

Effects of Timber Harvest on Aquatic Vertebrates and Habitat in the North Fork Caspar Creek¹

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Abstract: I examined the relationships between timber harvest, creek habitat, and vertebrate populations in the North and South forks of Caspar Creek. Habitat inventories suggested pool availability increased after the onset of timber harvest activities. Increased large woody debris in the channel was associated with an increase in the frequency of blowdown in the riparian buffer zone. This increase in large woody debris volume increased the availability of pools.

No dramatic changes in the abundance of young-of-the-year steelhead, yearling steelhead, coho, or Pacific giant salamanders were directly related to logging. High interannual variation in the abundance of aquatic vertebrates made it difficult to contrast changes in abundance between pre-logging and post-logging periods. Changes in channel morphology associated with increased volume of large woody debris in the channel suggest that yearling steelhead, coho, and Pacific giant salamanders may benefit from logging in the short-term because of increased living space. However, over a longer time scale these conditions will probably not persist (Lisle and Napolitano, these proceedings).

The impacts of timber harvest on aquatic ecosystems can range from detrimental to beneficial depending on the geology and geomorphology of the watershed, the method of timber harvest, and the presence of other activities in the watershed. Disturbance of hillslope and riparian soils can result in increased sediment delivery to streams. This increased sediment input may result in decreased depth and availability of pools (McIntosh and others 1993), decreased survival of incubating salmonid eggs (Reiser and White 1988), and/or increased turbidity (Burns 1972). Alterations in the routing of surface and subsurface runoff may result in increased peak storm flows (Wright and others 1990). Increased peak flows may scour redds or bury them under sediments (Lisle 1989). Removal of timber from riparian areas decreases the amount of large woody debris available for recruitment into the channel. Within the Pacific Northwest, large woody debris plays a critical role in pool formation, sediment storage, and cover availability (Beechie and Sibley 1997, Bilby and Ward 1991). In contrast, thinning of the riparian canopy allows greater amounts of solar radiation to reach the stream. Increased incident solar radiation has been linked to increased aquatic productivity (Bisson and Sedell 1984, Burns 1972, Holtby 1988, Murphy and Hall 1981, Newbold and others 1980, Thedinga 1989).

During the late 1960's, the abundance of salmonids declined in South Fork Caspar Creek after logging (Burns 1972). This decline was associated with disruption of the streambed by heavy

equipment, increased sediment input associated with slope and bank failures, road construction just upslope of the channel, and excessive amounts of slash left in the channel. However, after only 2 years salmonid abundance had returned to near pre-logging levels. Burns (1972) concluded that logging activities were compatible with anadromous fish production as long as adequate attention was given to stream and watershed protection. Unlike the logging which occurred in the South Fork, within the North Fork logging roads were constructed along ridge tops, about 81 percent of the logs were removed by cable yarding, heavy equipment was not operated in the channel, and a riparian buffer strip was maintained to protect the stream. Given this new set of conditions, the goal of this study was to document the effects of logging in the North Fork on the abundance of aquatic vertebrates and their habitat.

Study Site

The North and South forks of Caspar Creek lie approximately 11 km southeast of Fort Bragg, California, on the Jackson State Demonstration Forest. Before this study, the South Fork had been logged twice and the North Fork had been logged once. During the late 1800's the watersheds were clearcut and burned. After logging, the areas were primarily reforested by redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii*). Beginning in 1971, the South Fork was divided into three selective-cut logging sales. A network of skid trails was constructed to transport fallen trees by tractor. By the end of the 3-year operation, 15 percent of the watershed was in roads, landings, and skid trails, and 67 percent of the timber volume in the South Fork was removed (Keppeler and Ziemer 1990). Logging activities in the North Fork began in May 1989. The watershed was divided into eight separate clearcut logging units. High-lead (cable) logging was used to remove timber from approximately 44 percent of the watershed area. Thirty- to 60-m-wide riparian buffer zones were maintained along the entire length of the mainstem channel. Logging was completed in January 1992.

The study reaches in both creeks began upstream of impoundments created by V-notch weirs. Drainage areas in the study reaches were 473 ha and 424 ha in the North Fork and South Fork, respectively. Slopes in both watersheds are relatively gentle with about 35 percent of the two watersheds having slopes of <30 percent. Both watersheds contain well-drained soils derived from sandstone. The climate is typical of coastal northern California. Winters are mild and wet. Average annual precipitation is about 1,190 mm. Approximately 90 percent of the annual precipitation falls from October through April. Average discharges in the watersheds are similar, varying from less than 0.01 m³s⁻¹ during the summer to 0.71 m³s⁻¹ during the winter. Daily summer water temperatures in both creeks vary between 10 °C and 20 °C and

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average about 13 °C. Winter water temperatures in the creeks vary between 1 °C and 12 °C, averaging approximately 7 °C. Riparian vegetation in the South Fork is composed primarily of red alder (*Alnus rubra*) and tan oak (*Lithocarpus densiflorus*). Riparian vegetation in the North Fork is composed primarily of Douglas-fir, redwood, and grand fir (*Abies grandis*).

Steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*) spawn in both creeks. Stickleback (*Gasterosteus aculeatus*) occur only in the South Fork. Amphibians inhabiting the North Fork include Pacific giant salamander (*Dicamptodon tenebrosus*), tailed frog (*Ascaphus truei*), and rough-skinned newt (*Taricha granulosa*). Pacific giant salamander and rough-skinned newt are present in the South Fork; however, tailed frogs are absent.

Methods

I categorized habitat units in the North and South forks during the summers of 1986, 1990, 1993, and 1995 according to the classification system described by McCain and others (1990). Habitat inventories were conducted in those years when I perceived changes in habitat availability and distribution associated with high discharge events. The habitat inventories in both creeks began at the upstream ends of the weir ponds and extended to the upstream barrier to fish passage in the North Fork (approximately 2,700 m) and until the stream became intermittent in the South Fork (approximately 3,000 m). Once each habitat unit was identified, I recorded a minimum of three equally spaced width measurements and three equally spaced length measurements for each habitat unit. I measured habitat depth at three equally spaced locations along each of the width transects and maximum habitat depth.

On the basis of the results of the inventory, I randomly selected individual habitat units for sampling of aquatic vertebrates. The units were selected to represent the array of habitat types available in each creek. Selected habitat units were flagged to facilitate relocation during later surveys. New habitat units were randomly selected after successive inventories.

Except for the 1986 survey that took place in August, I surveyed aquatic vertebrates in June and July. Block nets were placed across the upstream and downstream boundaries of the habitat unit. Fish were sampled to depletion using multiple passes with a backpack electrofisher. Salamanders were not sampled to depletion, but few were captured in the final electrofishing pass. Captured vertebrates were anesthetized using tricaine methanesulfonate (trade name MS-222)³ and identified to species. I recorded fork length (mm) and total length (mm) for each of the fishes and body length from the tip of the snout to the anal vent for salamanders. I recorded maximum body length for all other amphibians. In addition, between 1990 and 1995 I recorded weights for fishes and amphibians using a portable electronic balance (Ohaus CT-200, readability 0.01 g). All fish and amphibians were then

returned to the habitat unit from which they were collected. I recorded the dimensions of the unit sampled (i.e., length, width, depth, etc.) using the same protocol as during habitat typing.

I used automated temperature-monitoring equipment to monitor air and water temperatures in the creeks between April 1989 to August 1994. The data recorders were positioned at sites just upstream of the weir ponds. The data recorders were programmed to record temperature at 1-hour intervals.

Data on habitat and vertebrates were summarized by sampling year and grouped into one of two survey periods: pre-logging (1986-1989) or logging (1990-1995) depending on the year in which the survey occurred. Road building and timber falling began in the North Fork in May 1989. Because my sampling took place only one month after the onset of logging, I assumed that there would be no detectable impact during that year. Timber harvest was completed in January 1992. I collected habitat availability data once during the pre-logging period and three times during the logging period. I divided habitat units into either fast (riffle, run, cascade, etc.) or slow (pool) types and calculated the availability of each type on the basis of area. I further determined the proportion of pool habitats in each creek associated with large woody debris (logs, rootwads). Vertebrates were divided into one of four groups: young-of-the-year (YOY), steelhead (≤ 70 mm fl), yearling steelhead (> 70 mm fl); coho; or larval Pacific giant salamanders. I calculated the difference in mean density within each year, between the two creeks and compared the differences before and after logging (Stewart-Oaten and others 1986). I conducted separate analyses for each of the vertebrate groups using Mann-Whitney-Wilcoxon tests to compare pre- and post-logging differences. I used the same method to analyze mean body length. Since the vertebrate biomass and temperature data were collected only during the logging period, the data were not subjected to statistical analysis.

Results

Habitat

The availability of fast and slow water habitat was similar between creeks during the 1986 habitat inventory (table 1). Slow water habitat comprised approximately 25 percent of the available

Table 1—Proportional habitat availability in the North Fork and South Fork Caspar Creek. Fast habitat types include riffles, cascades, runs, and glides. Slow habitat types include all pools. Habitat inventories were conducted during May or June of each assessment year. Pools with large woody debris (LWD) include the proportion of total pool availability that incorporated large woody debris as a critical element in their formation on the basis of frequency of occurrence.

Year	North Fork Caspar			South Fork Caspar		
	Slow	Fast	Pools with LWD	Slow	Fast	Pools with LWD
1986	0.27	0.73	0.70	0.29	0.71	0.46
1990	0.41	0.59	0.51	0.52	0.48	0.43
1993	0.40	0.60	0.55	0.45	0.55	0.41
1995	0.44	0.56	0.53	0.35	0.65	0.42

³ The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

habitat. However, after the 1990 habitat inventory the percentage of slow water habitat had increased to 41 percent in the North Fork and 52 percent in the South Fork. The 1993 and 1995 habitat inventories suggested that the habitat availability remained relatively stable in the North Fork whereas habitat availability in the South Fork tended to return to the 1986 level.

Large woody debris (LWD), including rootwads from standing trees, were critical in the formation of 70 percent of the pools in the North Fork during the 1986 habitat inventory (*table 1*). In contrast, only 55 percent of the pools in the South Fork incorporated LWD. Later inventories revealed that the percentage in the North Fork was reduced to between 45 percent and 57 percent. The proportion of pools associated with large woody debris in the South Fork ranged between 37 and 46 percent, between 1990 and 1995.

Mean monthly water temperatures in the North Fork were the lowest in December and the highest in July or August (*fig. 1*). Throughout the monitoring period mean monthly water temperatures ranged between 4.6 °C and 14.6 °C. Water temperatures averaged 0.4 °C higher in the North Fork compared to the South Fork. Air temperatures averaged 2.1 °C higher in the North Fork compared to the South Fork (*fig. 2*). The data suggested that air and water temperatures in the North Fork remained greater than temperatures in the South Fork throughout most of the monitoring period. The greatest differences for air and water temperatures between the North and South forks roughly coincided with the annual minimum and maximum monthly temperatures.

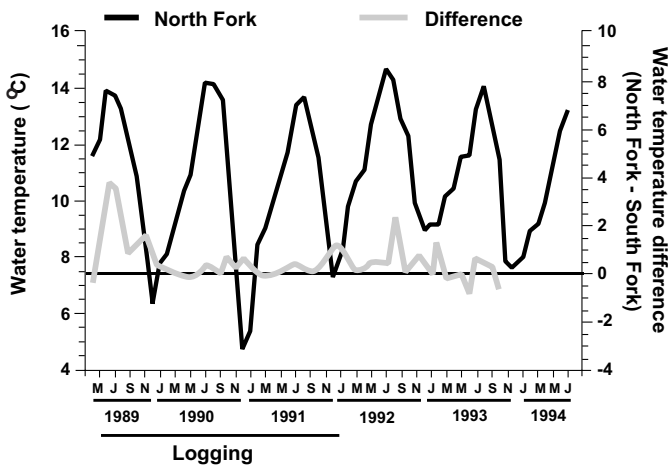


Figure 1—Mean monthly water temperature for the North Fork Caspar Creek and the difference in mean monthly water temperature between the North Fork and South Fork. The data were collected by automated temperature data loggers. The data loggers were programmed to record temperature at 1-hour intervals. The thermistors were accurate to within 0.2 °C.

Vertebrate Data

Young-of-the-Year Steelhead

Young-of-the-year (YOY) steelhead densities during the pre-logging period were slightly higher in the North Fork (0.93 YOY steelhead m^{-2} , $n = 4$, 0.12 S.E.) compared to the South Fork (0.78 YOY m^{-2} , $n = 4$, 0.09 S.E.) (*fig. 3a*). During the logging period, mean YOY steelhead densities in the North Fork (0.85 YOY m^{-2} , $n = 6$, 0.12 S.E.) were again greater than densities in the South Fork (0.59 YOY m^{-2} , $n = 6$, 0.04 S.E.), but lower than pre-logging densities. The differences in YOY steelhead density between creeks were not significantly different between survey periods ($p = 0.38$).

During the logging period YOY steelhead biomass in the North Fork averaged 0.97 $g\ m^{-2}$ ($n = 6$, 0.15 S.E.) whereas YOY steelhead biomass in the South Fork averaged 0.80 $g\ m^{-2}$ ($n = 6$, 0.07 S.E.) (*fig. 3b*). High interannual variation characterized the mean biomass in both creeks.

Young-of-the-year steelhead fork length averaged 40.6 mm ($n = 4$, 0.25 S.E.) for the pre-logging period and 45.2 mm ($n = 6$, 0.18 S.E.) for the post-logging period in the North Fork (*fig. 3c*). Mean fork length for steelhead from the South Fork averaged 42.5 mm ($n = 4$, 0.25 S.E.) for the pre-logging period and 45.8 mm ($n = 6$, 0.19 S.E.) for the post-logging period. The differences in mean fork length between creeks was not significantly different between survey periods ($p = 0.46$).

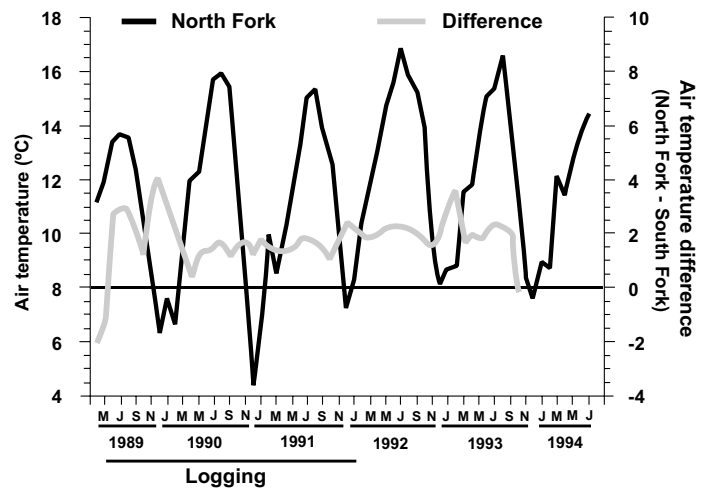


Figure 2—Mean monthly air temperature for the North Fork Caspar Creek and the difference in mean monthly air temperature between the North Fork and South Fork. The data were collected by automated temperature data loggers. The data loggers were programmed to record temperature at 1-hour intervals. The thermistors were accurate to within 0.2 °C.

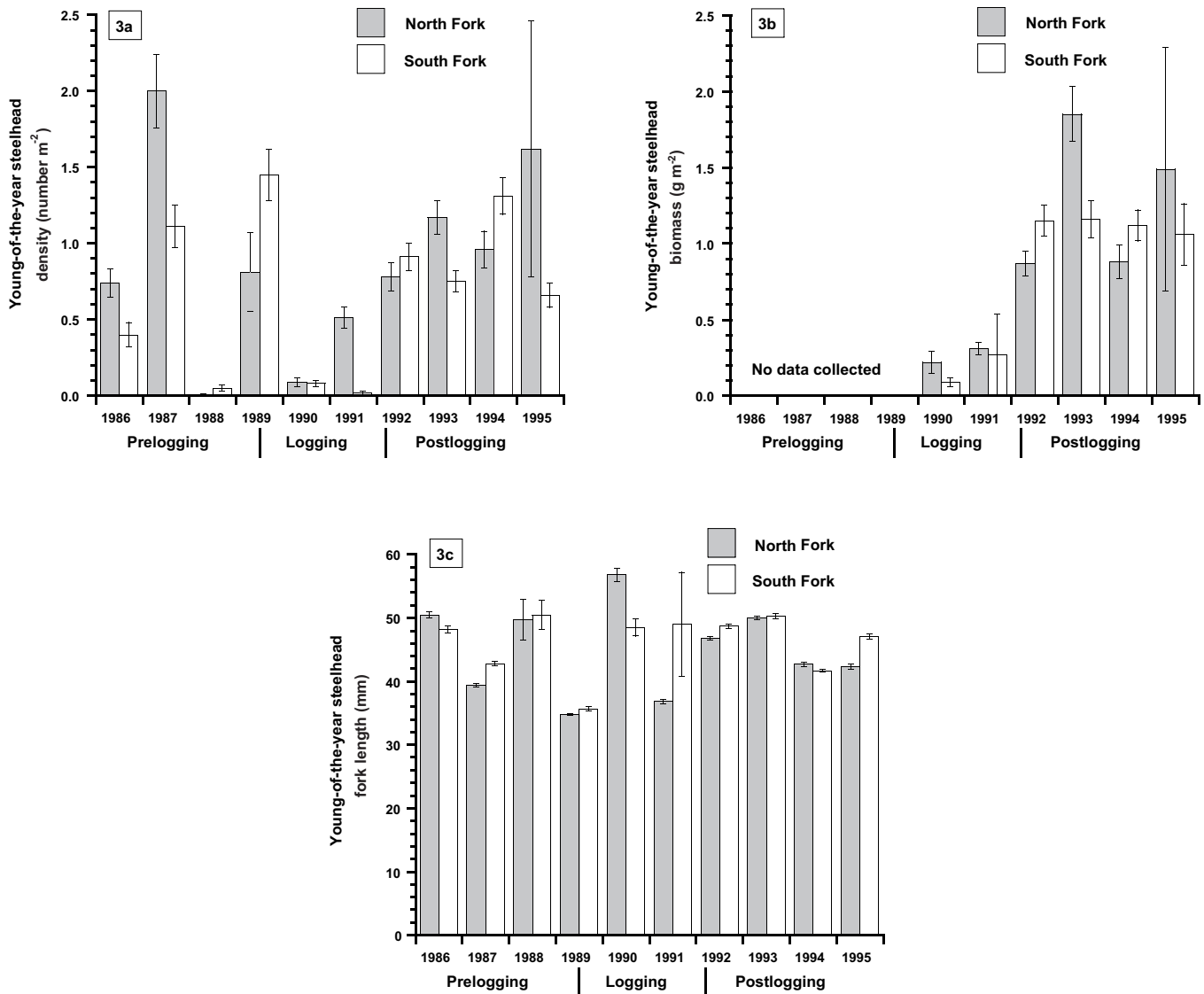


Figure 3—Mean and standard error for annual abundance (a), biomass (b), and fork length (c) for young-of-the-year steelhead in the North Fork and South Fork Caspar Creek, based on summer electrofishing surveys. Timber harvest activities began in May 1989 in the North Fork and were completed by January 1992.

Yearling Steelhead

Yearling steelhead densities during the pre-logging period in the North Fork and South Fork averaged 0.08 fish m⁻² (0.01 S.E.) and 0.05 fish m⁻² (0.01 S.E.), respectively (fig. 4a). During the logging period, steelhead densities averaged 0.12 fish m⁻² (0.02 S.E.) in the North Fork, slightly greater than for the pre-logging period. Steelhead densities in the South Fork were also slightly elevated at 0.07 fish m⁻² (0.01 S.E.). The difference in density between the creeks did not change significantly between pre-logging and logging periods (p = 0.54). Yearling steelhead biomass during the logging period averaged 1.31 g m⁻² (n = 6, 0.17 S.E.) in the North Fork and 0.97 g m⁻² (n = 6, 0.13 S.E.) in the South Fork (fig. 4b).

Mean fork length for yearling steelhead collected from the North Fork averaged 95.5 mm (2.36 S.E.) for the pre-logging period and 97.5 mm (1.37 S.E.) for the post-logging period (fig. 4c). Mean fork lengths for yearling steelhead collected from the South Fork were 104.0 mm (2.22 S.E.) and 97.0 mm (1.58 S.E.) for the pre-logging and post-logging periods, respectively. The differences in mean fork length between creeks were not significantly different between pre-logging and logging periods (p = 0.46).

Coho

Young-of-the-year coho densities were variable throughout the monitoring period (fig. 5a). Coho densities during the pre-logging

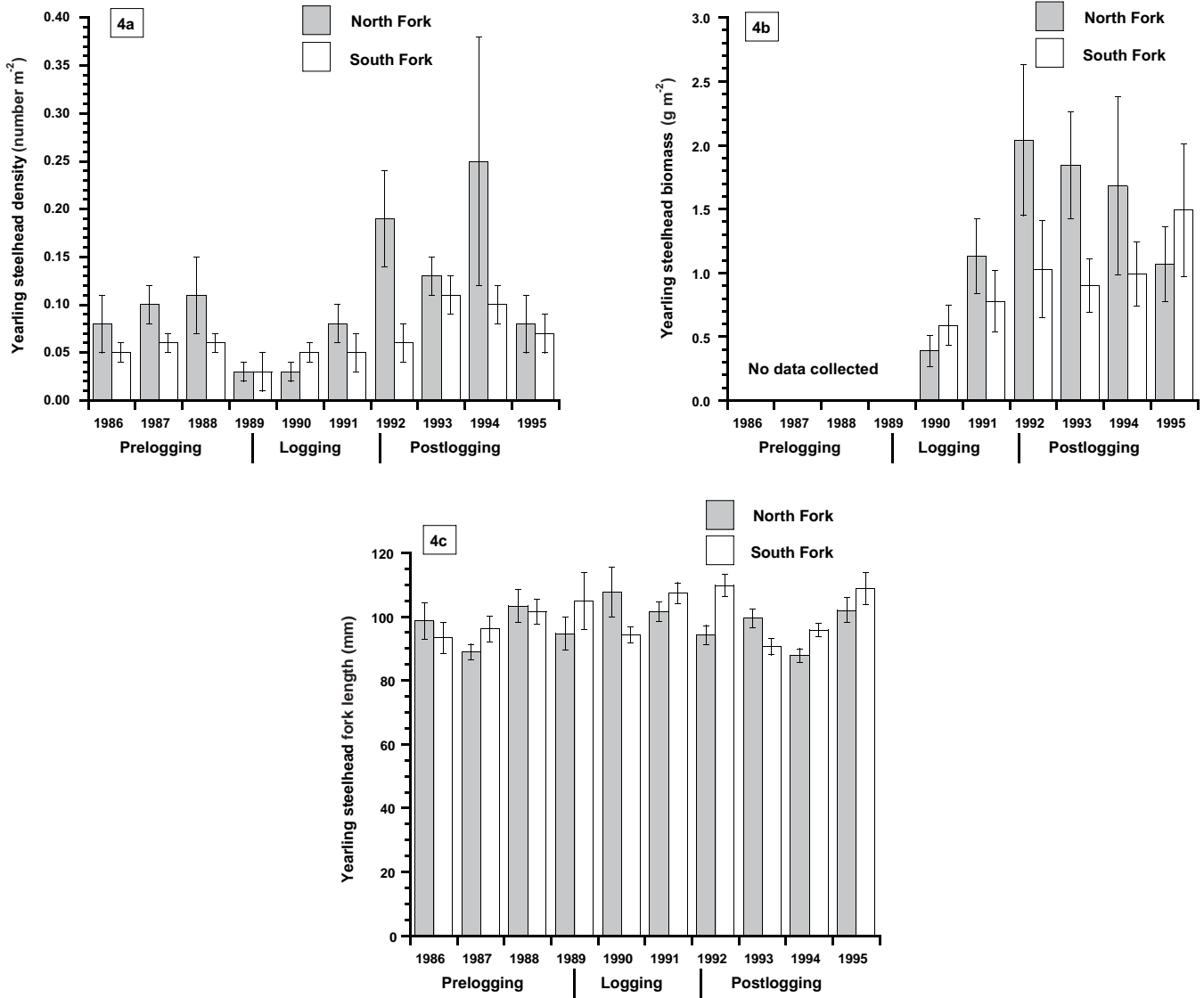


Figure 4—Mean and standard error for (a) annual abundance, (b) biomass, and (c) fork length for yearling steelhead in the North Fork and South Fork Caspar Creek, based on summer electrofishing surveys. Timber harvest activities began in May 1989 in the North Fork and were completed by January 1992.

period averaged 0.57 fish m⁻² (0.09 S.E.) in the North Fork and 0.65 fish m⁻² (0.08 S.E.) in the South Fork. Coho densities during the logging period declined significantly to 0.03 fish m⁻² (0.01 S.E.) in the North Fork and 0.07 fish m⁻² (0.01 S.E.) in the South Fork. The differences in coho density between creeks were not significantly different across survey periods (p = 0.18).

Coho biomass during the logging period declined to 0.07 g m⁻² (0.02 S.E.) and 0.21 g m⁻² (0.03 S.E.) in the North Fork and South Fork, respectively (fig. 5b). Throughout the logging period coho biomass remained extremely low in both creeks.

Coho from the North Fork averaged 55.7 mm fl (0.29 S.E.) and 59.8 mm fl (1.14 S.E.) for the pre-logging and logging periods,

respectively (fig. 5c). Coho from the South Fork averaged 54.8 mm fl (0.31 S.E.) during the pre-logging period and 61.9 mm fl (0.57 S.E.) during the logging period. The mean length of coho did not change significantly relative to the South Fork between pre-logging and logging periods (p=0.34).

Larval Pacific Giant Salamanders

Mean larval Pacific giant salamander (LPGS) densities throughout the monitoring period were higher in the North Fork compared to the South Fork (fig. 6a). Pre-logging densities in the North Fork averaged 1.33 LPGS m⁻² (0.18 S.E.) while densities in the South Fork averaged 0.93 LPGS m⁻² (0.09 S.E.) for the same period. Logging period

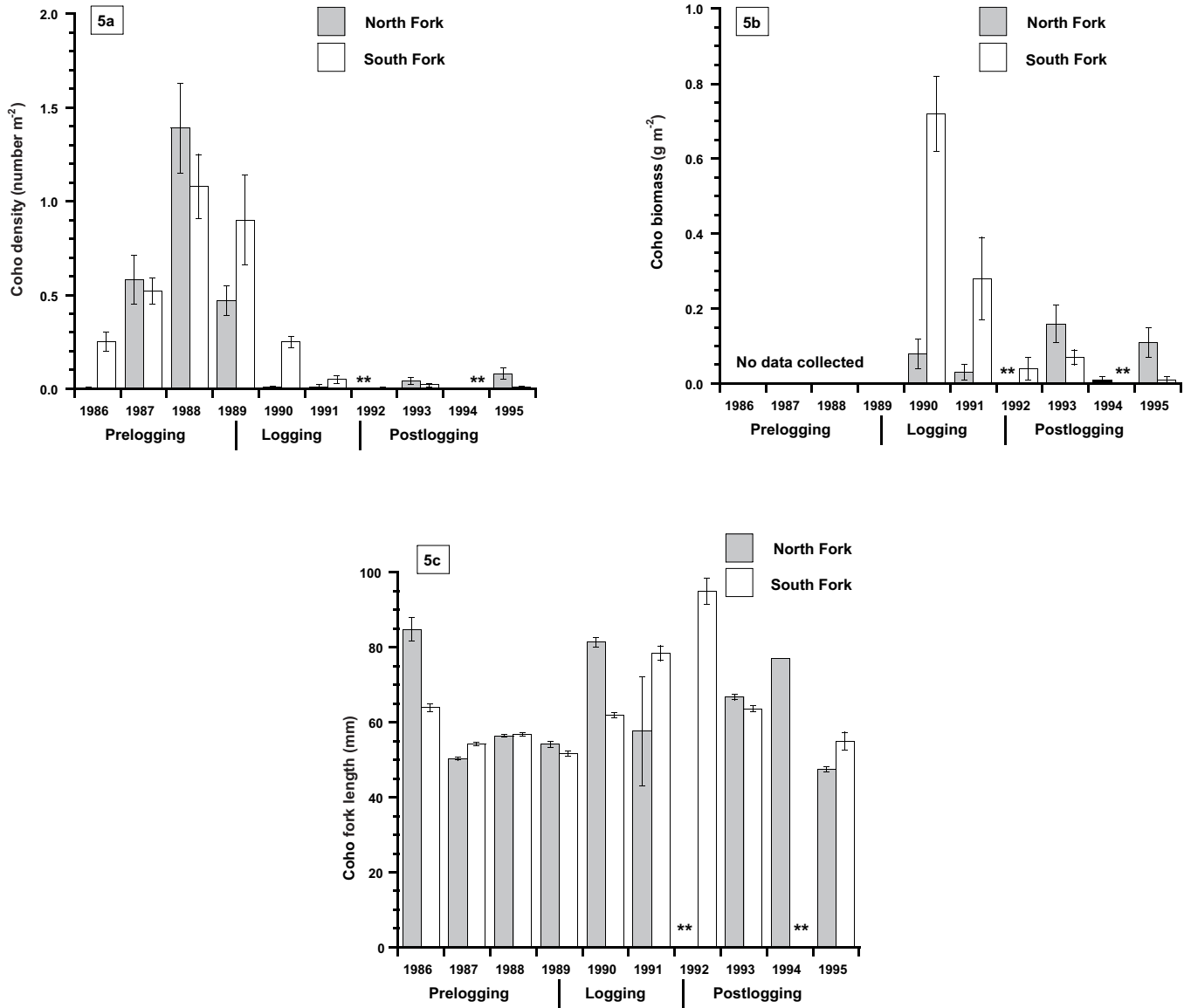


Figure 5—Mean and standard error for (a) annual abundance, (b) biomass, and (c) fork length for young-of-the-year coho in the North Fork and South Fork Caspar Creek, based on summer electrofishing surveys. Timber harvest activities began in May 1989 in the North Fork and were completed by January 1992. ** = no coho collected.

densities were slightly higher than pre-logging densities averaging 1.46 LPGS m⁻² (0.30 S.E.) in the North Fork and 1.28 LPGS m⁻² (0.07 S.E.) in the South Fork. No significant change in the mean density of North Fork LPGS was identified after logging (p=0.13).

Larval Pacific giant salamander biomass generally was 1.5 to 2.0 times greater than combined salmonid biomass for both creeks (fig. 6b). During 1995, LPGS biomass in the North Fork was estimated to be 10.4 g m⁻². Larval Pacific giant salamander biomass during the logging period averaged 5.39 g m⁻² (n = 6, 1.37 S.E.) in the North Fork and 4.39 g m⁻² (n = 6, 0.32 S.E.) in the South Fork.

Snout-to-vent length for LPGS collected during the pre-logging period averaged 36.6 mm (n = 3, 0.28 S.E.) in the North Fork and 39.6 mm (n = 3, 0.33 S.E.) in the South Fork (fig. 6c). Larval Pacific giant salamander collected during the logging period from the North Fork averaged 38.8 mm long (n = 6, 0.21 S.E.), while LPGS collected from the South Fork averaged 37.8 mm long (n = 6, 0.23 S.E.). The difference in snout-to-vent length between creeks was significantly larger during the logging period compared to the pre-logging period (p = 0.01).

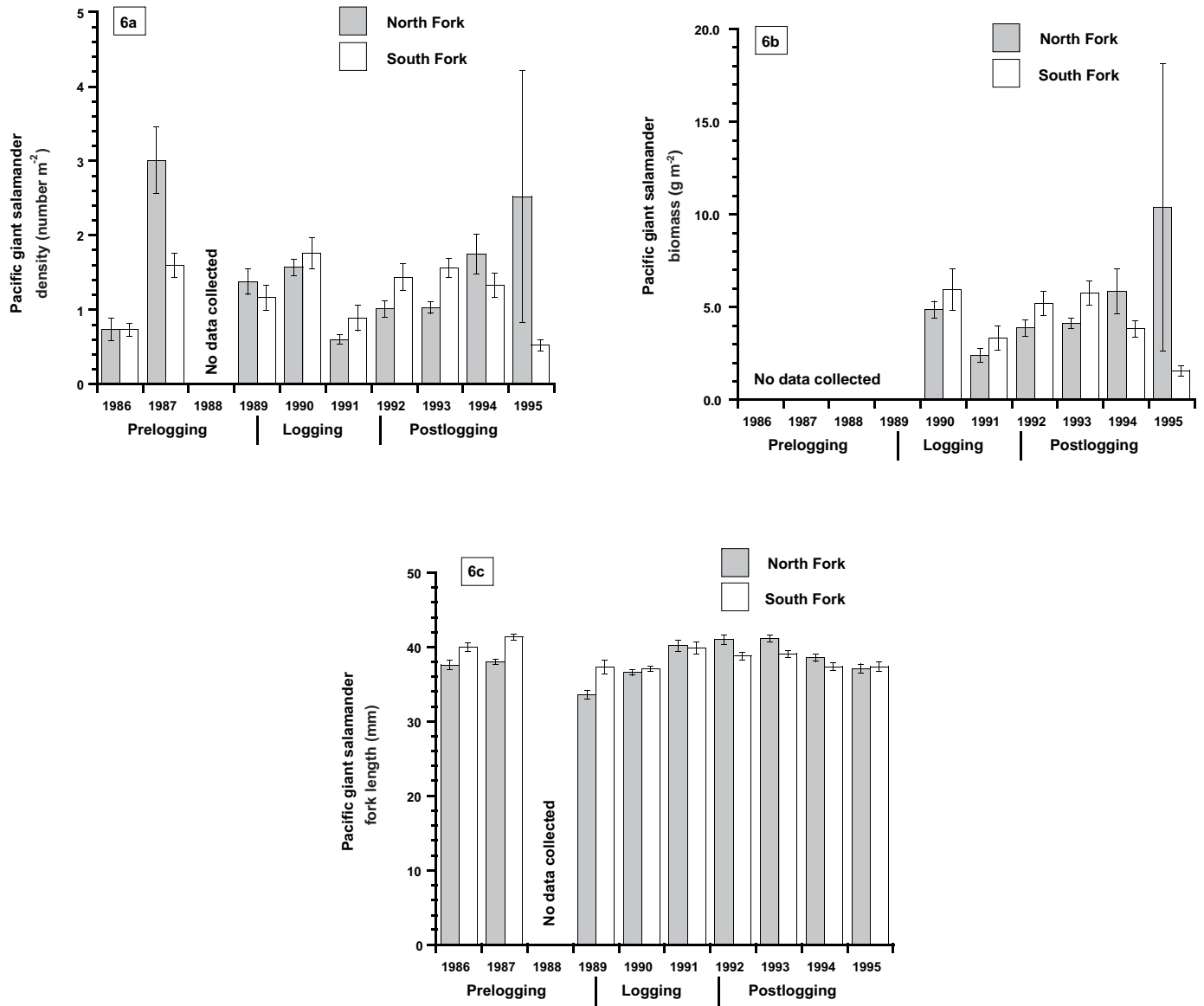


Figure 6—Mean and standard error for (a) annual abundance, (b) biomass, and (c) snout-to-vent length for larval Pacific giant salamanders in the North Fork and South Fork Caspar Creek, based on summer electrofishing surveys. Timber harvest activities began in May 1989 in the North Fork and were completed by January 1992.

Discussion

The effects of timber harvest in the late 1800's in the North Fork were still evident in 1987. Logging techniques used during that period left the channel relatively simple in form, lacking large woody debris (LWD) (Lisle and Napolitano, these proceedings). The increased rate of tree fall has significantly augmented the supply of LWD in the North Fork (Reid and Hilton, these proceedings). This increase in available LWD has been linked to the increase in pool availability observed in this study and by Lisle and Napolitano (these proceedings). However, my data suggested that the availability of pools associated with LWD had not increased after logging.

Differences in timing of assessments and differences in methodologies may in part explain this contradiction. Severe winter storms during 1990 and 1994 resulted in elevated rates of tree fall in the North Fork. However, during December 1995, an abnormally severe storm resulted in higher-than-usual tree fall (Reid and Hilton, these proceedings). The final habitat survey included in this report was completed in June 1995. Further, my habitat surveys included only those LWD that were in contact with the wetted perimeter of the channel during the summer low flow period. Reid and Hilton assessed all downed trees both in the riparian buffer strip and to a distance of

more than 200 m into uncut units. Exclusion of the LWD from my survey does not suggest that these pieces are not important components of the creek. Although much of the LWD contributed little to summer habitat complexity, this LWD may provide increased habitat complexity during winter high-flow periods, resulting in higher survival of juvenile salmonids and increased pool availability during the summer.

Stream temperatures in the North Fork in general were higher than stream temperature in the South Fork throughout the year. Increases in stream temperature have been widely observed after timber harvest (Brown and Krygier 1970, Holtby 1988, Meehan 1970). However, in the absence of data for pre-logging stream temperatures, it is impossible to determine whether logging resulted in higher temperatures in the North Fork. The increase in water temperature was small and the range of temperatures observed within the North Fork is within the tolerable range for salmonids.

The results of this study identified no dramatic short-term changes in the abundance of aquatic vertebrates directly related to logging. However, these results are far from definitive. The extremely low statistical power of the statistical tests casts some doubt over their conclusions. Burns (1972) concluded that high interannual variation in salmonid numbers made it difficult to separate timber harvest impacts from natural variation. However, changes in habitat suggest possibility of changes in abundance. Decreased availability of shallow water habitat and increases in the density of yearling steelhead may negatively affect YOY steelhead in the North Fork as size-dependent interactions favor yearling steelhead in pool habitats (Harvey and Nakamoto 1997). Larval Pacific giant salamander density is strongly influenced by substrate composition and cover availability (Parker 1991). Changes in sediment storage associated with increased LWD input could benefit LPGS. Reduced amounts of sediment transported past debris jams promote scour downstream. Transport of fine sediments from these downstream areas will increase the availability of interstitial space between cobbles. Increased cover area provided by LWD and the scour of fine materials create habitat conditions favoring LPGS.

The abundance of coho in both creeks was variable until 1990 after which coho virtually disappeared. The extremely low population levels in both creeks combined with the low statistical power of the comparison results in a low probability of detecting logging-associated changes in the coho population. However, current increases in LWD and pool availability in the North Fork should benefit coho (Bisson and others 1988, Murphy and others 1986, Reeves and others 1989) although, competition between juvenile coho and steelhead in Caspar Creek may slow the recovery of coho (Harvey and Nakamoto 1996). Depressed population levels in both creeks suggest that conditions in both watersheds will not support coho and/or that factors outside the watersheds are influencing coho reproduction. Some of these factors may include poor winter and/or summer rearing habitat, or early emigration from the study reach. During those years when creek discharge was not sufficient for operation of the fish ladder over the V-notch weirs, the creeks were largely inaccessible to adults.

The increase in pool availability is closely related to the increased amount of LWD in the channel. The price of the significant increases in LWD input associated with severe winter storms may be that fewer logs are left to contribute in future years. The volume of LWD may be reduced as current LWD decays and is transported downstream. The current rate of LWD input from the riparian zone may decrease as reserves are depleted and trees become more wind firm. Other trees in the riparian zone may reach sizes large enough to form pools (> 20 cm diameter) within 25 years (Beechie and Sibley 1997). However, it is unlikely that these small trees will contribute enough LWD to offset losses. Increased summer flow is expected to disappear within 5 years after logging (Keppeler and Ziemer 1990). It would appear that over a longer time scale, habitat conditions and the aquatic vertebrates have not benefited from logging operations in the North Fork.

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