian restoration in hardwood-dominated streams in northern California. We examine the ability of riparian restoration to effect three primary improvements to anadromous fish habitat that are commonly used to justify this restoration strategy: (1) increased LWD, (2) cooler water temperatures, and (3) narrower, deeper, and more complex channel morphology. We compared riparian vegetation, channel morphology, LWD, and water temperature within reaches on four streams with restored riparian corridors and within similar upstream control reaches. Although not initially established as experiments, existing restoration projects were used as opportunities for learning through long-term monitoring (Kondolf 1995, 1998).

Study Sites

Restored and control reaches were located in four streams within the Russian River basin, Mendocino County (Figure 1). The streams are within California's Mediterranean-climate zone, which is characterized by cool, wet winters and warm, dry summers (Gasith and Resh 1999). Throughout this region, the majority of annual precipitation falls as rain between November and April. The riparian corridors of these streams contain few or no conifer species, and are dominated by white alder *Alnus rhombifolia,* willows *Salix* spp., California bay laurel *Umbellularia californica,* oaks *Quercus*

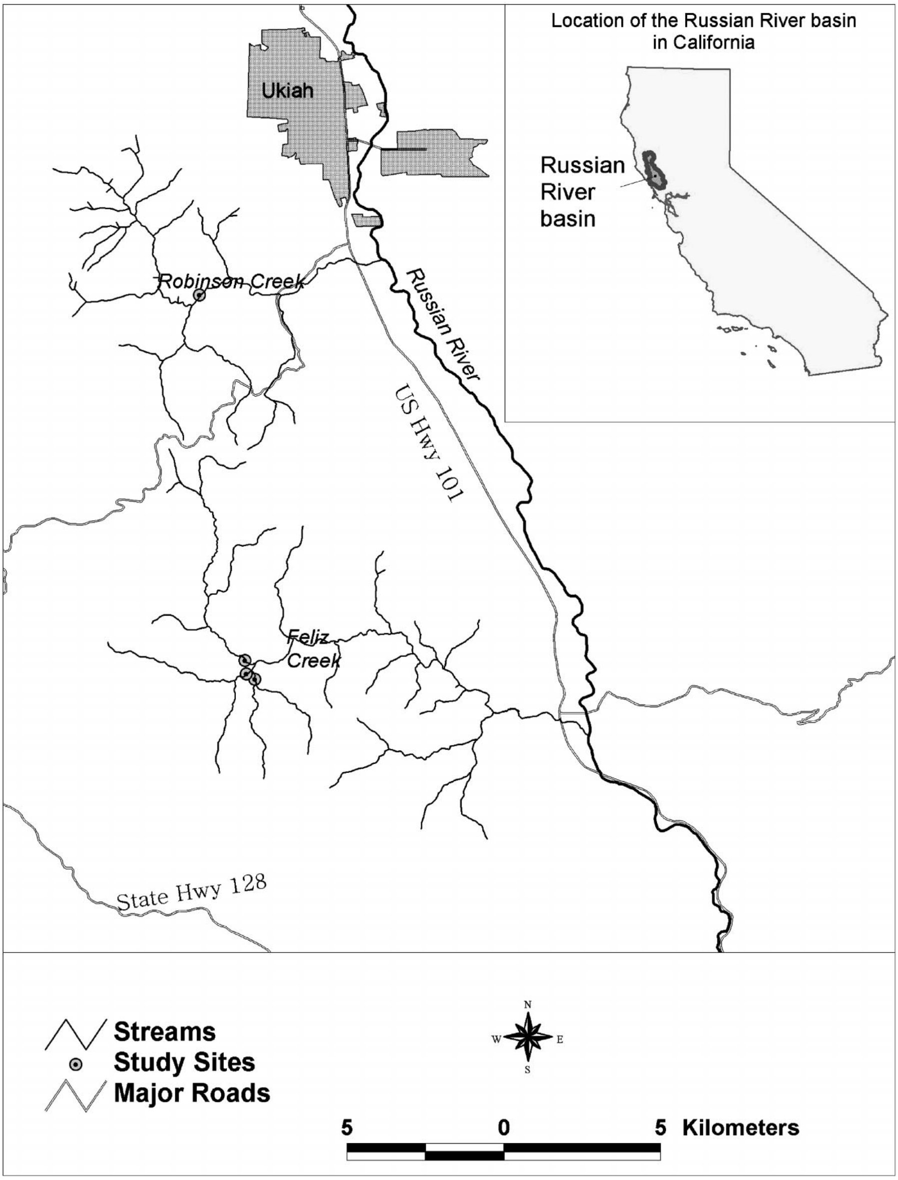

FIGURE 1.—Locations of the four study streams (Robinson Creek; North, Middle, and South forks of Feliz Creek) in the Russian River basin, Mendocino County, California.

spp., big-leaf maple *Acer macrophyllum,* and Oregon ash *Fraxinus latifolia*. The study streams provide spawning and rearing habitat for anadromous steelhead *Oncorhynchus mykiss*.

Reaches along three forks of Feliz Creek (all contained within a single property) were enclosed within deer fences in 1982: the North Fork (Feliz North), the Middle Fork (Feliz Middle), and the South Fork (Feliz South). In 1991, another landowner erected deer fencing along a reach of Robinson Creek. The riparian corridors on Robinson Creek and the three forks of Feliz Creek had almost no riparian vegetation prior to restoration. Both landowners informed us that the riparian corridors were heavily browsed by the livestock of previous owners, but neither landowner had grazed livestock since purchasing the properties (R. Morris and D. Meda, personal communication). Opper-

TABLE 1.—Drainage area and gradients of control and riparian exclosure reaches in four Northern California streams.

Stream	Drainage area (ha)	Exclosure gradient	Control gradient
Feliz Creek			
North fork	2,300	0.015	0.017
Middle fork	1,140	0.02	0.02
South fork	780	0.03	0.025
Robinson Creek	4,130	0.004	0.006

man and Merenlender (2000) provide further information on the study sites and restoration methods.

Considerable natural regeneration of woody riparian species occurred following construction of the deer fences; currently, the four exclosures contain dense stands of alder, willows, and other riparian trees (Opperman and Merenlender 2000). We selected control reaches that were upstream and adjacent to exclosures to ensure consistent ownership, drainage area, channel type, and valley form (sensu Frissell 1992). Control reaches were located on the same properties as the exclosure reaches and thus were under the same management, with the exception of the fencing, for several years prior to and since the restoration projects. Control and exclosure reaches had essentially identical drainage areas and similar gradients (Table 1).

Methods

Large woody debris.—We measured all pieces of LWD (defined as wood >1 m long and >10 cm in diameter) within the bank-full dimensions of the channel. We recorded the length, average diameter, species, and channel position of each piece of wood. Piece volume was calculated under the assumption that the item had a cylindrical shape (length $\times$ π $\times$ [average diameter/2]^2). We classified a piece of LWD as transported if it was of a different species or obviously different in size than the trees within the local riparian corridor. Debris jams were defined as accumulations of three or more pieces of LWD, and were classified according to their channel position (on the bank, partially spanning the channel, or spanning the channel). All pieces of wood within a debris jam were measured.

Riparian vegetation.—We sampled two riparian plots (one on each side of the channel) for every 100 m of channel. The plots extended 10 m along the channel and a variable distance perpendicular to the channel. The perpendicular distance was determined based on the possibility that a tree within the plot could fall and enter the stream (sensu Van Sickle and Gregory 1990). We determined the diameter at breast height (dbh), species, and slope-distance from the stream for each living tree and snag within the plots.

Channel morphology.—We compared the channel morphology of the reaches within exclosures and their paired controls. To do this, we used a surveyor's level to survey a long profile for the length of the study area. We recorded the thalweg and water surface, and surveyed four to six cross-sections within each reach (i.e., exclosure and control). Additionally, wetted channel width and thalweg depth were recorded every 10 m for the long profile. Surveys for the three branches of Feliz Creek were performed in April 2001, and Robinson Creek was surveyed in June 2001.

Temperature.—We recorded water temperature in pools within exclosure and control reaches for the three branches of Feliz Creek during late summer, when water temperatures are likely to be highest and most problematic for fish. Water temperatures were sampled on two dates: September 7, 2000 (air temperature = 38°C) and August 30, 2001 (air temperature = 30°C). All temperatures were measured between 1430 and 1630 hours. Pool temperature was recorded by placing a thermometer on the channel bed in the deepest part of the pool. We also recorded pool depth.

Analyses.—We used paired *t*-tests ($n = 4$) to compare riparian basal area, riparian tree density, LWD frequency, and LWD loading (m^3/ha of channel) between exclosure and control reaches. For channel dimensions (wetted and bank-full depths, thalweg depth), we used *t*-tests to compare exclosure and control values within a specific stream and paired *t*-tests to compare between treatments (control versus exclosure). Differences in pool temperature between control and exclosure reaches were compared by an analysis of covariance (ANCOVA) that contained treatment as a factor and pool depth as a covariate.

Results

Riparian Vegetation and Large Woody Debris

Trees were significantly more dense in the exclosure reaches (0.74 ± 0.3 plants/m^2 [mean ± SE]) than in the control reaches (0.08 ± 0.05 plants/m^2) ($t = 2.3$, df = 3, $P = 0.05$). Basal area of riparian trees within 5 m of the channel was significantly greater in the exclosure reaches (42 ± 7 m^2/ha) than in the control reaches (21 ± 8

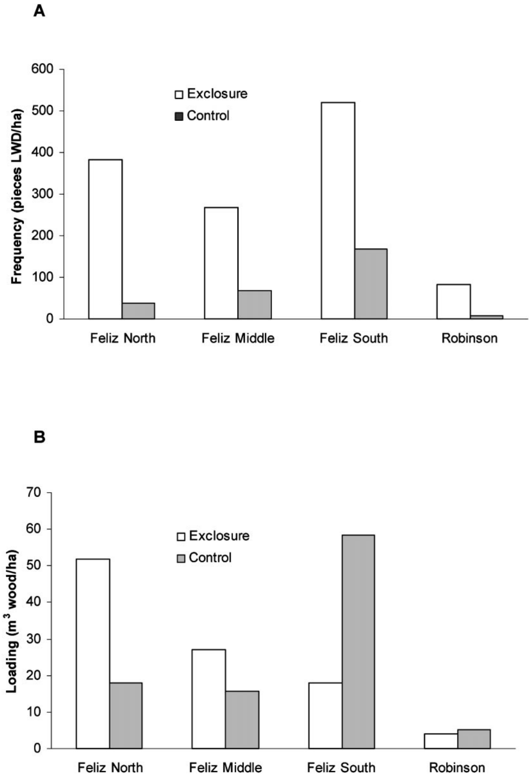

FIGURE 2.—(A) Large woody debris (LWD) frequency and (B) LWD loading per hectare of channel for paired control reaches (gray bars) and riparian exclosure reaches (white bars) in four northern California streams.

FIGURE 3.—Debris-jam frequency (number per 10 bank-full widths) for paired control reaches (gray bars) and riparian exclosure reaches (white bars) in four northern California streams.

m^2/ha) (t = 2.0, df = 3, P = 0.05). The number LWD pieces per hectare of channel area was also significantly greater within exclosures than in control reaches (t = 3.7, df = 3, P = 0.03; Figure 2A). Loading of LWD, however, was not consistently greater within exclosures (Figure 2B). Overall, the three branches of Feliz Creek had much higher LWD loading values than did Robinson Creek, which had the more recent exclosure. The greatest LWD loading among the Feliz Creek branches was within the Feliz South control reach (58.5 m^3/ha), which contained a large spanning debris jam caused by mass-wasting event from the hillslope into the channel. The second-highest LWD loading was within the exclosure on Feliz North (52.0 m^3/ha), which contained two spanning debris jams that trapped a large volume of wood.

Based on the species composition and size distribution of the LWD and riparian trees, we determined that all the LWD in Robinson Creek had been transported to the site. Large woody debris within the Feliz Creek reaches was a combination of transported wood and wood derived from the adjacent riparian corridor and hillslope.

Debris jams were five times more frequent within exclosures: 1.5 ± 0.5 jams for every 10 bank-full widths compared to 0.3 ± 0.2 jams per 10 bank-full widths (t = 3.1, df = 3, P = 0.05) (Figure 3). However, spanning jams were less frequent, and only two out of the eight study reaches contained any spanning jams; as mentioned above, the Feliz North exclosure had two spanning debris jams, and the Feliz South control reach had a single spanning debris jam. Debris jams in Feliz North resulted in locally heterogeneous gradients, and a large debris jam split the low-flow channel in two, creating a well-vegetated island (Figure 4).

Channel Morphology

Channels within the exclosure reaches had narrower bank-full widths than channels within control reaches (t = 6.5, df = 3, $P < 0.01$; Figures 5–7). Because the control reach of Robinson Creek was beginning to dry up at the time of the survey, its wetted dimensions reflect the declining flow as well as the channel morphology (Figure 5). For this reason, the paired analysis for wetted widths was restricted to the Feliz Creek branches, which were surveyed during spring base flow; we present a qualitative analysis of channel form for Robinson Creek. Cross-sections in Robinson Creek indicated that the well-vegetated exclosure reach had a more defined low-flow channel and its long profile showed more variety in channel form and depth than the control reach (Figures 7, 8). For the three branches of Feliz Creek, wetted widths were narrower in the exclosures than in the control reaches (t = 4.8, df = 2, P = 0.04; Figures 5, 6). Channels were generally deeper within exclosures than in control reaches, although this difference was not statistically significant (Figure 5).

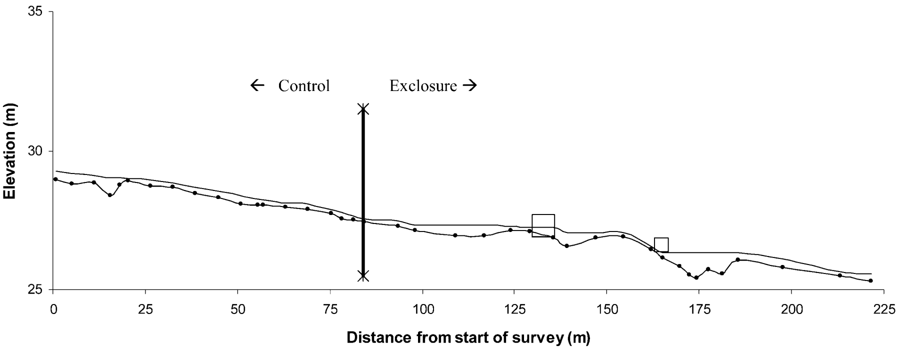

FIGURE 4.—Long profile of channel elevation for the North Fork of Feliz Creek, California. The horizontal line indicates the demarcation between the control and riparian exclosure reaches. Squares represent channel-spanning debris jams.

Temperature

Pools were significantly cooler in exclosure reaches than in control reaches. In September 2000, pools in exclosures ($n = 10$) averaged 17.7°C ± 0.3°C, whereas pools in control reaches ($n = 8$) averaged 20.2°C ± 0.4°C (ANCOVA with pool depth as the covariate, $F_{2,15} = 4.9$, $P < 0.01$). In August 2001, pools in exclosures ($n = 8$) averaged 18.2°C ± 0.5°C, whereas pools in control reaches ($n = 7$) averaged 22.7°C ± 0.6°C (ANCOVA, $F_{2,12} = 15.5$; $P < 0.01$).

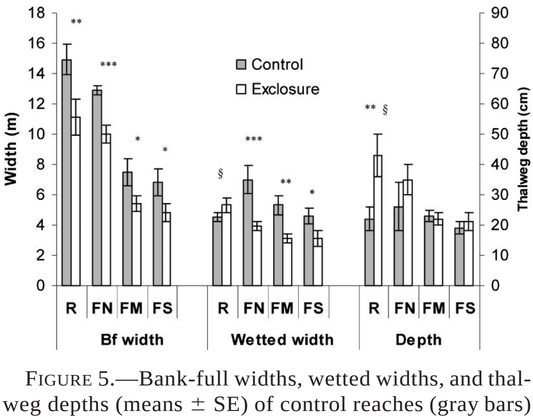

FIGURE 5.—Bank-full widths, wetted widths, and thalweg depths (means ± SE) of control reaches (gray bars) and riparian exclosure reaches (white bars) in four northern California streams (R = Robinson Creek; FN = North Fork of Feliz Creek; FM = Middle Fork of Feliz Creek; FS = South Fork of Feliz Creek). Asterisks indicate significant differences between control and exclosure reaches ($P \leq 0.10$ [*]; $P \leq 0.05$ [**]; $P \leq 0.01$ [***]). The symbol § denotes that the wetted channel dimensions on Robinson Creek were measured during the low-flow summer period, and thus reflect the declining flow.

Discussion

Postproject monitoring of riparian restoration on four streams in Mendocino County provided strong support for the ability of riparian restoration to effect improved stream habitat for fish. In addition to supplying the benefits of shading and LWD accumulation, the restored riparian corridors

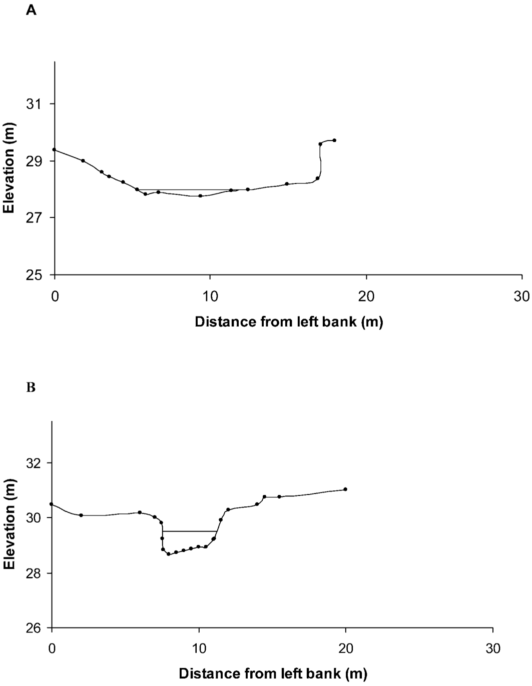

FIGURE 6.—Cross sections of the North Fork of Feliz Creek, California: (A) a typical cross section within the unfenced control reach, and (B) a typical cross section within the riparian exclosure reach, showing a narrow, single channel.

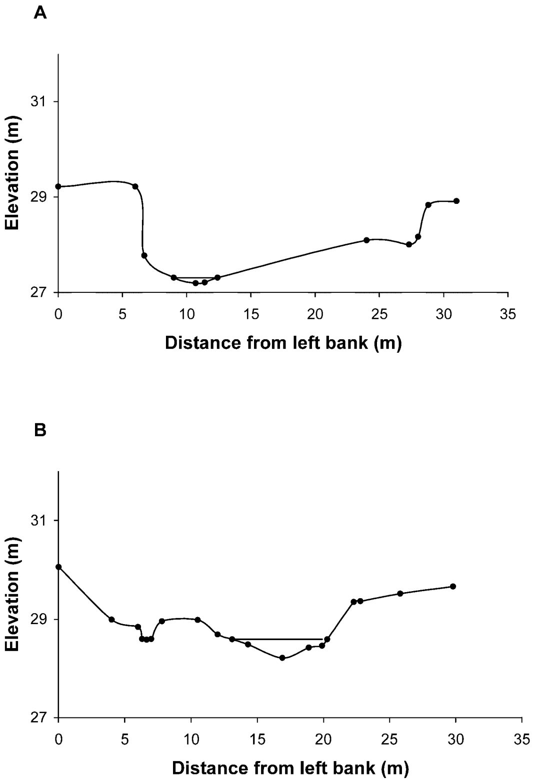

FIGURE 7.—Cross sections of Robinson Creek, California: (A) a typical cross section within the unfenced control reach, and (B) a typical cross section within the riparian exclosure reach.

apparently created narrower, more-complex stream channels.

Channel Morphology

Previous research has found equivocal support for the ability of riparian restoration to produce channel change within a period of years to decades. The range of results yielded by these prior studies suggests that practitioners cannot be certain that channel recovery will follow vegetative recovery within a reasonable time period. Inconsistent channel responses across studies are likely due to the fact that channel morphology is a function not only of bank vegetation but also a number of additional variables, such as substrate size distribution of the bed and banks, sediment load, flood history, and disturbances throughout the watershed (Frissell 1992; Kondolf 1993; Myers and Swanson 1997; Sarr 2002). For example, Kondolf (1993) hypothesized that an exclosure on a stream in California's White Mountains failed to produce channel narrowing because the stream's low sediment load and infrequent overbank flooding did not provide the conditions necessary for building banks. The four Mendocino County streams we examined are within a region characterized by very high sediment loads (Kelsey 1980; Mount 1995) and have experienced several high-flow years, which promoted the process of overbank deposition and channel narrowing. The ability of revegetation to improve channel form in a given region can likely be assessed through an analysis of a stream's hydrologic and geomorphic context; predictions could be tested and refined by monitoring restoration projects (Sarr 2002).

Postproject monitoring by comparing exclosures with selected control reaches must be viewed with some caution (Sarr 2002); clearly, the existence of pre-project surveys would strengthen inferences about channel responses to restored riparian vegetation (Downs and Kondolf 2002). However, we selected control reaches that were geomorphically similar and under the same ownership as the exclosure reaches. The fact that changes in channel form were coincident with the fence line in all four streams provides strong evidence that differences in channel form can be attributed to the restored riparian vegetation as opposed to other influences.

Large Woody Debris

Comparing restored sites with control reaches provides insight into the changes that have occurred since restoration. Greater understanding can be achieved by expanding our analysis to include more-mature forested sites from the same region, which provides information on the range of natural variability for hardwood-dominated streams (Hobbs and Norton 1996). To better understand the trajectory of LWD recovery in hardwood-dominated reaches, we compared the characteristics of LWD and debris jams in our exclosure and control reaches with values for streams within mature hardwood forests (Opperman 2002). Our exclosure reaches were much more similar to mature-forest streams in terms of LWD frequency than in terms of LWD loading. For example, LWD frequencies within Feliz North and Feliz South were comparable to the average value for mature-forest streams (490 ± 10 LWD pieces/ha; Opperman 2002). However, LWD loading values in our study were much lower than those from streams with mature riparian corridors, which averaged 100 ± 10 m^3/ha and had a maximum value of 173 m^3/ha (Opperman 2002).

The riparian trees along Robinson Creek were

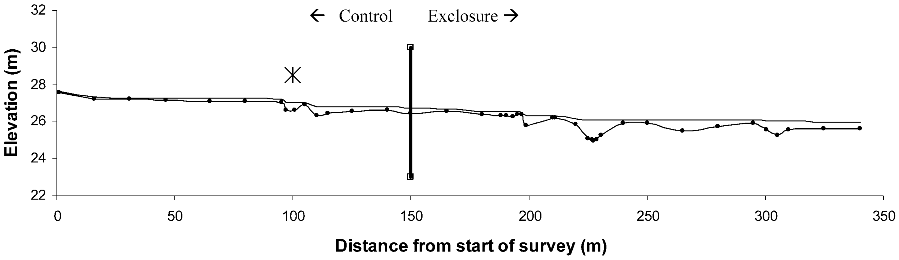

FIGURE 8.—Long profile of channel elevation for Robinson Creek, California. The asterisk indicates the location of riprap (installed to prevent bank erosion) that contributed to the formation of pools. The horizontal line indicates the demarcation between the control and riparian exclosure reaches.

less than 10 years old; frequency of LWD was approximately one-third that of mature-forest streams, and LWD loading was an order of magnitude lower. Trees within the riparian corridor of Robinson Creek were too small to provide LWD, and the only LWD within the study reaches had floated in from upstream. The three forks of Feliz Creek, with the more established riparian corridors (>20 years old), had LWD frequencies comparable to those of mature-forest streams. Loading of LWD, however, averaged only one-third of the values from mature-forest streams.

Within the three Feliz Creek branches, LWD was a combination of wood derived from the reach and wood that was deposited from upstream (or entered via mass wasting in the Feliz South control reach). Although some of the larger trees within the restored riparian corridors of the Feliz Creek branches reached a sufficient size to provide LWD (20–30 cm in diameter), mortality was generally occurring among smaller trees, and the largest pieces of LWD in these reaches were apparently transported. Nearly 80% of the LWD in the four restored reaches was deposited against trees rooted near the bank-full channel, either as debris jams or individual pieces. Thus, through this trapping function, riparian restoration can result in relatively rapid increases in the amount of LWD within a reach, even before the trees within the riparian corridor become large enough to provide LWD directly. Although bank jams were very common in the restored reaches (comparable or greater than frequencies for mature-forest streams), channel-spanning jams were rare. Channel-spanning jams have been found to be the most important mechanism by which LWD influences channel morphology, and can potentially trap and store large quantities of wood (Martin and Benda 2001; Opperman 2002).

Feliz North had the greatest LWD loading among the restored reaches, with approximately half the level from mature-forest streams. Feliz North's drainage area is twice that of Feliz Middle and three times that of Feliz South. Thus, Feliz North has the greatest transport capacity for LWD among the three branches, based on its greater width, depth, and stream power (Braudrick et al. 1997; Braudrick and Grant 2000). The increased transport capacity may have increased total LWD loading by two related processes. First, Feliz North contained the largest single pieces of transported LWD, which increased loading simply due to their size. Second, the large pieces functioned as key components of channel-spanning jams, which increased the trapping efficiency of the reach and were capable of storing large volumes of wood.

Due to the transport of larger pieces into the exclosure reach and, consequently, the formation of channel-spanning jams, Feliz North provides the best example of channel responses to restored LWD loadings. Responses included the creation of pools, formation of secondary channels, and increased heterogeneity of the long profile, including low-gradient depositional reaches upstream of spanning jams (Figure 4; Montgomery et al. 1996).

These observations suggest a three-stage process of LWD recovery following riparian restoration:

(1) Young riparian trees (e.g., < 10 years old) begin to trap LWD in transport, thereby creating bank jams, but cannot provide a local source of LWD (e.g., Robinson Creek).
(2) Loading levels increase as trees within the corridor age (10–20 years) and begin to provide some local contribution of LWD. Larger, older trees are more effective for trapping LWD in transport because they no longer bend with high flows. Because local trees are still too small to provide key pieces for channel-spanning jams, such jams can only form if LWD pieces of sufficient size are either trans-

ported to the reach during high flows and trapped by trees rooted at the bank margin (e.g., Feliz North exclosure reach) or enter through hillslope mass-wasting (e.g., Feliz South control reach). Because channel-spanning jams are so effective at trapping and storing LWD, reaches that contain channel-spanning jams will have considerably greater LWD loading than those that do not (e.g., Feliz North exclosure reach versus Feliz South and Feliz Middle exclosures).

(3) Full recovery of LWD will occur as local riparian trees grow large enough to provide a local source of key pieces, increasing the frequency of channel-spanning jams and the trapping efficiency of the reach, as illustrated by the streams with mature riparian corridors described in Opperman (2002).

Water Temperature

Pool temperatures were recorded on only two dates in the late summer of 2000 and 2001. Because of this limited sampling, we can only draw cautious conclusions regarding riparian restoration and water temperature for these reaches. During these two hot sampling days in the late summer, characteristics of the vegetation and channels within the Feliz Creek exclosures were apparently able to maintain significantly cooler water temperatures than those measured within the upstream controls. Pool temperatures within exclosures were within or just above the optimum range of 15–18°C (Moyle 2002) for growth of steelhead fry and juveniles. Temperatures within the control reaches, particularly in 2001, approached levels at which steelhead begin to experience oxygen deprivation (21°C) (McEwan and Jackson 1996) or death (23°C) (Moyle 2002).

Cooler water temperatures within exclosures may be due to the shading provided by riparian vegetation and to differences in channel morphology (Poole and Berman 2001). Narrower channels have less surface area to assimilate atmospheric heat energy, and deeper channels may allow greater infiltration of hyporheic groundwater (Poole and Berman 2001). The effects of riparian shading, channel form, and groundwater cooling may become more pronounced during the late summer, when surface flow levels drop to near zero and isolated pools in some areas become separated by dry riffles (Story et al. 2003).

Effectiveness Monitoring and Comparison of Restoration Strategies

Monitoring is essential to the long-term success of a restoration program (Kondolf 1995, 1998; Bash and Ryan 2002; Downs and Kondolf 2002). Ultimately, the results of restoration investments must be demonstrated by meaningful outcomes, such as habitat created or populations established, over sufficient time scales. These metrics are more useful measures of success than documenting the number of trees planted, instream projects constructed, or miles of stream fenced. Because of the time scale over which some of the more important changes occur, long-term monitoring may be required to demonstrate successful outcomes. This is particularly true in stream restoration, where sustainable success may require testing of a project during relatively infrequent flooding events (Schmetterling and Pierce 1999; Downs and Kondolf 2002).

In addition to quantifying and demonstrating the sustainable and meaningful benefits of restoration, monitoring is also essential for learning about and improving restoration programs (Downs and Kondolf 2002). Effectiveness monitoring can improve the application of specific techniques and, more broadly, can allow funding entities and policy makers to compare the relative costs and benefits of various strategies.

Postproject monitoring on the four study creeks provided valuable information regarding the success of deer fencing for riparian restoration and subsequent improvements in habitat for anadromous fish. We demonstrated that, following riparian restoration, several key habitat values were quantitatively improved in the exclosure reaches and that the restoration projects resulted in qualitatively different stream habitats. Our results are partly a function of the specific characteristics of the streams and their watersheds, including channel types, patterns of inter- and intra-annual hydrological variability, sediment loads, and riparian tree species. Therefore, this study provides an example of improved channel form and fish habitat resulting from a passive restoration technique (i.e., fencing) ; the efficacy of this restoration approach for other regions will require further investigation and analysis.

Several of the changes to habitat values documented in this study, such as improved channel morphology and increased levels of LWD, replicate the objectives of restoration techniques that employ instream structures. Passive restoration of riparian corridors through fencing, as demonstrated in our study, provides three primary advantages over restoration with instream structures: (1) multiple (rather than single) benefits, (2) higher reliability and longevity, and (3) lower cost and technical-knowledge requirements.

Riparian restoration provides numerous direct benefits, including leaf litter and LWD inputs, shading, bank stability, and terrestrial habitat. Subsequently, restored vegetation can promote narrower, deeper channels. Ultimately, LWD inputs over time will increase pool formation, cover, and channel heterogeneity. In contrast, instream structures generally provide a single benefit or few benefits, such as creating a scour pool or providing cover. Generally, these benefits are limited to the stream channel itself, whereas restored riparian corridors can provide benefits that can extend from reach to landscape scales (e.g., as wildlife corridors) (Malanson 1993; Naiman et al. 1993; Hilty 2001).

Second, passive restoration through fencing generally entails low risk in areas with high potential for natural regeneration, although restoration that also requires planting entails greater risk (Opperman and Merenlender 2003). If fences are maintained, dense vegetation can generally establish within a decade; riparian corridors should be self-sustaining thereafter, provided that they are protected from major anthropogenic disturbances. The apparent longevity and resiliency of these projects is demonstrated by the fact that the restored reaches in our study have undergone several high-flow events (recent Russian River basin floods: 63-year flood, January 1995 ; 21-year flood, February 1986 ; 13-year flood, January 1997) . Rather than acting as a disturbance that can destroy a restoration project, these high flows instead are essential to the process of restoration. High flows transport LWD, which can form debris jams, and sediment, which can rebuild banks during overbank flow. Elsewhere, high flows may erode banks and cause mature trees to topple. This adds more LWD and opens space for new regeneration, resulting in a riparian corridor with more diverse age- and size-classes.

In contrast to riparian exclosures, instream projects are vulnerable to failure during high flows and often do not last a decade (Ehlers 1956; Rinne 1981; Frissell and Nawa 1992; Lassetre 1997; Miles 1998). Frissell and Nawa (1992) found that more than half of the 161 instream structures they assessed on 15 streams in Oregon and Washington had failed before 5 years; the structures had experienced floods with recurrence intervals of 2–10 years. Miles (1998) reported similarly high failure rates for instream structures in British Columbia. Roni et al. (2002) concluded that more recently installed log structures had a higher success rate, with 85% remaining in place, although the authors estimated that the structures generally functioned for less than 20 years. Structures that are stable for longer periods often do not function through time as originally intended (Thompson 2002).

Instream projects often require heavy equipment and have greater requirements for technical knowledge. Unfortunately, many instream projects are installed by people that lack sufficient training (Miles 1998), and some studies have even demonstrated that instream projects can have negative effects over the long term (Thompson 2002). Thus, instream projects require the practitioners or landowners to have significant installation expertise, without which they risk implementing projects that fail to meet objectives or that might impose negative impacts on the stream. On the other hand, fencing of riparian corridors does not require the same level of technical knowledge, and there is little risk of improper installation.

Instream projects tend to be more expensive than riparian exclosures. A comparison of the costs for riparian fencing and instream structures provides insight into the relative costs and benefits of these strategies. Based on the dimensions of the fenced areas and a cost estimate for materials and labor gleaned from current restoration projects (US$2.50/ft), installation of fences on the three forks of Feliz Creek would cost $12,300, and fence installation on Robinson Creek would cost $6,400. We randomly sampled the budgets for seven recent California Department of Fish and Game restoration projects that built a total of 118 instream structures. Most of these projects were combinations of log and boulder structures designed to create pools and/or provide cover. The average cost per structure was $1,400 (SD = $223). For the same amount of funding spent to fence the Feliz Creek branches and Robinson Creek, nine instream structures could have been placed in the Feliz Creek branches, and 4.5 structures could have been placed in Robinson Creek. This translates to approximately one structure per 100 m of channel for the Feliz Creek branches and one structure per 65 m for Robinson Creek. Thus, for similar costs, a strategy based on instream structures would have influenced channel morphology at the habitat unit scale over a proportionally small length of stream, and with an unknown level of sustainability. Conversely, the restoration of the riparian corridors apparently contributes to fundamentally different channels across entire reaches. Thick riparian vegetation, narrower, deeper, more-complex channels, cooler water temperatures, and significantly more LWD and debris jams are benefits of riparian restoration that can likely be maintained for decades or centuries.

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