Napa River Tributary Steelhead Growth Analysis

Final Report

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Executive Summary

Steelhead (*Oncorhynchus mykiss*) in the Napa River watershed have exhibited substantial declines in abundance since the 1960s (Leidy et al. 2005), and nearly all steelhead populations in California are currently imperiled (NMFS 2006). A pilot steelhead growth study conducted in summer of 2001 in Dry Creek and Ritchey Creek (Stillwater Sciences and Dietrich 2002) documented negative growth rates for young-of-the-year steelhead, implying that food resources in the study reaches were insufficient in summer 2001 to satisfy metabolic demands. These findings indicate that reduced prey availability due to insufficient flow over riffles could result in smaller smolts, which would be expected to have poor survival during emigration and early ocean rearing, thereby limiting production of steelhead from the Napa River watershed.

To verify the findings of the 2001 pilot growth study, and to determine if growth is limiting production of steelhead from tributaries to the Napa River, we studied seasonal steelhead growth in selected Napa River tributaries from summer 2005 through spring 2006. Of particular importance was determining if food availability and growth during the rest of the year, especially spring and fall, could offset any summer growth deficits and allow smolts to outmigrate at a large enough size to confer high marine survival. The specific study objectives were to:

1. Estimate seasonal growth rates for age 0+, 1+, and 2+ steelhead in order to determine when positive growth occurs and what size they can attain prior to smolt outmigration.
2. Assess potential food availability during low flow conditions to evaluate the effect of flow in riffles on invertebrate production and delivery to downstream pools where juvenile steelhead are rearing.

Overall growth during the low flow period (summer/early fall) in 2005 was relatively low, and apparently not related to flow or invertebrate prey availability. Warm summer/early fall water temperatures, by increasing the metabolic rate of juvenile steelhead, increase energy requirements beyond that which can be met by available food resources and appear to effectively curtail summer growth. Survival during the summer/early fall was poor for the youngest steelhead (age 0+), but apparently increased for older age classes. With the exception of a few stream reaches that dried completely during fall, the study streams produced age 2+ steelhead large enough to likely have high ocean survival rates. Low flow during the summer/early fall period, while potentially reducing the delivery of invertebrate drift to juvenile steelhead, by itself does not appear to have deleterious impacts to the average size of age 2+ steelhead in spring. Rapid growth during the spring appears to compensate for growth limitations during the remainder of the year—especially the warm, dry summer and fall months. However, winter and spring flows during the period of this study were exceptionally high compared to other years, so this spring growth advantage may not occur in all years.

Although we found that steelhead in our study streams can apparently overcome dry season growth limitations prior to smolting at age 2+, it is possible that low summer/early fall flows could reduce steelhead carrying capacity and limit overall production. Low flows (<1 cfs) in summer/early fall can reduce steelhead carrying capacity in two ways: (1) low flows can result in higher water temperatures and if temperatures reach lethal levels the juvenile steelhead will be lost; and (2) low flows can result in drying of the pools that steelhead often depend on for summer survival. In either case, the abundance of juvenile steelhead is reduced. However, if low flows do not result in either of these two conditions, our study results suggest that the lack of growth in the summer due to low flows may not, by itself, be deleterious to steelhead production.

Based on the results of this study, long-term monitoring and adaptive management is recommended to continue to evaluate Napa Valley steelhead populations and refine management priorities. Of particular importance is the collection of steelhead outmigrant data. In addition, it is recommended that water diversions from key steelhead rearing tributaries be managed to ensure that the duration and magnitude of high spring flows are similar to the unimpaired flow regime. Protection against an anthropogenically early onset of the summer low flow period will maximize the critical spring growth period for juvenile steelhead.

Table of Contents

Tables

Figures

Appendices

1 INTRODUCTION

1.1 Study Background

Steelhead (*Oncorhynchus mykiss*) in the Napa River watershed have exhibited substantial declines in abundance since the 1960s. The *Napa River Basin Limiting Factors Analysis* (Stillwater Sciences and Dietrich 2002) concluded that fine sediment and high water temperatures were not the primary mechanisms responsible for the decline of steelhead in the basin. The limiting factors analysis concluded that, although multiple factors may have contributed to the decline, a likely hypothesis is that flow reductions have reduced food availability for juvenile steelhead, limiting growth and size at outmigration, consequently reducing survival during outmigration and early ocean occupancy.

Growth of juvenile steelhead during their freshwater rearing period is critical for their survival during outmigration and ocean phases, as well as to the overall viability of the population. Several studies have shown a strong relationship between the size at which a steelhead smolt migrates to the ocean and the probability that it returns to freshwater to spawn (Kabel and German 1967, Hume and Parkinson 1988, Ward and Slaney 1988, Ward et al. 1989). For example, in a mark-recapture study on the Eel River, California, Kabel and German (1967) demonstrated an exponential relationship between smolt size at outmigration and successful adult return. The increased survival is usually attributed to larger smolts being better able to escape predation during outmigration, and in the estuary and ocean. Most marine mortality of steelhead occurs soon after they enter the ocean and predation is believed to be the primary cause of this mortality (Pearcy 1992).

The most important food source for juvenile salmonids is usually invertebrate drift from riffles. Benthic macroinvertebrate production is concentrated in highly oxygenated riffle habitats. Juvenile steelhead can minimize energy expended in feeding by establishing feeding stations where riffles enter pools or where they can hold near boulders, large wood, or other flow obstructions while remaining adjacent to higher velocity water with higher food delivery rates (Fausch 1984). Invertebrate production in riffles may be reduced by decreased surface flows, changes in channel geomorphology that reduce available habitat for benthic macroinvertebrates (such as sedimentation), and poor water quality that may reduce primary and secondary production or result in direct mortality of invertebrates.

During reconnaissance surveys of Napa River tributaries by Stillwater Sciences in summer 2000, numerous dewatered riffles and isolated pools were encountered. Some of the isolated pools held dense aggregations of steelhead that showed signs of food stress (i.e., low condition factor), leading to the supposition that limitations in food availability may be limiting growth and overall fitness. In addition, monitoring during summer 2000 indicated that stream temperatures became high enough to cause significant increases in fish metabolic rate, which, in turn, could negatively affect growth if sufficient food resources were not available. These observations led us to hypothesize that low flows, whether natural or exacerbated by human activities, reduce food availability for juvenile steelhead.

The ability of fish to convert energy sources to physical growth is a function of their food intake and metabolic rate. Consumed food sources have varying energetic value, which are first allocated to catabolic processes (maintenance and activity metabolism), then to waste losses (feces, urine and specific dynamic action). Any left over energy is allocated to somatic storage (body growth and gonad development). Because fish are poikilothermic, their metabolic rate is determined by the water temperature. High water temperatures increase energy allocated to catabolic processes, and thus less energy remains to allocate to growth. Therefore the key environmental parameters that potentially affect growth are food availability (e.g., invertebrate drift) and water temperature. Both of these key variables can be affected by instream flows, since flow delivers invertebrate drift, and solar radiation increases temperatures in small volumes of water more quickly than in large volumes of water. Other parameters, such as fish density and channel morphology, may also indirectly affect growth. For example as fish density increases, food resources are portioned among more individuals, leaving less caloric energy available for each fish. Channel morphology can affect water temperature by influencing the volume of water within the channel exposed to solar radiation, and can affect invertebrate drift, since most invertebrate production originates from riffles. Water temperature and food availability, both influenced by channel morphology and flow, may combine to produce a synergistic effect on fish growth. At low flows, when water temperature may be high and food delivery may be low, fish growth may be reduced.

To explore the relationship between water temperature, stream flow, and steelhead growth, a pilot study was conducted in summer of 2001 in eight pools located in two Napa River tributaries: Dry Creek and Ritchey Creek (Stillwater Sciences and Dietrich 2002). At the beginning of the summer, steelhead were measured, weighed, and given an individual mark. At the end of the summer, steelhead were recaptured and individual growth rates were estimated.

Negative growth rates for young-of-the-year steelhead were observed at all sites in summer 2001, implying that food resources in the study reaches were insufficient in summer 2001 to satisfy their metabolic demands. Significant weight loss during the summer may stress fish and reduce survival during the remaining juvenile rearing period. These findings suggest that reduced prey availability due to insufficient flow in riffles could result in smaller smolts, which would be expected to have poor survival during emigration and early ocean rearing, thereby limiting production of steelhead from the Napa River watershed.

1.2 Objectives

Due to the observed relationship between smolt size and probability of return from the ocean, understanding the environmental factors that influence food availability and fish growth could be important for restoring steelhead in the Napa River watershed. The focus of this study was to determine if growth is limiting production of steelhead from tributaries to the Napa River, or if food availability and growth during the rest of the year, particularly spring and fall, could offset any reductions in summer growth and allow smolts to outmigrate at a large enough size to have high marine survival and increase the probability of returning to spawn. The specific objectives were to:

1. Estimate seasonal growth rates for age 0+, 1+, and 2+ steelhead in order to determine when positive growth occurs and what size they can attain prior to smolt outmigration.
2. Assess potential food availability during low flow conditions to evaluate the effect of flow in riffles on invertebrate production and delivery to downstream pools where juvenile steelhead are rearing.

2 METHODS

2.1 General Approach

The general approach taken during this study was to use individually marked juvenile steelhead to measure growth rates during periods of (1) low flows with warm water temperatures (summer/early fall); (2) frequent freshets with cooler water temperatures (fall/winter); and (3) fairly stable flows with cool but increasing water temperatures (spring) in tributaries to the Napa River. Twelve (12) study reaches were selected (Figure 1) to represent the range of channel morphology and hydrologic conditions currently found in tributaries of the Napa River that support steelhead. Juvenile steelhead were initially captured during the low flow period in 2005 (after stream flows reached summer base levels), and were measured and weighed. Prior to release, each fish was given a unique mark. Recapture surveys occurred three additional times: fall 2005, late winter 2006, and early summer 2006. Drift of invertebrates was measured in each study tributary to assess food availability. Data analysis focused on seasonal steelhead growth patterns, particularly as they related to food availability, flow, and water temperature.

2.1.1 Study sites

Eighteen reaches in six tributaries were originally identified as potential study sites, based on surface flow assessments (Stillwater Sciences and Dietrich 2002), steelhead surveys (Ecotrust and FONR 2001, 2002, and NCRCD 2005), stream gradient information (Stillwater Sciences and Dietrich 2002), contacts with landowners regarding access, and site reconnaissance visits in May 2005.

Final study reaches were selected based on:

- reaches had at least some flow throughout the summer months to maintain pool habitat (may have little to no flow over riffles);
- reaches contained documented densities (low to high) of juvenile steelhead (Ecotrust and FONR 2001, 2002);
- reaches were representative of geomorphic conditions typical of Napa River tributary streams (step-pool, pool-riffle, forced pool-riffle, or plane-bed channel types) (Montgomery and Buffington 1997); and
- reaches were accessible during all sampling periods.

Selection of study reaches was finalized in June, 2005 based on comments received from the Napa Valley Watershed Information Center and Conservancy (WICC) Technical Advisory Committee (TAC) on the Draft Scope of Work and access agreements with local landowners. The final selection of study sites included reaches in each of the four channel-flow types in five tributaries (Table 1). A total of 12 non-contiguous study reaches were selected, with 2–3 reaches per stream. Study reaches were selected to represent the range of channel morphology and hydrologic conditions currently found in tributaries of the Napa River. Wherever possible, study reaches were selected from areas documented to have medium or high steelhead density (0.5–1 steelhead/m^2 and >1 steelhead/m^2, respectively) (Ecotrust and FONR 2001, 2002). Flow regimes were initially determined based on a reconnaissance visit to all streams, but were re-classified based on flow measurements taken at all study reaches during the July 2005 fish sampling visit.

Table 1. Selected study reaches.

Stream	Channel type	Steelhead density	Number of study reaches	Study reach location(s)
Ritchey Creek	forced pool-riffle/ plane-bed	low to medium	2	Within or upstream of Bothe-Napa State Park
	step-pool	low to medium	1	
Redwood Creek	forced pool-riffle/ plane-bed	medium to high	1	Downstream of Pickle Creek confluence
	step-pool	medium to high	1	Upstream of Pickle Creek confluence
Heath Canyon Creek	step-pool	medium	2	Upper reach
	step-pool	medium	1	Lower reach
York Creek	step-pool	medium	2	Mid to upper reaches, adjacent to Spring Mountain Vineyards
Pickle Creek	step-pool	low to medium	2	Middle reach, upstream of plane-bed section

2.1.2 Stream habitat characteristics

Study reaches were classified into geomorphic channel types following the classification scheme of Montgomery and Buffington (1997). Due to winter floods, channel conditions changed during the study. As a result, channel classifications were conducted in October/November 2005 and repeated in February 2006 and May 2006. In addition, physical data were collected for each study reach at each sampling event. The following habitat characteristics were recorded at each habitat unit of each study reach, during each visit:

- average wetted width and length of each habitat unit
- substrate composition
- maximum depth
- average depth
- fish cover type (e.g., boulder, woody debris, bedrock ledges, vegetation) and approximate percent cover
- riparian vegetation type and percent canopy cover

Discharge was measured at selected cross sections using a Marsh-McBirney Model 2000 flow meter for each study reach during site reconnaissance and during each visit for fish and invertebrate sampling. If flow was too low to obtain readings using a flow meter, flow volume per unit time was calculated by recording the amount of time it took to fill a graduated cylinder or five gallon bucket (which was then emptied into 1 liter containers for a more precise measurement). To improve the accuracy of low-flow measurements, several measurements were taken and averaged to obtain a single discharge measurement for a given reach. Nevertheless, measurements taken at very low flows (<1 cfs) are considered less accurate than measurements at higher flows due to inherent limitations in the measurement equipment and techniques.

For each flow measurement a "flow index" was calculated by dividing the discharge at each site by the wetted channel width. The flow index is correlated with the depth and velocity of flow, and is used to correct for potential differences in invertebrate production and delivery (i.e., drift) in reaches with equal discharge but different width-to-depth ratios. For example, in two channels with equal discharge but unequal width, the wider channel will have a shallower depth and lower water velocity, resulting in comparatively lower rates of production and delivery of invertebrate drift. The flow index corrects for differences in channel geometry and allows for unbiased comparison of flow-related parameters among study reaches. Water temperature loggers (Onset Tidbits) and stage loggers (pressure transducers) were installed in or near each study reach in July, 2005, and left to record changes in stage and water temperature throughout the study. In addition, conductivity, turbidity, and dissolved oxygen were measured using an YSI Model 85 multi-probe meter in each stream reach during each field visit. Turbidity was measured in Nephelometric Turbidity Units (NTUs).

2.1.3 Fish sampling

Four (4) sampling efforts were conducted (Table 2) to measure growth during typical conditions in the following three seasonal periods:

- summer/early fall flows: low flows with warm water temperatures,
- fall/winter flows: frequent freshets with cooler water temperatures, and
- spring flows: fairly stable flows with cool, but increasing water temperatures.

Table 2. Sampling dates and methods.

Sample event	Sample period	Method	Sample type	Mark type
1	2–10 August 2005	Electrofishing	mark	Elastomer + PIT tag
2	26–29 October; 1–4 November 2005	Electrofishing	mark/recapture	Elastomer + PIT tag
3	15–20 February 2006	Electrofishing	mark/recapture	PIT tag
4	17–22 May 2006	Electrofishing	recapture	None

Before sampling, each habitat unit was block netted using 6-mm mesh netting at the upstream and downstream ends, then electrofished, using a minimum of four passes. The total number of juvenile steelhead in each habitat unit was estimated using the Moran-Zippen removal estimator (Seber 1965). Juvenile steelhead density and biomass were estimated for each sampled habitat unit. All juvenile steelhead captured were anesthetized with MS-222 before fork length (FL, nearest mm) and wet weight (nearest 0.01 g) were measured. Scales were also collected from 22 steelhead in Redwood Creek and 19 steelhead in Heath Canyon during August 2005 to assess age composition. Age of fish was determined using scale analysis following the methods of DeVries and Frie (1996).

All captured juvenile steelhead greater than 65 mm were implanted with a passive integrated transponder (PIT) tag, and juvenile steelhead smaller than 65 mm were given a unique color mark using elastomer dye. Fish were marked in all sampling efforts, except during the final effort in May 2006. The 11.5-mm PIT tags were inserted into the body cavity anterior to the pelvic fin with a 12-gauge hypodermic needle (Prentice et al. 1985). To reduce risk of infection and tag loss, each tag was placed in a solution of Betadine, and then rinsed with saline prior to implantation. After tag insertion, the needle entry wound was sealed using Vetbond adhesive glue (3M Corp., Saint Paul, MN). After inserting PIT tags, the tag number and habitat unit of origin for each tagged fish were recorded. Fish were then allowed to recover before being returned to the habitat unit where they were captured.

Captured steelhead measuring less than 65 mm in length were given two visible subcutaneous elastomer tags. The tags were implanted beneath transparent or translucent tissue where they could be identified using an ultraviolet light. The two tags were injected into two of four possible mark locations using a combination of four different fluorescent colors. Mark locations included the left and right lower mandible and behind each eye. The multiple locations and colors allowed for individual identification of fish. Each color and location was recorded along with the fish size and weight data and capture location.

During subsequent sampling all marked fish were scanned with a tag reader; the tag number, fork length, wet weight, and habitat unit of capture were then recorded. Newly captured juvenile steelhead (those without marks) were marked (PIT or elastomer), weighed, and measured. Recapture efforts extended upstream and downstream of each study reach to increase the probability of recaptures.

2.1.4 Growth analysis

Growth was analyzed for the following periods:

- August to October/November (summer/early fall)
- October/November to February (fall/winter)
- February to May (spring)

Since growth is typically dependent on size, cohorts were analyzed separately. All steelhead were classified into cohorts based on the year that individuals emerged as fry. Cohort classification was based on the fork length when fish were observed, and was aided by size at age data from scales collected in August 2005 and from growth data from recaptures of fish of known age.

Incremental growth rates (*IG*) were calculated for all recaptured steelhead. Incremental growth was calculated as:

$$IG = \frac{S_2 - S_1}{t_2 - t_1}$$

where S_t= wet weight (g) or fork length at time *t*. Incremental growth provided an indication of absolute growth that occurred during the period of observation, while standardizing for time at large (since time between tagging and recapturing varied among sites).

Relative growth rates (*RG*) were also calculated to express the percent increase in fish size, standardized for time at large. Relative growth rate was calculated as:

$$RG = \left(\left(\frac{FL_2 - FL_1}{FL_1} \right) \Big/ t_2 - t_1 \right) \bullet 100$$

where FL_t = fork length at time t.

Fish length, rather than weight, was used for growth calculations because of the documented relationship between length of steelhead smolts at the time of outmigration and the probability of successful adult return (Shapovalov and Taft 1954, Kabel and German 1967, Ward et al. 1989).

2.1.5 Invertebrate drift sampling

Invertebrate drift was measured in one pool-riffle-pool complex in each study tributary to assess food availability for juvenile steelhead. The objectives of invertebrate drift sampling were to (1) characterize drift (i.e., food availability) in streams with different flow regimes, and (2) determine the influence of flow on drift delivery to the downstream pool.

Site (riffle) selection for invertebrate drift sampling included the following considerations:

- Sample at a pool-riffle-pool complex in each fish study tributary, representing the full range of flow and channel types,
- Sample riffles of approximately equal length,
- Sample the longest riffles possible, and
- Choose riffles a sufficient distance upstream (or downstream if none present upstream) of fish sampling reaches to avoid possible effects on growth due to interception of drift.

Invertebrate drift sampling was conducted during late September and early October, 2005. Approximately 170 separate drift net samples were collected. The drift sampling effort was conducted during the early fall low flow period because available information indicated that food availability is of the greatest bioenergetic importance to steelhead during this low growth period (Sullivan et al. 2000, Stillwater Sciences and Dietrich 2002), presumably due to the higher water temperatures that typically occur during this time. By sampling invertebrate drift during fall, we were able to maximize the amount of food availability data obtained during this bioenergetically critical period.

Drift nets were deployed at two locations in each riffle (Figure 2). The net at the top of the riffle (Net A) was used as a control, eliminating any drift entering the riffle from upstream. The net at the bottom of the riffle (Net B) captured drift originating from within the riffle. Drift nets with 363-micron nylon mesh were placed at the two sampling locations in each pool-riffle-pool complex and situated so they intercepted the entirety of the flow. In areas where the wetted channel was too wide to sample with a single net, two nets were placed side-by-side. Nets were left in place to sample during the three hours bracketing sunset (i.e., 1.5 hours before and 1.5 hours after sunset) for 12 consecutive nights. Nets were secured in place with rebar driven into the streambed, and the rebar was flagged and left in the streambed so that nets could be placed in the same location each evening. Water depth at the net mouth was measured with a meter stick, and velocity was measured with a Marsh-McBirney 2000 flow meter at 0.6 total depth at two equally-spaced locations in the mouth of each net to estimate the volume of water sampled.

Net contents were removed by washing the nets with water to move all contents into the removable collection reservoirs, which were then emptied directly into labeled sample bottles. Contents were preserved with 90% ethanol. Processing involved sorting each sample to remove debris and identifying all invertebrates to the lowest practicable taxonomic level (usually genus or family) and life stage. Each sample was processed in full (no subsampling) using a dissecting microscope at 12x magnification. Only invertebrates that were live at the time of capture, or dead invertebrates with significant amounts of internal tissue remaining, were counted. Each invertebrate was measured to the nearest millimeter to permit the use of taxon-specific length-mass regression equations to calculate invertebrate biomass. Terrestrial and aquatic invertebrates were sorted separately, to better assess food availability. The biomass of each prey item was determined using published length to biomass relationships that allowed determinations of the food value of potential invertebrate prey in each study reach.

2.1.6 Invertebrate drift analysis

Larval, pupal, and adult life stages, as well as total biomass, were used for analyses comparing invertebrate drift with relative steelhead growth rate. Analyses relating flow to invertebrate drift focused on biomass and frequency of the most common taxa available to fish. Preliminary analysis indicated that statistical comparisons were not warranted, and box and whisker plots were therefore used for graphical comparisons of drift among sites.

To reduce stochastic (i.e., random) bias, invertebrates >10 mm (generally of terrestrial origin; e.g., wasps) were removed from the data set for analysis. Because the effect of flow on prey delivery for steelhead was the focus of the analysis, the random occurrence of large individuals would have created a bias in the data because the occurrence of these large individuals in the drift is not related to flow. Rare taxa were also excluded from the data for purposes of prey availability analysis. If a taxon had fewer than 6 individual representatives in all of the drift net samples, that taxon was considered to rarely occur and was excluded from the analysis, unless there was a minimum of 1 representative in 3 or more of the study tributaries.

3 RESULTS

A total of 3,723 fish were captured, of which 91% were steelhead (Appendix A). Scale analysis indicated that, in August 2005, age 0+ steelhead ranged from approximately 65–93 mm fork length (FL); age 1+ ranged from approximately 96–201 mm FL, and the two steelhead aged 2+ and older were 154 mm and 213 mm FL (Figure 3). Of the 3,385 steelhead captured, 433 were recaptured at least once, and the overall recapture rate of marked steelhead was 19%. Mortality of steelhead related to sampling (i.e., electrofishing) was 2% overall. Bluegill (*Lepomis macrochirus*), California roach (*Lavinia symmetricus*), sculpin spp. (family Cottidae), mosquitofish (*Gambusia affinis),* green sunfish (*Lepomis cyanellus*), and a juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were also captured during fish sampling (Appendix A).

Steelhead growth, and the influence of each environmental parameter measured during this study, is discussed below.

3.1 Steelhead Growth

Four cohorts were present during the study period. The size range for each cohort at the time of sampling is presented in Table 3. Although it appeared that some steelhead captured were older than the 2003 cohort, no definitive criteria were available to assign them to a cohort, and thus they were grouped with a cohort designated as “2003 and older.”

Table 3. Cohort and age classification.

Cohort	Size range (mm FL)			
	August 2005	October 2005	February 2006	May 2006
2003 and older[a]	>151 (age 2+)	>151 (age 2+)	>166 (age 3+)	–
2004	101–150 (age 1+)	101–150 (age 1+)	111–166 (age 2+)	>210 (age 2+)
2005	0–100 (age 0+)	0–100 (age 0+)	0–110 (age 1+)	86–210 (age 1+)
2006[b]	–	–	–	0–85 (age 0+)

[a] Smolted during Spring 2006.
[b] Emerged in Spring 2006.

The sizes of all steelhead captured at different sampling dates are shown in Figure 4 for each cohort. Lines connecting the points between sampling events represent the growth of individual steelhead from one sampling period to the next, and illustrate the growth trajectory of each fish throughout its freshwater residence. The age 0+ fish captured in May 2006 showed a broad range in fork lengths (Figure 4). There are no growth data associated with these fish, since they emerged after the previous sampling period in February. Age 0+ fish captured in August 2005 (2005 cohort) show a similar range in sizes but are slightly larger than those from the 2006 cohort, indicating that age 0+ fish captured in May 2006 have the potential for continuing growth in late spring.

Overall, steelhead growth was greatest in spring (Figure 4). Figures 5–9 show the growth data for individual streams, illustrating a similar pattern among the study streams. Figure 10 shows the summarized growth increments for each cohort for the three growth intervals, again demonstrating the importance of the spring period for steelhead growth. As described below, the spring period during both years of this study had particularly high flows, which may have partially contributed to the pattern of high relative growth during spring. In addition, younger cohorts appeared to grow at slightly higher rates than older fish during all growth intervals in all streams (Figures 5–9; Figure 10), although growth of the 2003 cohort in most streams was not measurable for the fall/winter and spring periods.

The 2005 and 2004 cohorts generally showed little or no growth during the low-flow period of summer/early fall (August–October) (Figure 4). Steelhead belonging to the 2003 cohort that remained in the study streams (rather than outmigrating) also showed very little growth during this period. Despite poor growing conditions, the number of fish of each cohort recovered in October (following the summer/early fall growth period) was relatively high (Table 4 and Figure 4) indicating good summer/early fall survival, except in Pickle Creek (Figure 6), where fewer than 20% were recovered.

Table 4. Number and mean fork length (FL) of steelhead captured during each sampling event.

Steelhead captured during sampling (all reaches), 2005 to 2006

Cohort	All recoveries				Previously marked fish		
	Sampling event	Count	Mean FL (mm)	Stdev	Count	Mean FL (mm)	Stdev
2006	May	830	48	11.5	0	–	–
2005	August	1019	67	13.3	NA	NA	NA
	October	733	70	12.6	231	73	12.9
	February	123	83	13.6	11	95	14.8
	May	168	125	16.3	30	131	15.9
2004	August	141	122	13.6	NA	NA	NA
	October	154	124	14.2	83	124	13.9
	February	35	136	16.3	13	138	14.7
	May	52	171	17.6	6	160	19.9
2003	August	52	175	22.3	NA	NA	NA
	October	57	182	33.8	31	178	22.8
	February	10	203	60.4	1	159	NA
	May	9	224	10.1	0	NA	NA

Positive growth rates were observed among both the 2005 and 2004 cohorts during fall/winter in all study streams where February recaptures occurred (Figures 4–10). However, there was a very low recapture rate of all marked steelhead following the fall/winter period. Of the 168 steelhead captured in February 2006 (all cohorts combined) only 25 (15%) were fish that had been previously marked (Table 4). This indicates that steelhead were generally unable to persist in the stream reaches during the high flow fall/winter period and were likely displaced downstream. Winter survival during the period of study may have been influenced by an extreme rainfall and flood event that occurred in late December 2005 (Section 3.2.2). The fate of these steelhead is unknown, but unless there was good winter rearing habitat downstream they would likely have died.

Growth was greatest during spring 2006 (February–May) for the 2005 and 2004 cohorts (Figure 4). Spring growth analysis was not possible for the 2003 and older cohort due to insufficient recaptures. In the spring period between February and May 2006, steelhead belonging to the 2005 cohort grew rapidly and recovery rates of marked fish were relatively high, especially in Ritchey Creek (Figure 8), indicating a tendency for site fidelity of fish that did survive the winter. Interpreting growth of the 2004 cohort in the spring period is problematic because many of these older fish marked in February 2006 would have smolted and outmigrated prior to the May 2006 sampling. Nevertheless, the relatively few members of the 2004 cohort that were recaptured in May 2006 again indicate high growth rates in spring (Figure 4), with the highest recapture rates occurring in Heath Canyon Creek (Figure 5).

3.2 Influence of Environmental Factors on Steelhead Growth

The influence of channel morphology, stream discharge, invertebrate drift, water temperature, and steelhead density on growth of steelhead in the sampled Napa River tributaries is discussed below.

3.2.1 Channel morphology and growth

Many of the pool-riffle reaches in the selected areas for sampling were characterized as "forced pool-riffle" morphologies, where flow obstructions such as logs or boulders cause scour and/or deposition in what would otherwise be considered plane-bed channels (Montgomery and Buffington 1997) (Table 5). Most channels sampled were step-pool, or forced pool riffle in a predominantly plane-bed channel. There were no apparent differences in steelhead growth between plane-bed and step-pool channel types in any season (Figures 11–13). Apparently the environmental factors that most likely influence growth were not strongly influenced by the channel types observed during the period of study. There were no obvious differences in the study reaches based on amount of pool habitat or riffle habitat (Appendix B). Photographs taken at all sites (Appendix C) illustrate that differences in riparian canopy characteristics and coarse-scale channel morphology were relatively minor.

Table 5. Channel morphology in study reaches.

Stream	Reach	Channel type
Ritchey Creek	Lower	Forced pool-riffle/plane-bed
	Middle	
	Upper	Step-pool
Redwood Creek	Lower	Forced pool-riffle/plane-bed
	Upper	Step-pool
Heath Canyon	Lower	Step-pool
	Middle	
	Upper	
York Creek	Lower	Step-pool
	Upper	
Pickle Creek	Lower	Step-pool
	Upper	

3.2.2 Stream flow and growth

Hydrologic conditions in 2005 and 2006, the water years in which the study was conducted, were wetter than normal, with several high intensity storms during the study period. A large magnitude flood occurred on 31 December 2005, with a peak flow of 18,300 cfs as measured at the Napa River near St. Helena (USGS gage #11456000), which is the largest recorded flow measured at this gage for the period of record (WY 1930–1931, and 1940–2006). Rainfall amounts coinciding with this flood had recurrence intervals ranging from 25 to 100 years throughout the Napa basin (USGS unpublished data).

Although season-average hydrological conditions resembled a typical "wet" water year (Figure 14), winter (2005–2006) and spring (2006) flows during the study were of unusually high magnitude and duration (Figure 15). For example, flows during the spring are typically far less than were observed during 2005 or 2006 (Table 6). While winter and spring flows in the Napa River were atypically high during the study period, late summer flows were relatively low, and in fact resembled a "dry" water year during August and September (Figure 16). However, high spring flows in 2005 and 2006 persisted longer into the summer than in typical years, and flows did not reach summer baseflow levels until early August (Figure 16).

Baseflow conditions during July 2005 in the study reaches ranged from 0.05 cfs in the upper reach of Pickle Creek to 1.18 cfs in the lower reach of Redwood Creek (Table 7). The lowest flows during the study period were observed during August, and the highest flows were observed during February. Some reaches, including both reaches in Pickle Creek, lost surface flow during late summer and early fall of 2005 (Appendix D). In general, baseflow during the summer and early fall was persistent and relatively constant in the study reaches. Water level (stage) in most study reaches began fluctuating in November, with large, abrupt stage changes occurring throughout the winter and spring rainy period (Appendix D). Collection of stage data was confounded by channel drying in late summer/fall 2005 and displacement of several of the water stage loggers by high flows in winter 2005–2006, resulting in discontinuous or missing stage data in some reaches (Appendix D).

Table 6. Monthly average discharge in the Napa River near St. Helena (USGS gage #11456000) for selected months.

Month/Year	Average monthly flow (cfs)	Approximate % of years where flow was less in indicated month
March 2005	281	80
April 2005	79	75
May 2005	131	100
June 2005	28	100
July 2005	7	95
March 2006	521	95
April 2006	441	95
May 2006	46	90
June 2006	14	80

Table 7. Flow characterization in study tributaries.

Stream	Reach	Baseflow (cfs)					Flow index (flow/width)				
		July 2005	Aug 2005	Oct/ Nov 2005	Feb 2006	May 2006	July 2005	Aug 2005	Oct/ Nov 2005	Feb 2006	May 2006
Heath Canyon	Lower	0.28	NA	0.20	2.31	0.97	0.05	NA	0.06	0.22	0.13
	Middle	0.23	NA	0.19	2.36	NA	0.03	NA	0.06	0.22	NA
	Upper	0.21	0.06	0.14	1.07	0.95	0.05	0.01	0.02	0.11	0.14
	Invert[a]	NA	NA	0.02	NA	NA	NA	NA	0.001	NA	NA
Pickle Creek	Lower	0.07	NA	NA	1.45	0.38	0.02	NA	NA	0.14	0.06
	Upper	0.05	NA	0.06[b]	1.39	0.37	0.07	NA	0.03[c]	0.17	0.07
Redwood Creek	Lower	1.18	0.34	0.47	12.02	8.16	0.12	0.05	0.05	1.01	0.76
	Upper	0.54	NA	0.30	8.02	3.96	0.06	NA	0.06	0.50	0.17
	Invert[b]	NA	NA	0.08	NA	NA	NA	NA	0.02	NA	NA
Ritchey Creek	Lower	0.20	0.50	0.24	2.29	1.30	0.04	0.04	0.04	0.18	0.11
	Middle	0.41	0.42	0.30	NA	NA	0.04	0.09	0.04	NA	NA
	Upper	0.43	0.41	0.42	1.88	1.40	0.08	0.06	0.07	0.19	0.17
	Invert[b]	NA	NA	0.22	NA	NA	NA	NA	0.04	NA	NA

Stream	Reach	Baseflow (cfs)					Flow index (flow/width)				
		July 2005	Aug 2005	Oct/ Nov 2005	Feb 2006	May 2006	July 2005	Aug 2005	Oct/ Nov 2005	Feb 2006	May 2006
York Creek	Lower	0.70	NA	0.43	3.73	2.15	0.10	NA	0.11	0.35	0.18
	Upper	0.76	NA	0.57	NA	2.02	0.13	NA	0.08	NA	0.21
	Invert[b]	NA	NA	0.14	NA	NA	NA	NA	0.03	NA	NA

NA = flow not measured

[a] Measurements taken during invertebrate drift sampling in late September-early October 2005.

[b] Based on estimated flow index during July 2005.

[c] Measurement was taken in 2006.

Growth of age 0+ and 1+ steelhead was generally higher in reaches with higher flow indices than in lower flow reaches during summer/early fall (Figures 17 and 18) and fall/winter (Figures 19 and 20), but this apparent trend had exceptions. In upper Heath Creek, which had a low flow index, growth of age 0+ steelhead was relatively high (Figure 17). In upper York Creek, flows were relatively high but growth of age 1+ steelhead was relatively low (Figure 18). No relationship was evident between steelhead growth and flow during spring for either age cohort (Figures 21 and 22). It is possible, however, that the prolonged duration of relatively high spring flows during the study period provided a longer spring growth season for steelhead than would occur in more typical (i.e., “normal” or “dry”) water years. Although steelhead growth data from dryer years are not available to test this hypothesis, our observations of high spring growth rates suggest that a longer spring growth period would likely result in additional growth if conditions (e.g., water temperature, food availability) were favorable. Apparent relationships between growth and flow, as well as the aforementioned exceptions, should be interpreted with caution due to low sample sizes, especially in fall/winter (Figures 19 and 20) and spring (Figures 21 and 22).

3.2.3 Invertebrate drift and growth

The most common taxa present in the drift samples were chironomid midges and mayflies (Appendix E), and were thus the taxa used for all analyses. Chironomids were classified to family (Chironomidae), whereas mayflies were generally classified to species or genera. The most common mayfly taxa present in the samples included:

- *Baetis tricaudatus,*
- *Centroptilum/Procloeon spp.,*
- *Diphetor hageni,*
- *Ecdyonurus criddlei,*
- *Ironodes spp.,*
- *Paraleptophlebia spp.*, and
- *Tricorythodes minutus*

Average daily biomass of all invertebrates was relatively high in Redwood, Ritchey, and York creeks, and low in Heath and Pickle creeks (Figure 23). Average daily biomass of larval life stages was particularly high in York Creek, and adult biomass was particularly high in York and Ritchey creeks. Among the streams with the lowest flow indices (Pickle and Heath creeks) biomass and frequency of chironomids and mayfly larvae was also very low (Figures 24–27). Pickle Creek had little or no measurable surface flow during invertebrate sampling; consequently invertebrate drift was very low. Among the streams with higher flows there was no apparent relationship between flow index and biomass or frequency of chironomids or mayflies (Figure 24–27). It is possible that a stronger relationship between flow and invertebrate drift exists, as has been observed by other researchers (e.g., Harvey et al. 2006), but was not apparent in this study, since all streams sampled essentially had low flow (<1 cfs) during October drift sampling (Table 7).

Mean drift rate in our study streams ranged from approximately 1.5 to 13.5 mg/hr and mean drift concentration ranged from approximately 0.4 to 3.0 mg/m^3. These results are slightly lower but generally comparable to those found in Harvey et al's (2006) mid-September experimental treatments in Jacoby Creek, a small northern California trout stream. The low drift rates and concentrations observed by Harvey et al. (2006) were cited as a primary factor explaining the low rainbow trout growth rates observed in their low-flow experimental treatments. If the similarly low invertebrate drift rates and concentrations observed during our October drift sampling are representative of summer/early fall food availability in Napa River tributaries, this may indicate that food availability is a key factor limiting steelhead growth during the low flow season.

Despite these observations, no patterns were evident between growth of steelhead and invertebrate drift (Figures 28–31). It is likely that there was insufficient variation in drift among streams to see the effect of invertebrate drift on steelhead growth. If flow indices in some reaches had been higher, there may have been more invertebrate biomass and thus greater differences in growth.

3.2.4 Water temperature and growth

Daily mean water temperatures in most study reaches were typically between 15 and 20°C during summer 2005 and less than 15°C during winter (Appendix F). However, temperatures in Pickle Creek regularly exceeded 20°C during summer (Appendix F). Overall, all streams were much warmer in summer 2006 than 2005. Temperature spikes in Pickle Creek in summer 2006 were likely due to the stream becoming dry, and the temperature data logger being exposed (Appendix F). Because this study was conducted under wetter than normal hydrological conditions, it is assumed that water temperatures during this study were lower than they would be in normal or dryer water years. This assumption is supported by water temperature data from summer 2006, after the conclusion of the growth study, when flows in the study reaches were lower (Table 7) and water temperatures were in fact considerably higher than in summer 2005 (Appendix F).

Most fish maintain body temperatures that closely match their environment (Moyle 1993). As a result, water temperature has a strong influence on almost every life history stage of steelhead (Berman 1998), including metabolism and growth (Sullivan et al. 2000). Growth depends on temperature and food availability. Sullivan et al. (2000) found that juvenile steelhead growth opportunities were maximized, and long-term growth deficits were most effectively overcome, when maximum weekly water temperatures were between 14.5 and 21°C. Similarly, Wurtsbaugh and Davis (1977, as cited in Myrick and Cech 2001) reported maximum growth of juvenile steelhead at temperatures ranging from approximately 14–16°C, depending on ration size. Water temperatures during this study were relatively consistent among the study streams, and were generally within the range most suitable for steelhead growth during summer/early fall 2005 (Appendix F). However, water temperatures fell below this range during the fall/winter period. Temperature data during fall/winter were not reliably recorded in all reaches due to displacement of some thermographs by high flows, but temperatures during this period can be deduced based on trends before and after the data gaps. Although water temperatures during the spring growth period remained below the range of optimal growth (Appendix F), growth was highest during spring for all cohorts in all study reaches (Figures 4–10). This indicates that spring water temperatures and food availability were within the range conducive to positive growth. These findings are consistent with growth data reported by Myrick and Cech (2001) and Wurtsbaugh and Davis (1977), which generally showed positive growth at temperatures as low as 6.9°C, as long as ration levels were at least 50–60% of maximum. It appears, therefore, that although summer/early fall water temperatures in the study tributaries are most suitable for steelhead growth, growth is indeed limited by food availability.

While temperatures during colder months with higher flows are typically less than optimum for growth, they are nonetheless within a range that allows for substantial growth given adequate food resources.

3.2.5 Steelhead density and growth

We compared the August and October densities of steelhead in each age class (0+, 1+, and 2+ and older) in each study stream to examine whether densities declined significantly during summer/early fall. We also compared August 2005 densities of age 0+ and age 1+ steelhead with growth, under the assumption that if density was affecting growth, it would be during the summer/early fall period. Densities of age 0+ steelhead declined significantly during the summer/early fall period in almost every study reach (Figure 32, Table 8). Only in Heath Canyon Creek, where the similarity in densities at the upper study reach influenced the statistical comparison for Heath Canyon Creek as a whole, was the decline not significant. Differences in August and October densities for age 1+ and 2+ (and older) steelhead were not significant in any of the study streams (Figures 33 and 34, Table 8). These results indicate that survival during the summer/early fall is poor for the youngest steelhead, but apparently increases for older age classes. Although it is possible that members of the 0+ age class may have migrated to other parts of the study streams rather than perishing, it is unlikely that habitat conditions (e.g., water temperature, flow persistence, food availability, cover) or conspecific density would have been more favorable to survival in other areas.

Table 8. Results of Wilcoxon paired-sample test (Wilcoxon 1945, Wilcoxon and Wilcox 1964, as cited in Zar 1999) comparing August vs. October 2005 steelhead densities in each study reach.

Cohort	Stream	n	P-value
Age 0+	Heath Canyon Creek	13	0.1460
	Pickle Creek	7	0.0078
	Redwood Creek	7	0.0078
	Ritchey Creek	15	0.0011
	York Creek	16	0.0016
Age 1+	Heath Canyon Creek	13	0.2217
	Pickle Creek	7	0.2500
	Redwood Creek	7	0.1875
	Ritchey Creek	15	0.3428
	York Creek	16	0.2129
Age 2+ and older	Heath Canyon Creek	13	0.1406
	Pickle Creek	7	1.0000
	Redwood Creek	7	0.6875
	Ritchey Creek	15	0.2188
	York Creek	16	0.0625

Growth rates of age 0+ steelhead during summer/early fall were highest in reaches with relatively low steelhead densities (Figure 35). The highest summer/early fall growth rate of age 0+ steelhead occurred in the upper reach of Heath Canyon, which had the lowest density of any reach. Conversely, the middle reach of Heath Canyon had the highest density of age 0+ steelhead and the lowest growth rate. Other reaches where low growth rates of age 0+ steelhead were observed (e.g., lower Ritchey Creek, upper and lower Pickle Creek, lower Heath Canyon) had densities that ranged from very low to high (Figure 35). This suggests that density may influence growth when density is very low or very high, but that other factors such as food availability, water temperature, or cover may become important at intermediate densities. The summer/early fall density of age 1+ steelhead did not appear correlated with growth rate (Figure 36), although growth rates for this age class were so low that patterns may have been obscured.

3.3 Population Level Effects of Reduced Summer Growth

In California, it is widely accepted that most adult steelhead returns are from fish that smolted at age 2+ or older. For example, in Waddell Creek Shapovalov and Taft (1954) found that 69% of the adult returns were from fish that smolted at age 2+, and 19% had outmigrated as age 3+, while only 10% were from fish that outmigrated as age 1+. In addition, the size of age 2+ smolts is positively correlated with marine survival, with smolts greater than 170 mm typically having high (>10%) survival in the marine environment (Ward et al. 1989), and in streams with robust steelhead populations (e.g., Keogh River in British Columbia) age 2+ smolts often average around 170 mm or larger (Ward and Slaney 1988).

Data on the size of outmigrating steelhead smolts could not be obtained for this study. However, the age 2+ fish that were observed during May 2006 were likely the fish that did *not* outmigrate, and thus were likely smaller than the fish that did outmigrate as smolts. Age 2+ steelhead that do not outmigrate typically rear in fresh water until age 3+, and outmigrate during the subsequent fall or winter. For all study reaches combined, the length of age 2+ steelhead averaged 136 mm FL in February and 171 mm in May (Table 9). In Lagunitas Creek, Marin County, California, which is considered to have a robust steelhead population, age 2+ steelhead also averaged 136 mm FL in February, and outmigrated at around 165 mm (Stillwater Sciences 2007). Based on size in February, steelhead in the Napa River tributaries we studied appear likely to be able to attain a smolt size sufficient to allow high marine survival and adult returns.

Table 9. Summary of size of steelhead in all reaches combined.

Survey date	Cohort (age)	Average FL (mm)	Sample size	SD
August 2005	2003 (age 2+)	175.0	52	22.3
	2004 (age 1+)	122.3	141	13.6
	2005 (age 0+)	66.5	1,019	13.3
October 2005	2003 (age 2+)	182.4	57	33.8
	2004 (age 1+)	123.8	154	14.2
	2005 (age 0+)	70.1	733	12.6
February 2006	2003 (age 3+)	202.8	10	60.4
	2004 (age 2+)	135.7	35	16.3
	2005 (age 1+)	83.3	123	13.6
May 2006	2003 (age 3+)	224.4	9	10.1
	2004 (age 2+)	170.7	52	17.6
	2005 (age 1+)	124.6	168	16.3
	2006 (age 0+)	48.2	830	11.5

Based on a predominance of age 2+ steelhead generally greater than 170 mm in May, August, and October, and February sizes averaging 136 mm (Table 9 and Figure 37), it does not appear that low summer and fall flows are having deleterious impacts on the size of outmigrants. However, the average size of age 2+ steelhead in February in Ritchey Creek and Pickle Creek was less than 136 mm (Table 10 and Figure 38), suggesting that production of large smolts in these streams may be poor. In addition, observed growth rates were highest during spring (Figure 10), and flows during the study period were exceptionally high during spring compared to other years (Section 3.2.2). Therefore it is possible that the suitable outmigrant sizes observed in this study were at least partially attributable to the unusually high spring flows. High flows could contribute to high spring growth rates by increasing food (i.e., invertebrate drift) delivery rates and by reducing steelhead density, thereby reducing competition for food and space.

Table 10. Summary of age 2+ steelhead size (fork length) in February 2006.

Stream	Sample size	Average FL (mm)
Ritchey Creek	7	126.0
Redwood Creek	3	140.3
Heath Canyon	13	139.9
York Creek	11	137.6
Pickle Creek	1	115.0

The growth analysis conducted in this study is one means of assessing population level affects of low summer/early fall flows. However, in streams such as Pickle Creek, which completely dry in many locations during the late summer and fall, production of steelhead is clearly limited, regardless of growth or outmigrant size. In some reaches, many fish may have migrated or died in response to some combination of low flows, high water temperature, and low food availability. This is partly reflected in the low density of fish observed in some reaches where growth was observed (Figures 35 and 36). In these instances the recapture rate is indicative of the ability of fish to remain in a reach (i.e., “persistence”). In the Lower Pickle Creek reach for example, over 90% of the fish tagged during August were not recaptured during the October sampling (Figure 39). In some reaches with high growth, persistence was high (e.g., upper Heath Canyon), perhaps demonstrating a preference for those habitats (Figure 39), but overall there was not a clear relationship between growth and persistence of individual steelhead (Figure 40). For example, in Ritchey Creek persistence is relatively high and growth is relatively low (Figure 39).

Low flows in summer/early fall (<1 cfs) can reduce steelhead carrying capacity in two ways: (1) low flows can result in higher water temperatures and if temperatures reach lethal levels the juvenile steelhead will be lost; (2) low flows can result in drying of the pools that steelhead often depend on for summer survival. Complete drying will obviously kill rearing steelhead if they cannot relocate to areas with suitable wetted habitat. Even if pools do not completely dry up, reduced pool depth can increase the risk of predation by animals such as birds or garter snakes. If the low flows do not result in either of these two conditions, our study results suggest that the lack of growth in the summer due to low flows may not, by itself, be deleterious to steelhead production.

3.4 Uncertainties

If steelhead can survive the summer, it appears that juvenile growth is likely sufficient to produce large smolts with a high probability of ocean survival. However, winter survival of juvenile steelhead appears to be very low, though winter survival during this study may have been influenced by an extreme rainfall and flood event that occurred in late December 2005 (Section 3.2.2). While this study was not designed to specifically examine winter survival, the retention rate of both age 0+ and 1+ steelhead over the winter was very low, leading to low numbers of age 2+ steelhead in February. Substantial embeddedness of coarse substrate (i.e., cobbles and boulders) is believed to result in low winter carrying capacity for juvenile steelhead. It is possible that an increase in the quantity or quality of winter refuge habitat would increase smolt production, but additional studies would be needed to confirm overwinter survival limitations and to quantify the type and quality of available overwintering habitat in the study streams.

A total of 35 age 2+ steelhead were captured in all study reaches in February 2006. While it is possible that additional age 2+ steelhead reared in downstream reaches or the mainstem Napa River, the absence of outmigrant trapping data made it impossible to assess actual steelhead production from the study reaches. Therefore, the size of age 2+ steelhead in February was used as a proxy for the ability of the population to produce large smolts. If outmigrant data were collected, they might indicate that some of the studied stream reaches have very low production of large juvenile steelhead.

The narrow range of flow, invertebrate drift, and water temperatures in summer/early fall in the streams sampled was indicative of the environmental conditions in the majority of tributaries to the Napa River. It is possible that a stronger relationship between flow, invertebrate drift, and growth exists, but was not apparent in this study because of the range of the low (<1 cfs) flows during the summer/early fall sampling period. As a result, we cannot determine whether a threshold flow, or flow index, may exist that would potentially define a lower limit for adequate steelhead growth.

3.5 Conclusions and Recommendations

Overall, growth during the low flow period (summer/early fall) in 2005 was relatively low for all cohorts and in all study reaches. These results are consistent with the research of Harvey et al. (2006), who showed that reduced flows resulted in lower growth rates. However, with the exception of a few stream reaches that dried up during fall, the study streams likely produced age 2+ smolts large enough to have high survival rates in the marine environment. These results are also consistent with the work of Harvey et al. (2006), who observed that despite reduced growth rates during summer, survival of juvenile rainbow trout was unaffected. In our study streams, rapid growth during the spring appears to compensate for growth limitations during the remainder of the year. However, flows during the period of this study were exceptionally high during spring compared to other years (Section 3.2.2), and this growth advantage may not occur in all years. If steelhead did not grow during spring, this advantage would be lost. Therefore, environmental conditions during spring, including invertebrate production, water volume, and water temperature, are likely the key factors affecting steelhead growth in Napa River tributaries. The risk of losing the growth advantage during spring may be particularly acute during naturally dry water years. During dry water years, the effects of naturally low flows can be exacerbated by additional water diversions for frost protection of crops, which is more likely to occur during the cold conditions associated with dry water years.

Additional research, together with long-term monitoring and adaptive management, is recommended to continue to evaluate steelhead populations and refine management priorities and strategies. Specific recommendations are listed below.

3.5.1 Recommended Research

- ***High Priority:*** Conduct outmigrant trapping to determine the size and timing of outmigrating Napa River steelhead smolts and directly measure production. These data will help managers evaluate the likelihood of population persistence.
- ***High Priority:*** If smolt outmigration data indicate low numbers of smolts, evaluate potential winter habitat limitations with focused field studies to measure over-winter survival and assess quality and quantity of winter refuge habitat.
- ***Medium Priority:*** Implement a study to determine the potential effects of predation on juvenile steelhead survival in the mainstem Napa River and tributaries.
- ***Medium Priority:*** Conduct additional steelhead growth monitoring, especially during years with normal and/or dry hydrologic conditions, to further investigate effects of stream flow on growth and determine if the results of this study were unique.

3.5.2 Recommended Monitoring and Management

- ***High Priority:*** Monitor stream flows in key reaches to ensure that steelhead rearing areas remain wetted during crucial growth periods. Of key importance for steelhead is the maintenance of connectivity between habitat units, and uninterrupted food (i.e., invertebrate drift) delivery from riffles to pools.
- ***High Priority:*** Develop guidelines for the Napa River basin that ensure that water diversions in tributaries do not dewater key steelhead rearing reaches, substantially impair connectivity between habitat units, or eliminate food delivery to pools. This may be especially important in summer/early fall to prevent complete dewatering and in spring to ensure growth opportunities are maximized.
- ***Medium Priority:*** Manage water diversions from key steelhead rearing tributaries to ensure that the duration and magnitude of high spring flows are similar to the unimpaired flow regime. Protection against an anthropogenically early onset of the summer low flow period will maximize the critical spring growth period for juvenile steelhead.
- ***Medium Priority:*** Increase outreach and education to landowners, growers, and other water users regarding key anthropogenic factors affecting steelhead populations to promote voluntary reductions in human water use and impacts, especially during spring and late summer.

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Figures

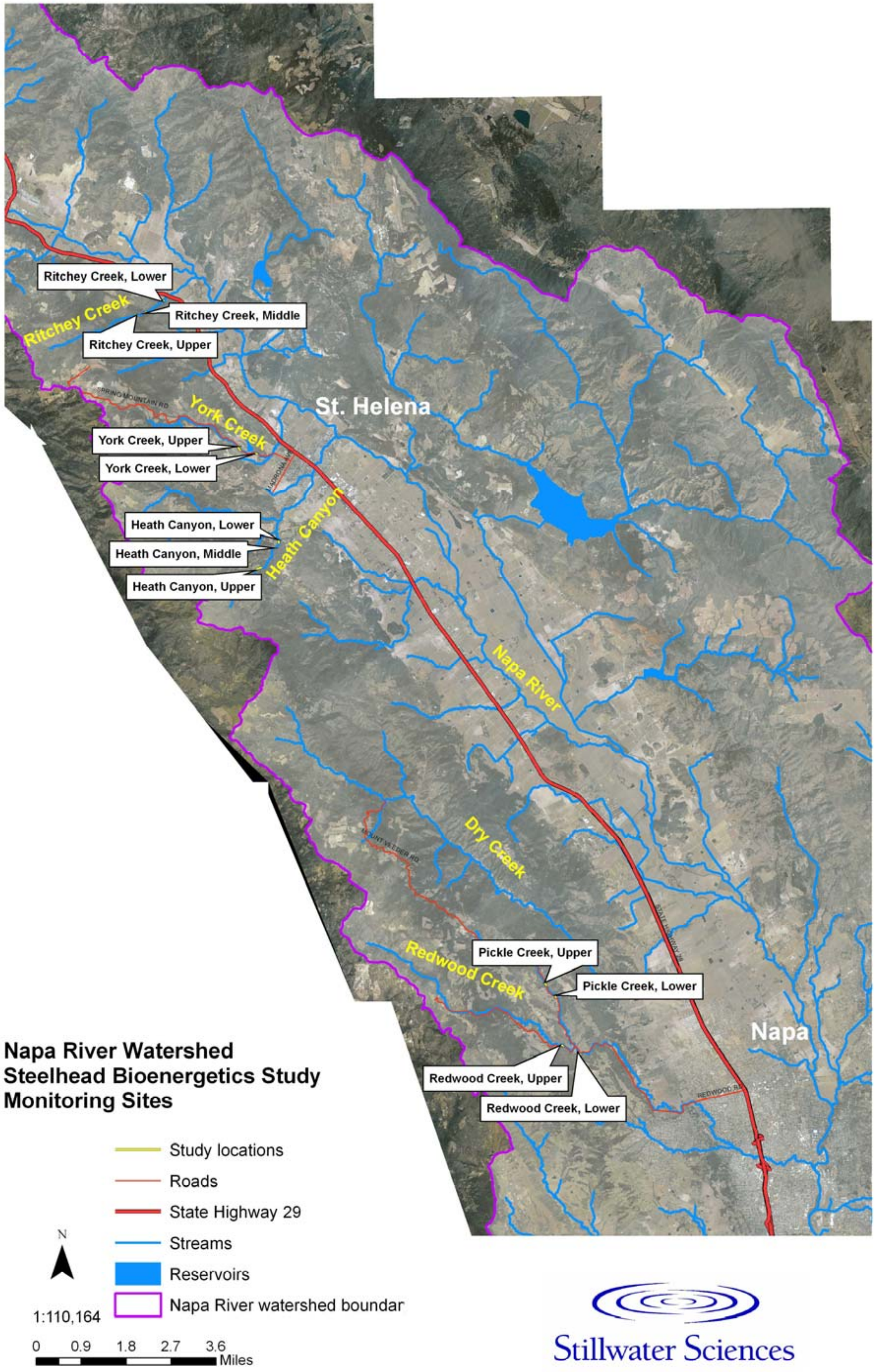

Figure 1. Study Area.

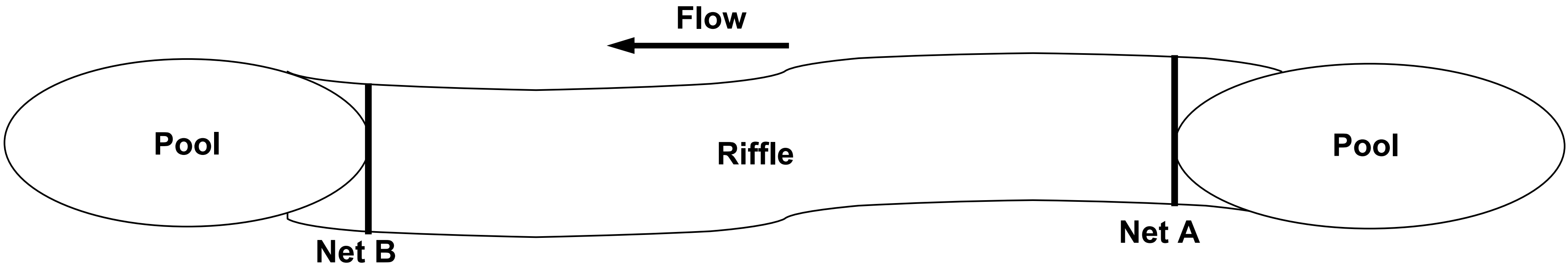

Figure 2. Schematic diagram of invertebrate drift sampling at a hypothetical pool-riffle-pool complex.

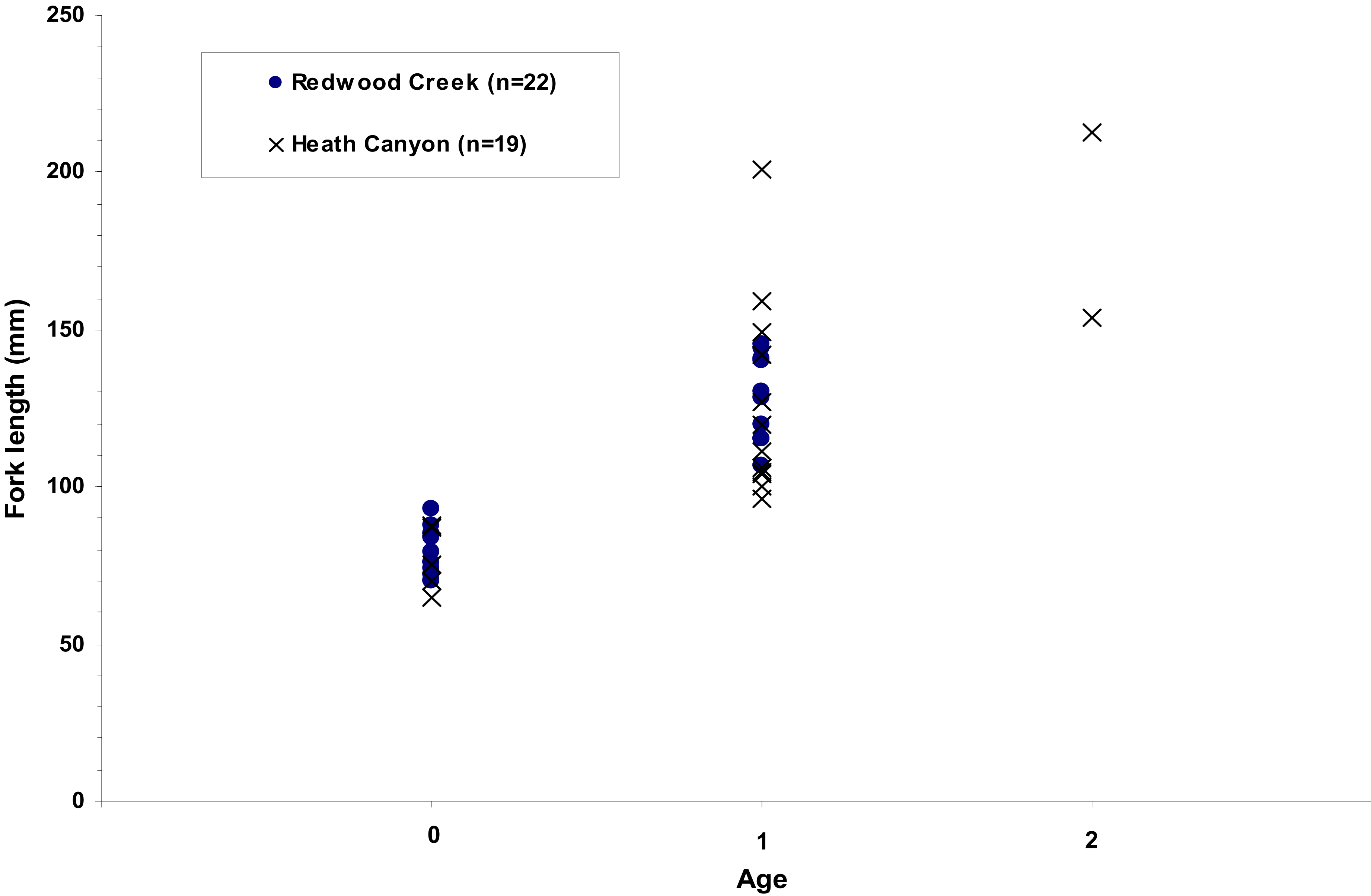

Figure 3. Size at age for steelhead in Redwood Creek and Heath Canyon, based on scales collected in August 2005.

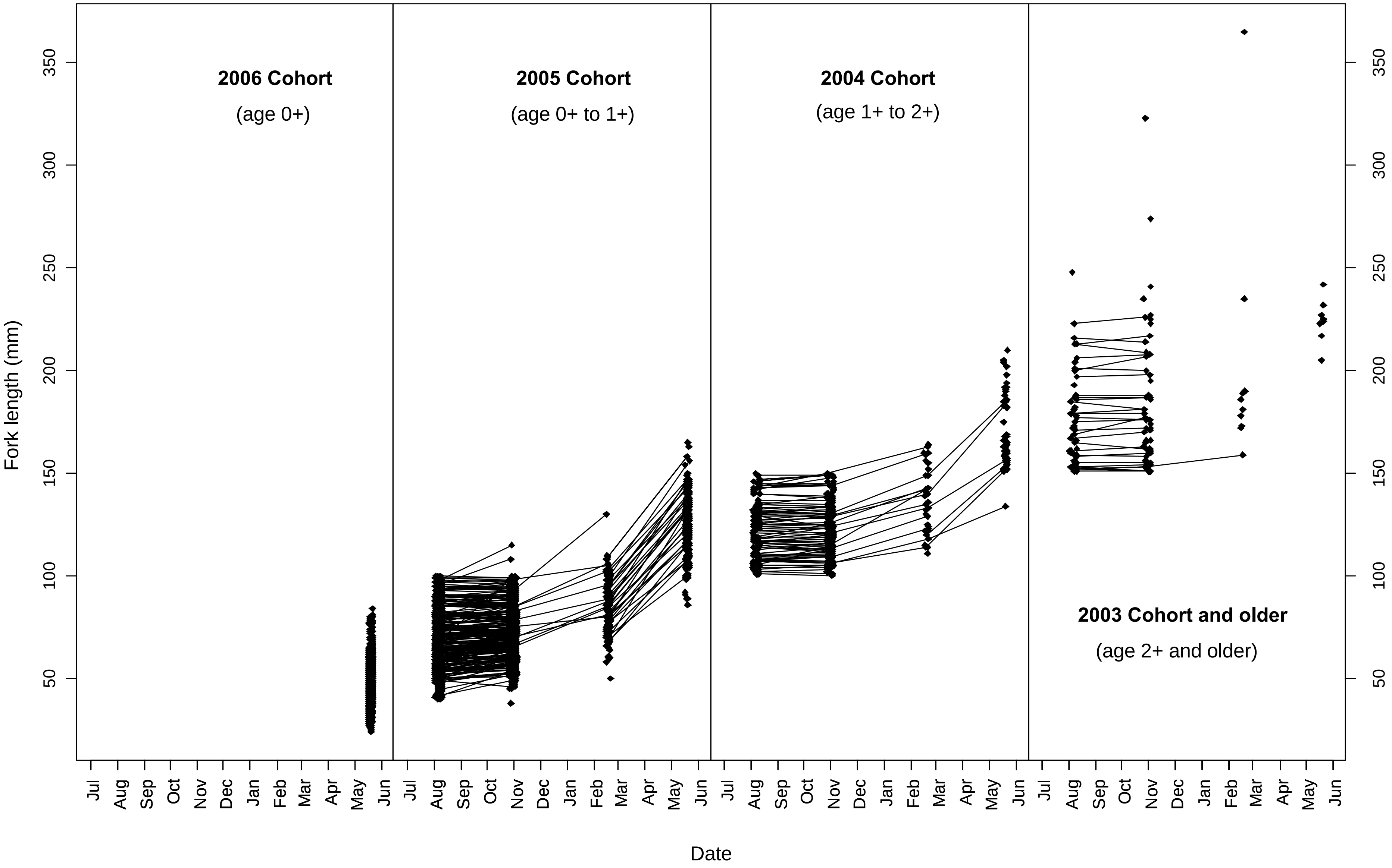

Figure 4. Steelhead size and growth in all study reaches combined, 2005 to 2006. Solid diamonds mark the sizes of individual fish, and successive measurements of the same individual are joined by line segments.

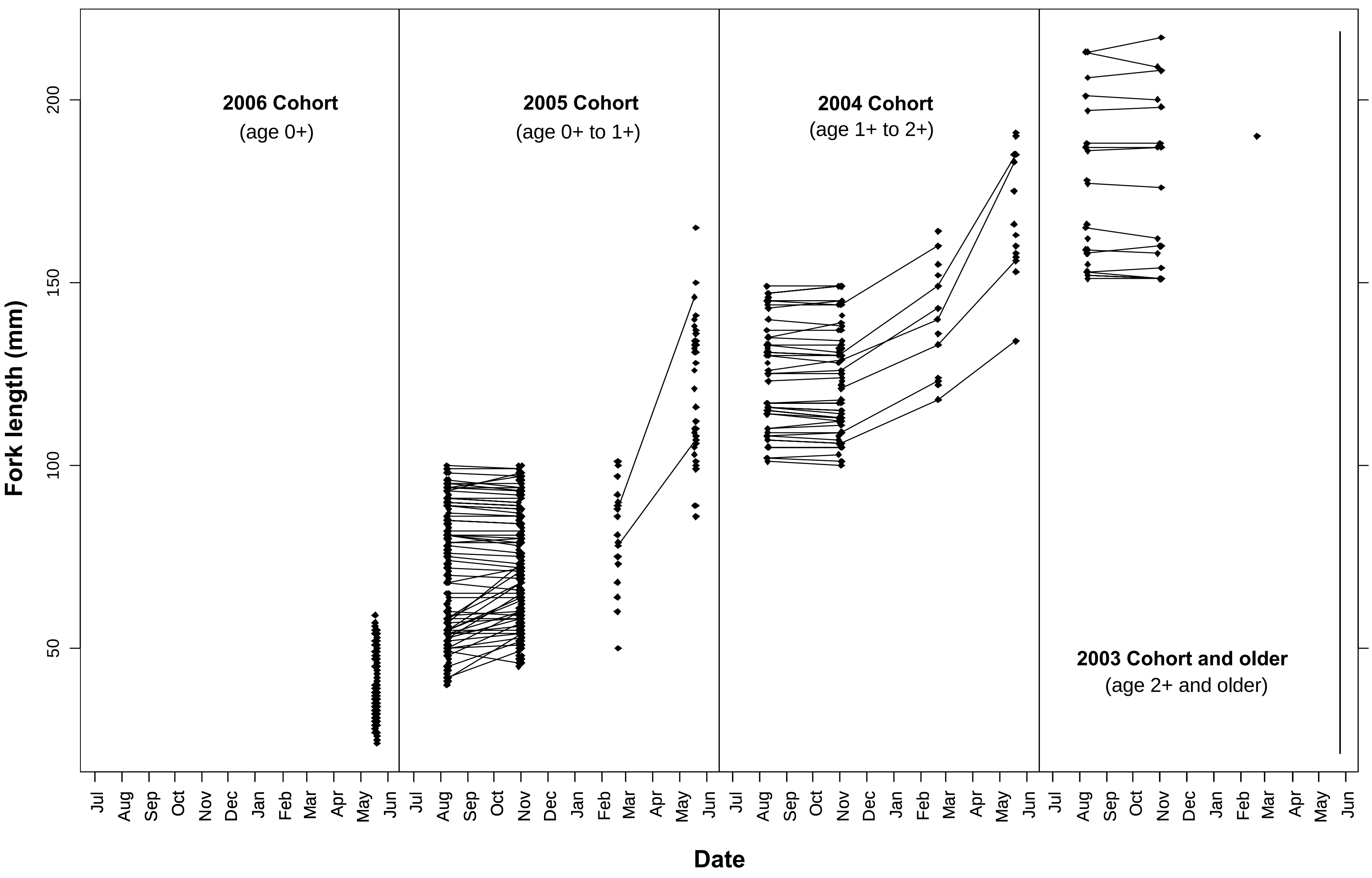

Figure 5. Steelhead size and growth in Heath Canyon, 2005 to 2006. Solid diamonds mark the sizes of individual fish, successive measurements of the same individual are joined by line segments.

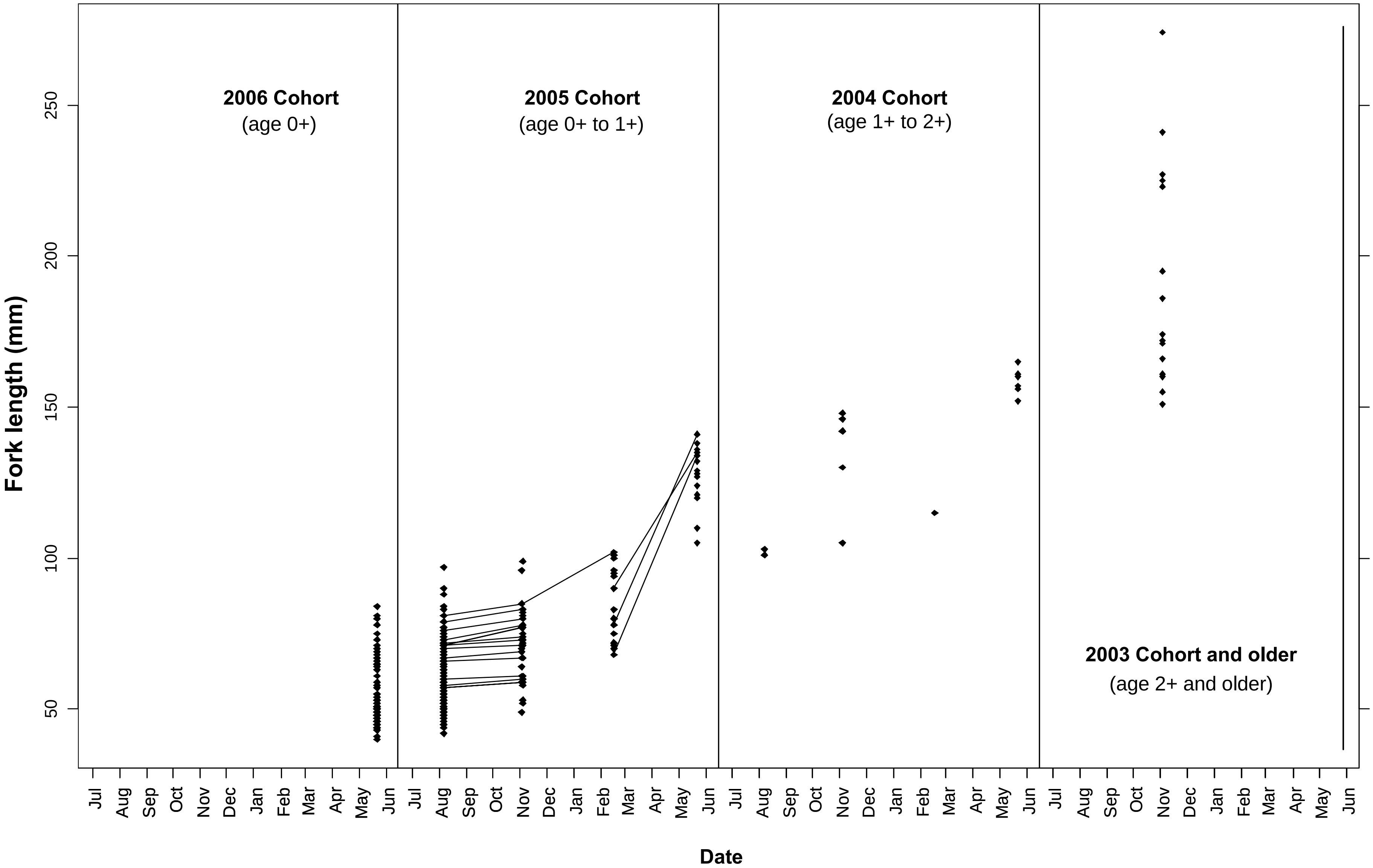

Figure 6. Steelhead size and growth in Pickle Creek, 2005 to 2006. Solid diamonds mark the sizes of individual fish, successive measurements of the same individual are joined by line segments.

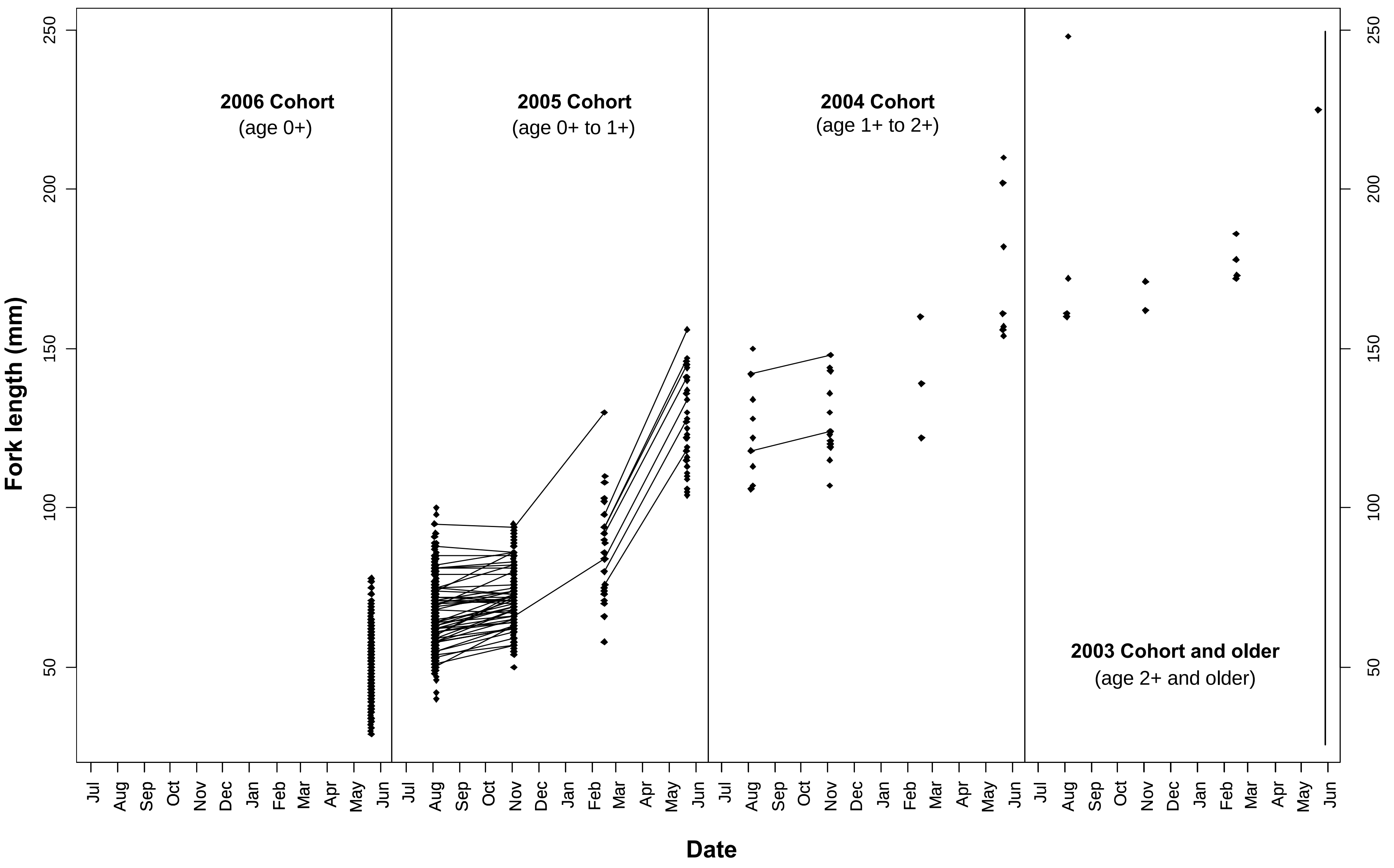

Figure 7. Steelhead size and growth in Redwood Creek, 2005 to 2006. Solid diamonds mark the sizes of individual fish, successive measurements of the same individual are joined by line segments.

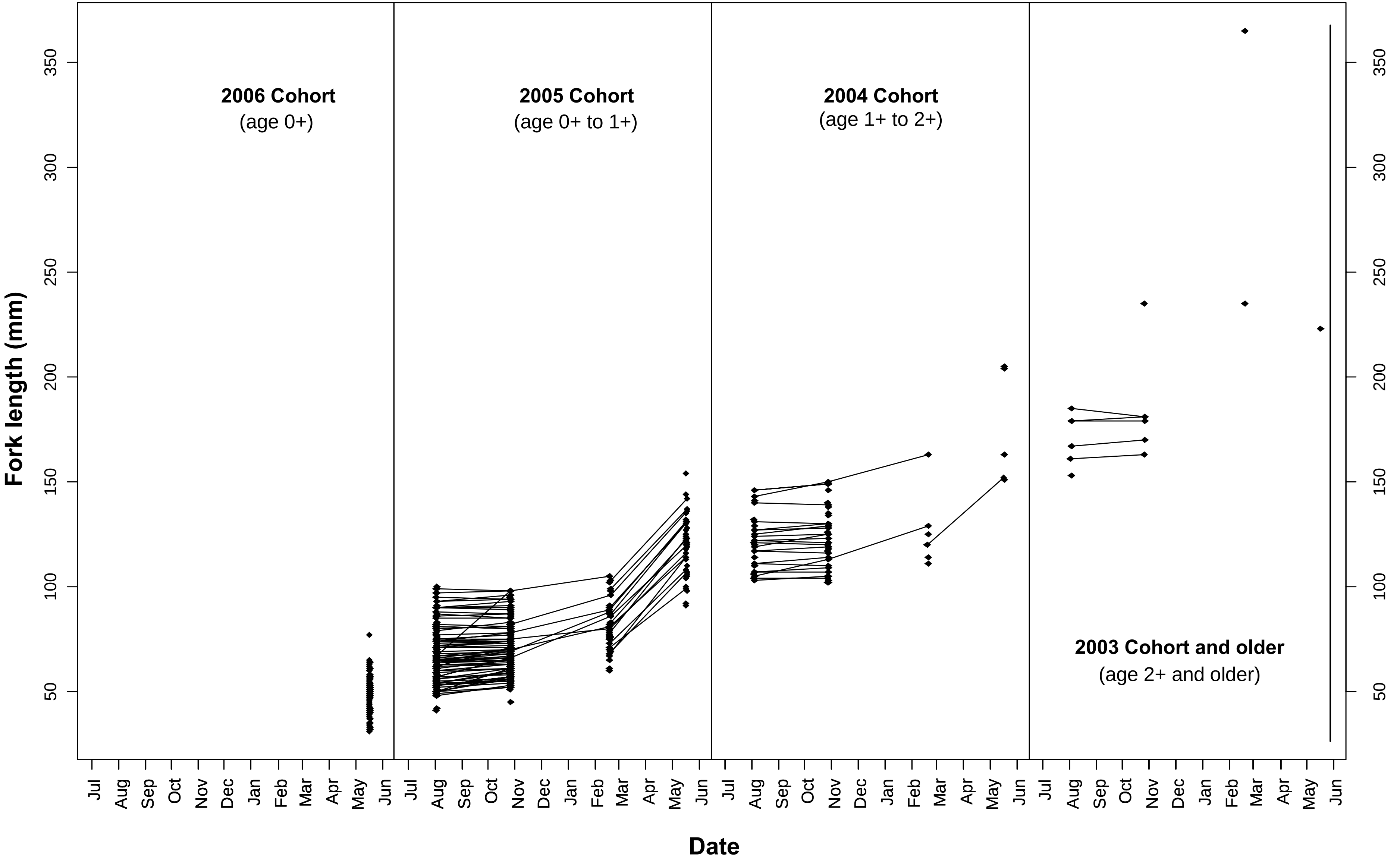

Figure 8. Steelhead size and growth in Ritchey Creek, 2005 to 2006. Solid diamonds mark the sizes of individual fish, successive measurements of the same individual are joined by line segments.

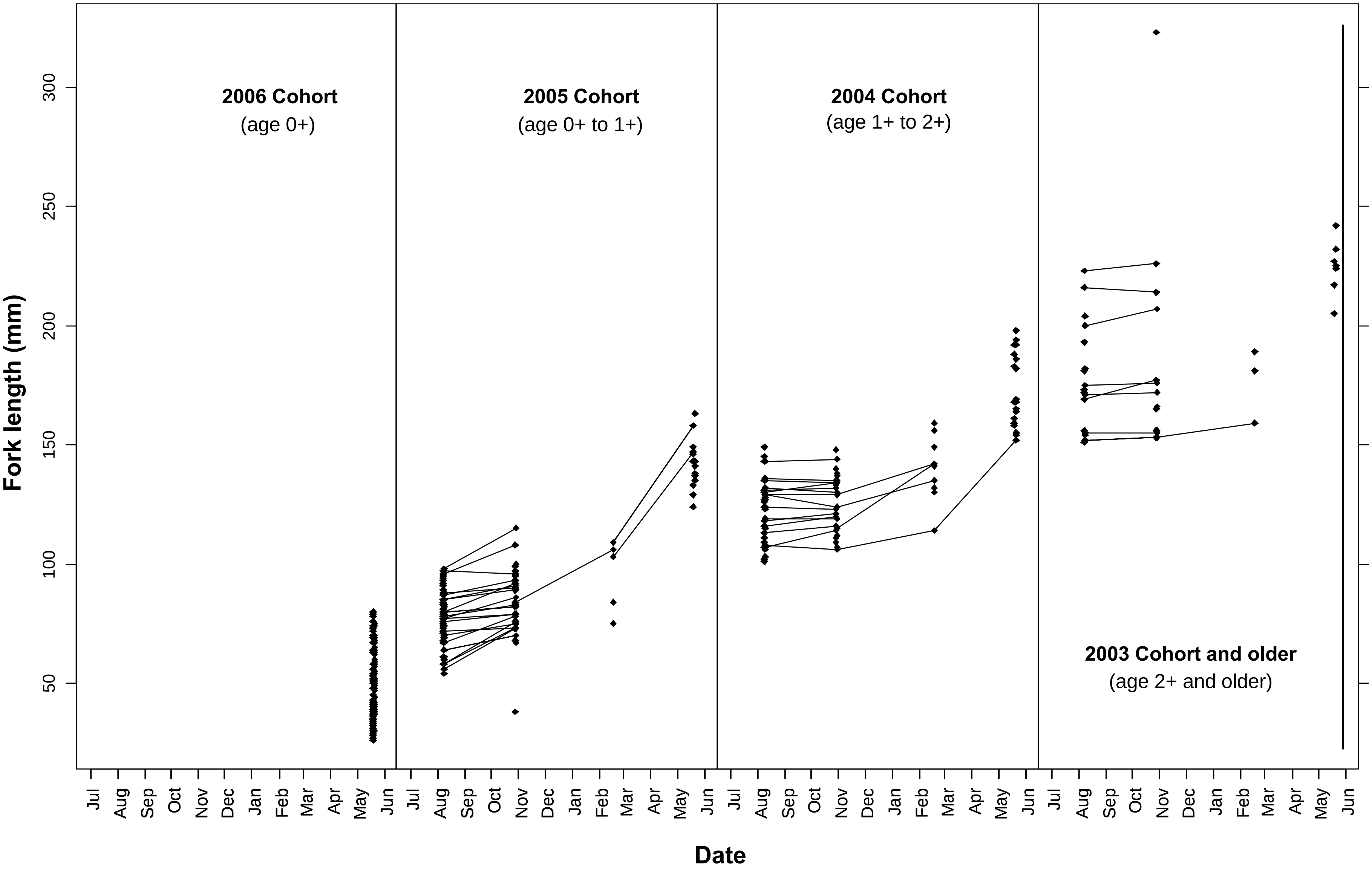

Figure 9. Steelhead size and growth in York Creek, 2005 to 2006. Solid diamonds mark the sizes of individual fish, successive measurements of the same individual are joined by line segments.

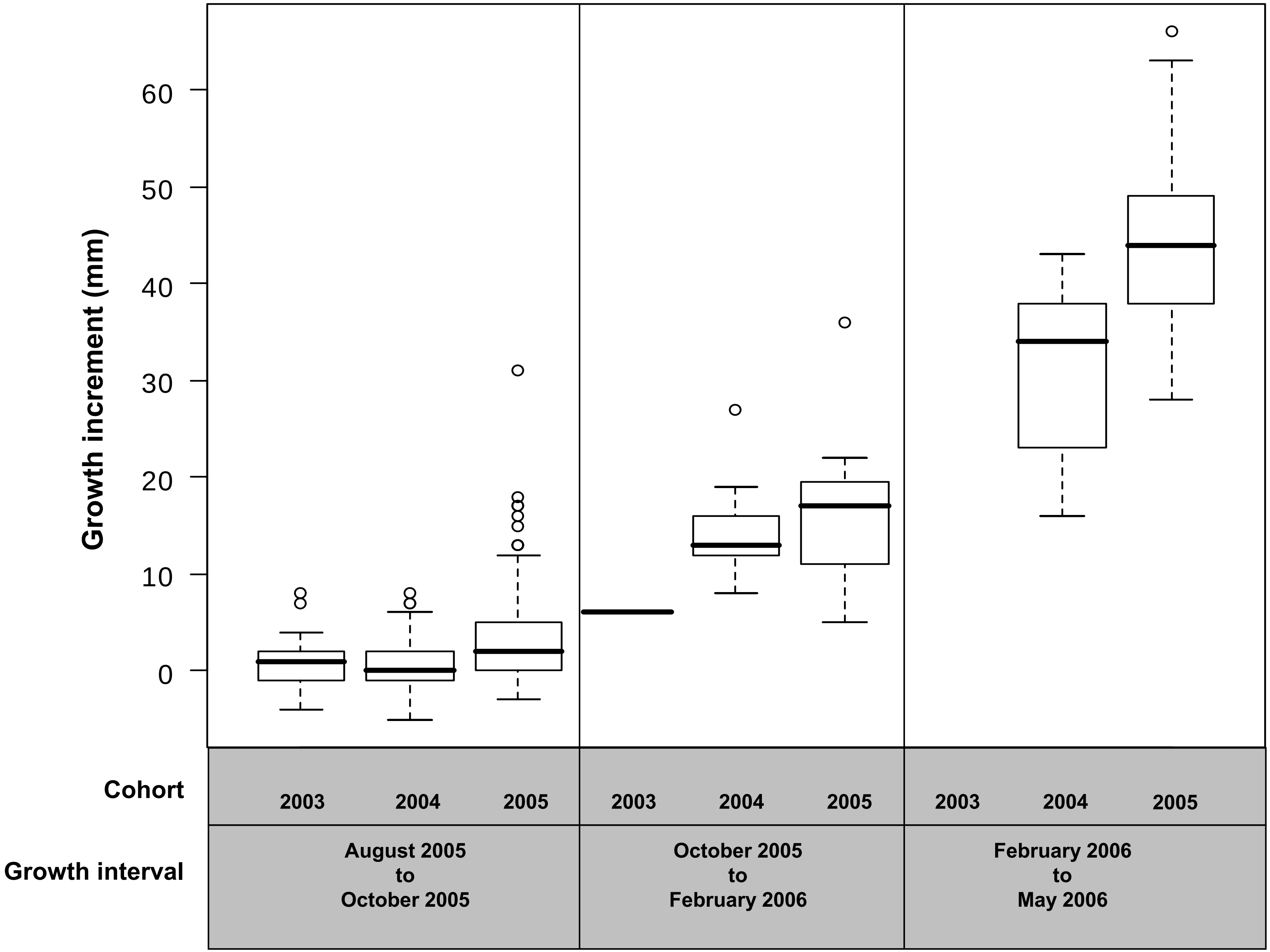

Figure 10. Growth summary for recaptured steelhead in all study reaches, 2005-2006.

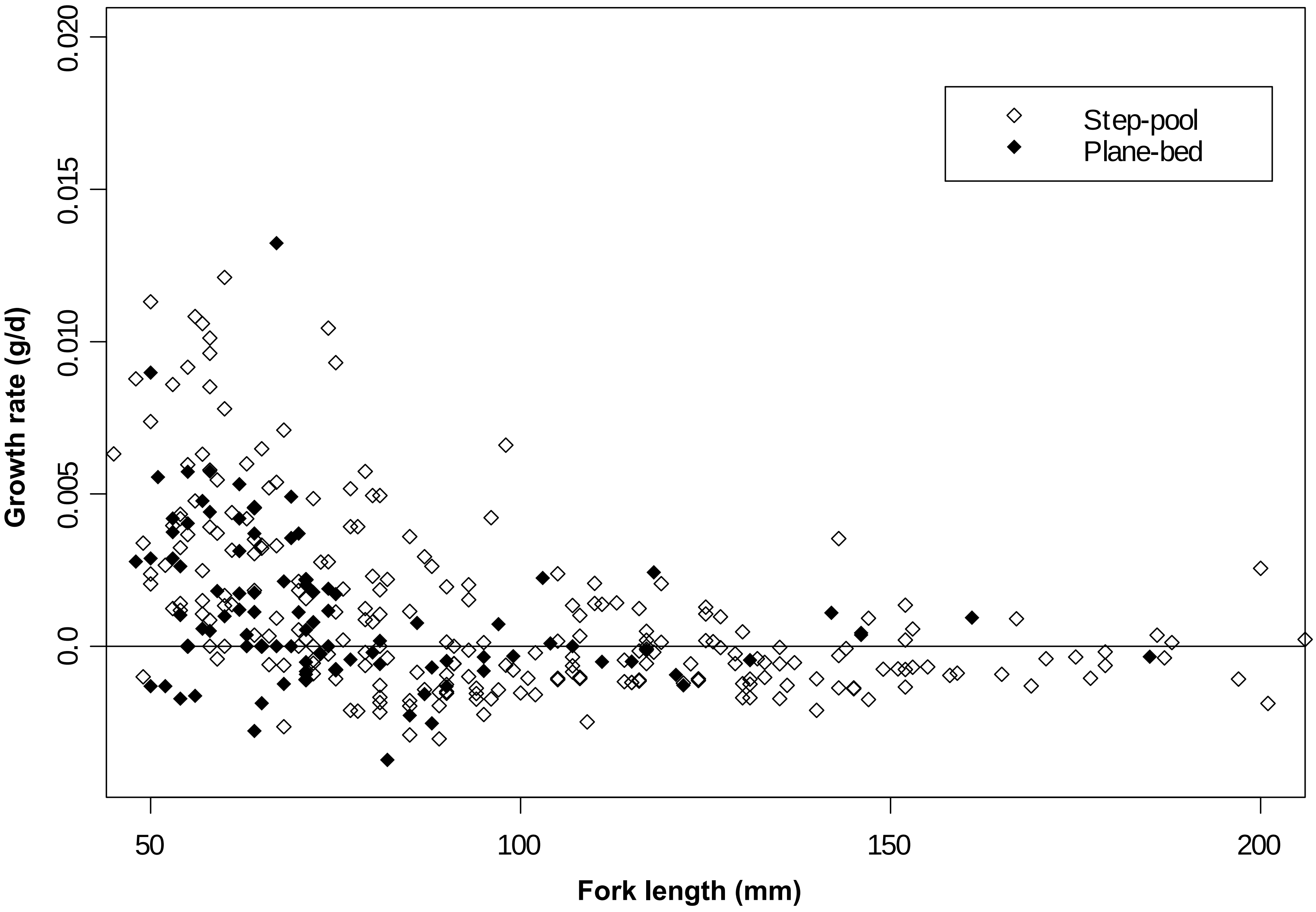

Figure 11. Steelhead growth from August to October 2005 in step-pool and forced pool-riffle/plane-bed reaches in all study reaches combined.

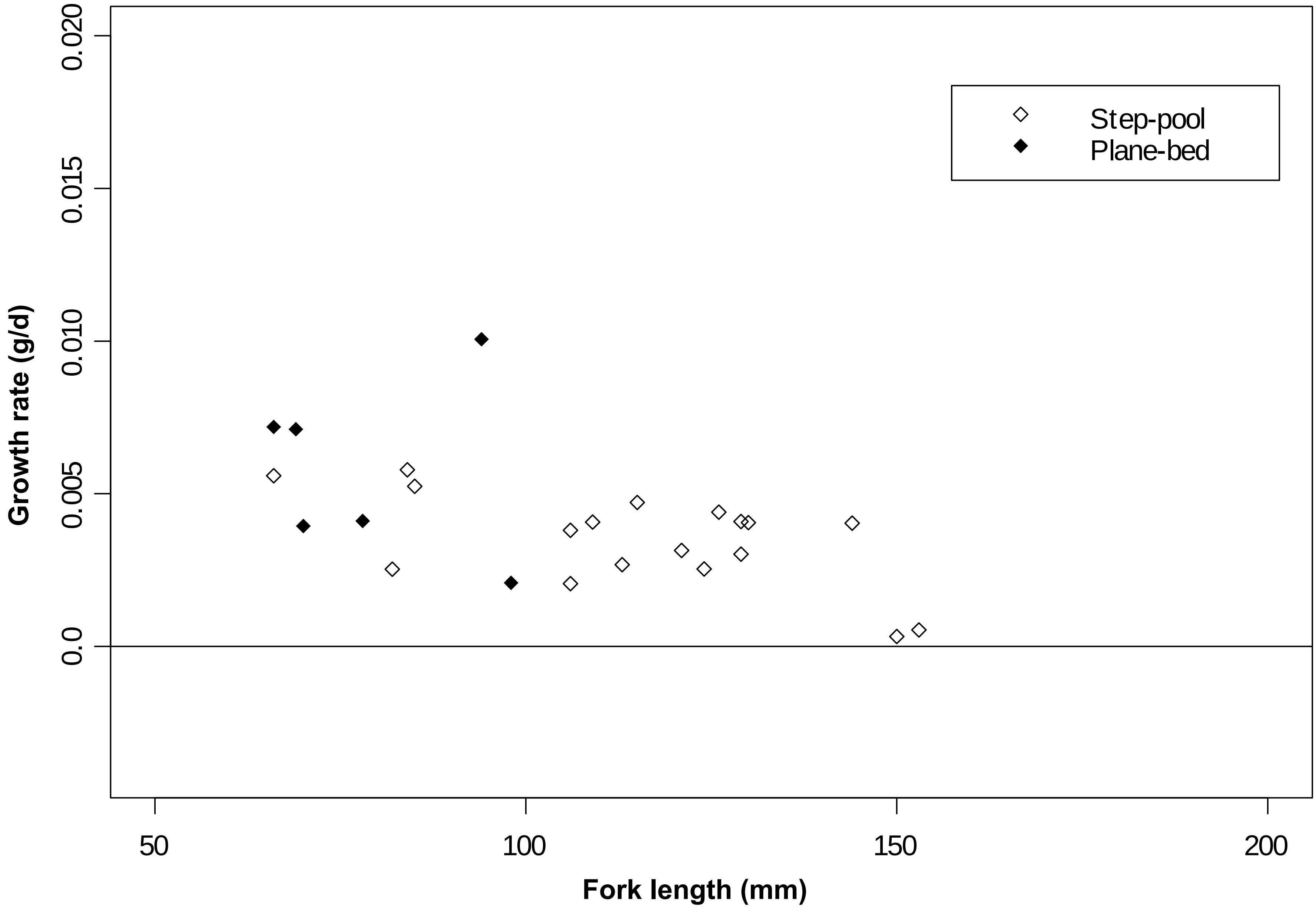

Figure 12. Steelhead growth from October 2005 to February 2006 in step-pool and forced pool-riffle/plane-bed reaches in all study reaches combined.

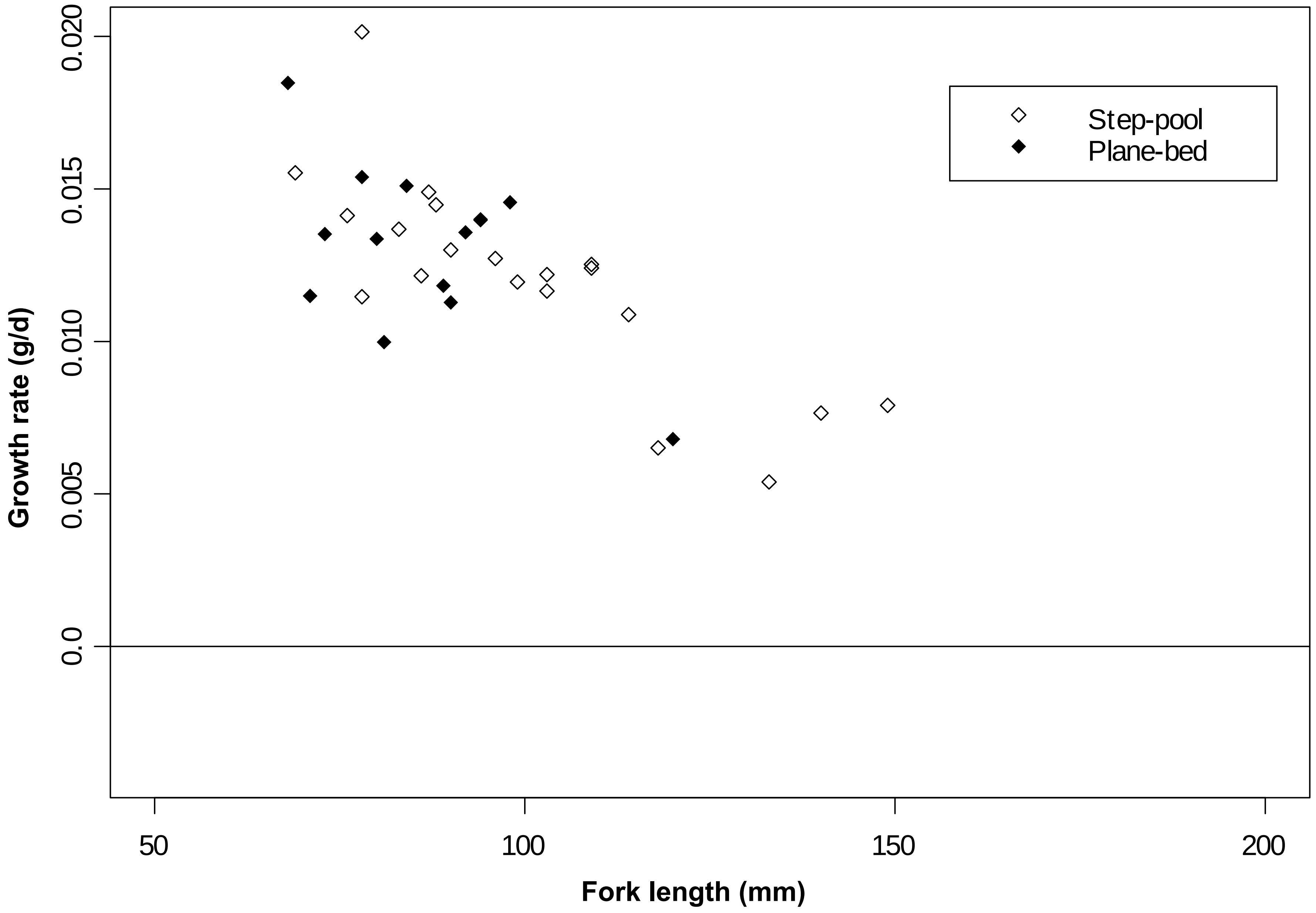

Figure 13. Steelhead growth from February to May 2006 in step-pool and forced pool-riffle/plane-bed reaches in all study reaches combined.

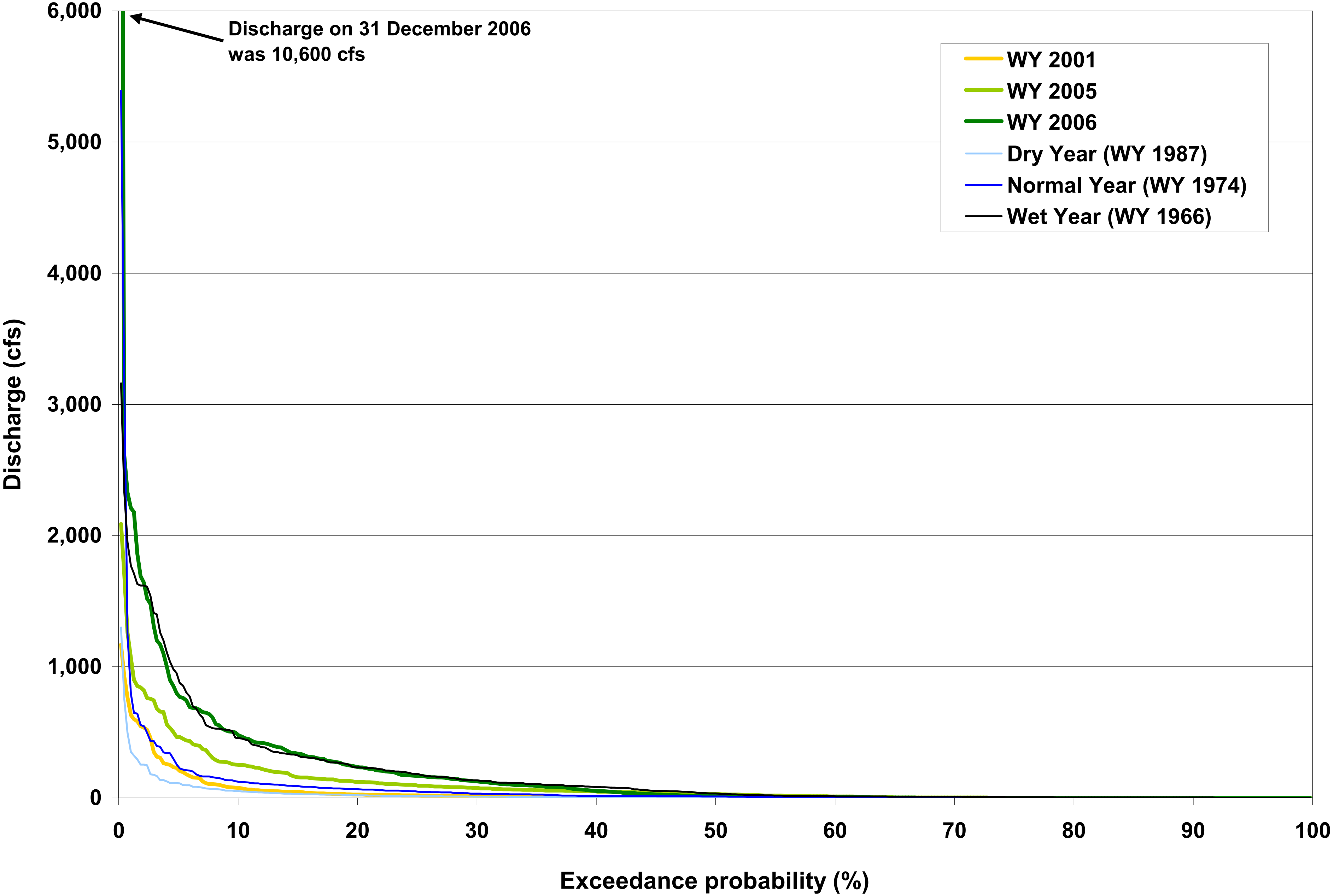

Figure 14. Napa River flow duration curves based on daily average discharge for study years and example water year types at the USGS Napa near St. Helena gage (#11456000).

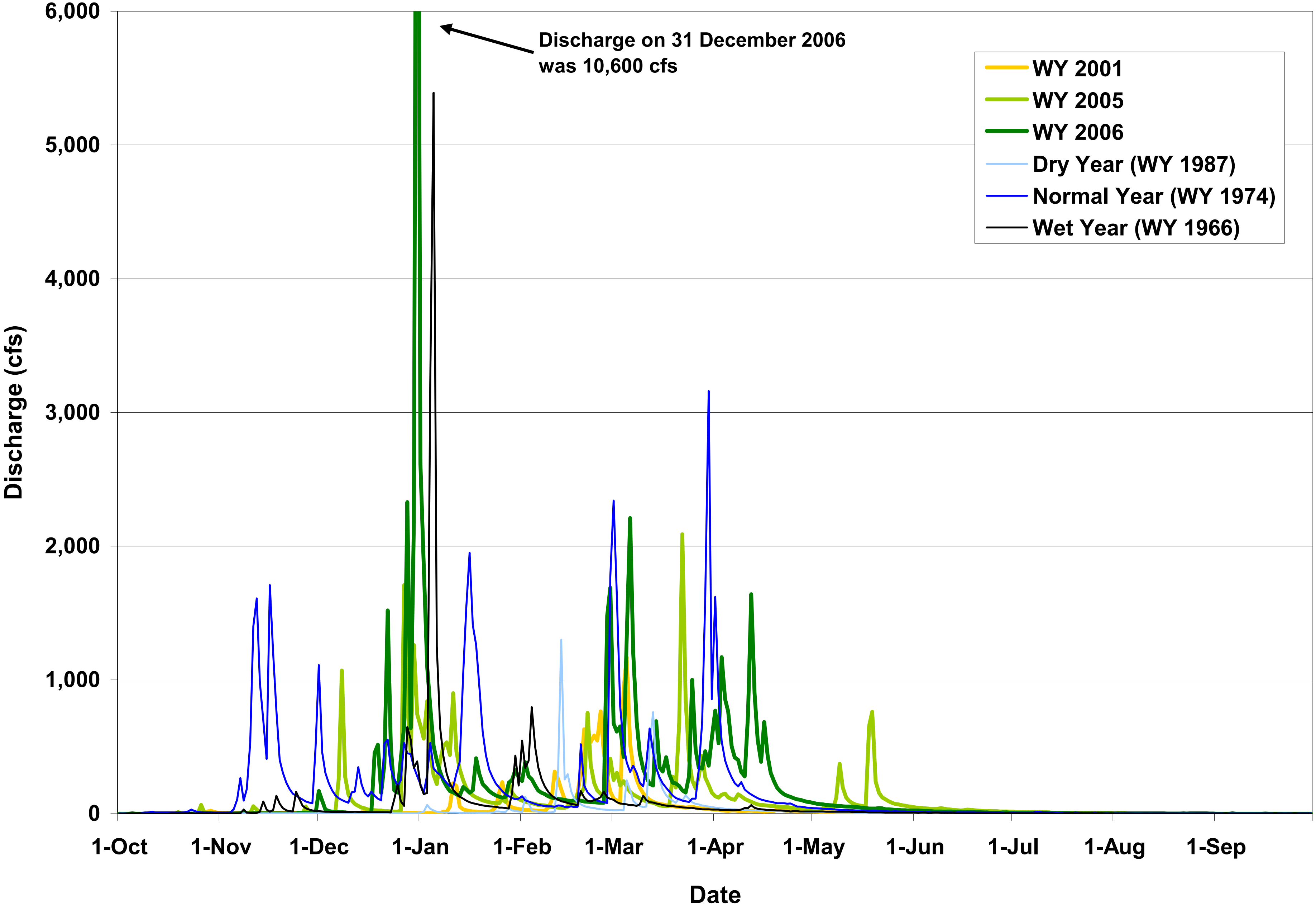

Figure 15. Annual Napa River hydrographs based on daily average discharge for study years and example water year types at the USGS Napa near St. Helena gage (#11456000).

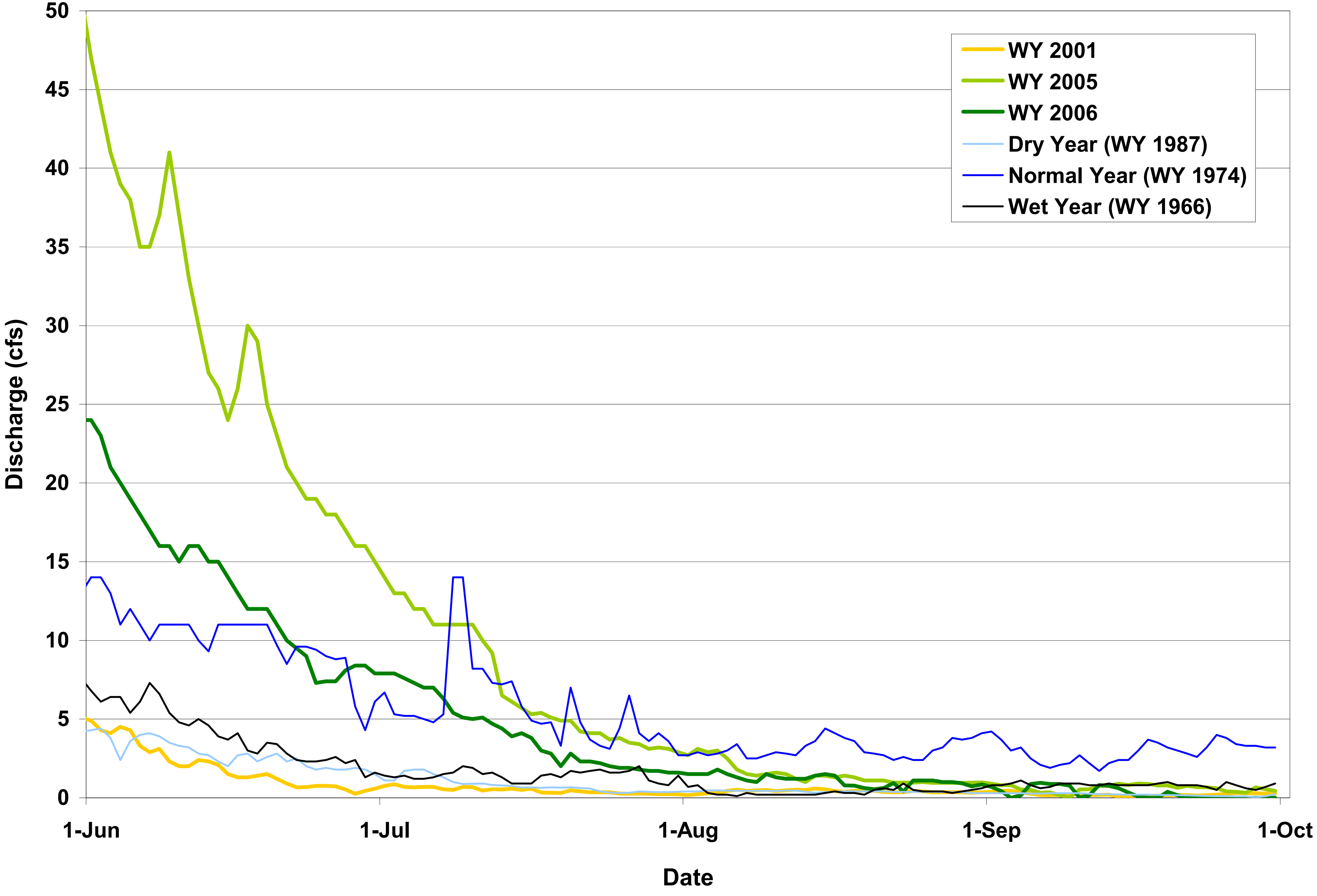

Figure 16. Napa River hydrographs for the months of June–October based on daily average discharge for study years and example water year types at the USGS Napa near St. Helena gage (#11456000).

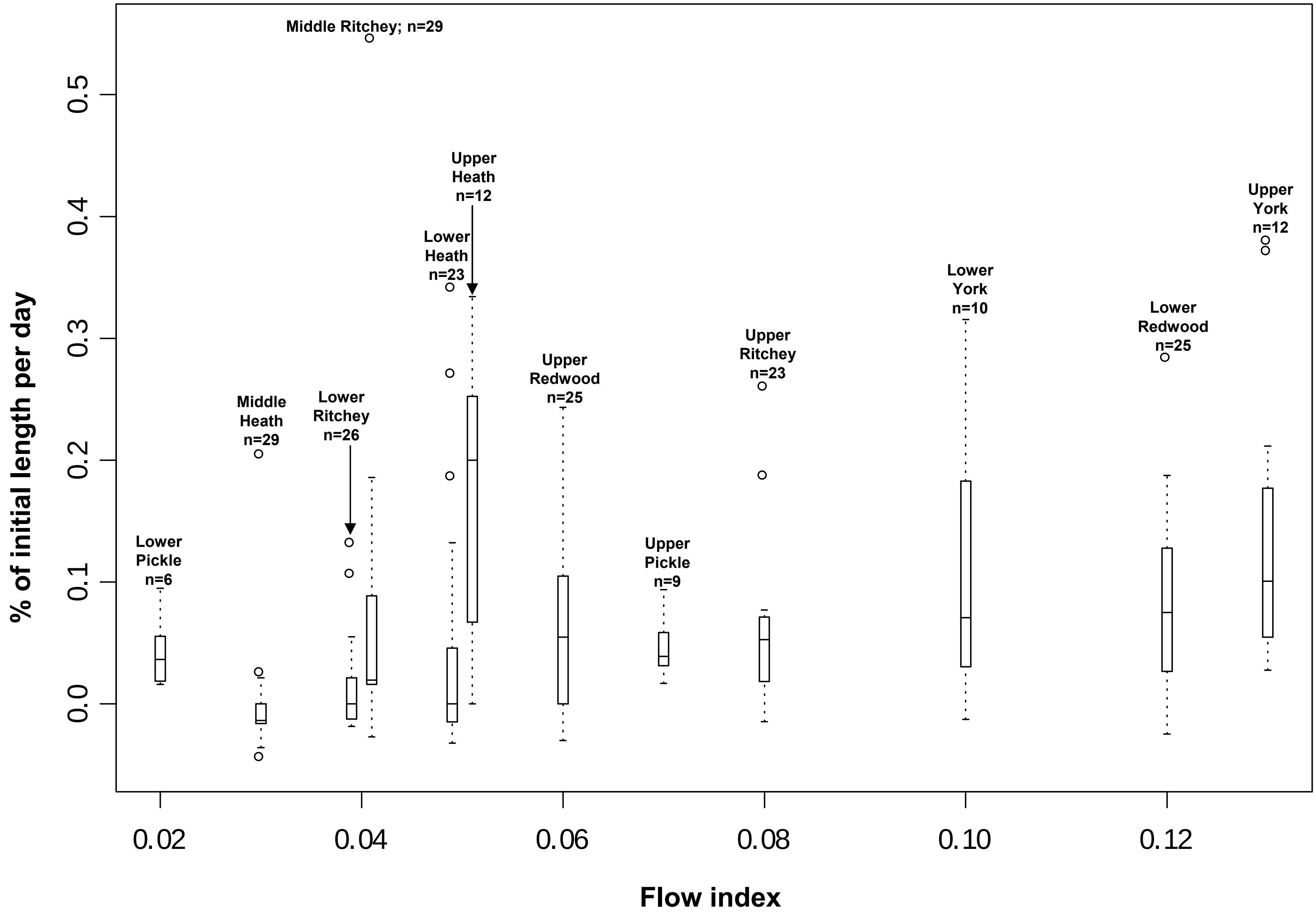

Figure 17. Relative age 0+ steelhead growth rate from August to October 2005 in all study reaches. Flow index is based on data from July 2005.

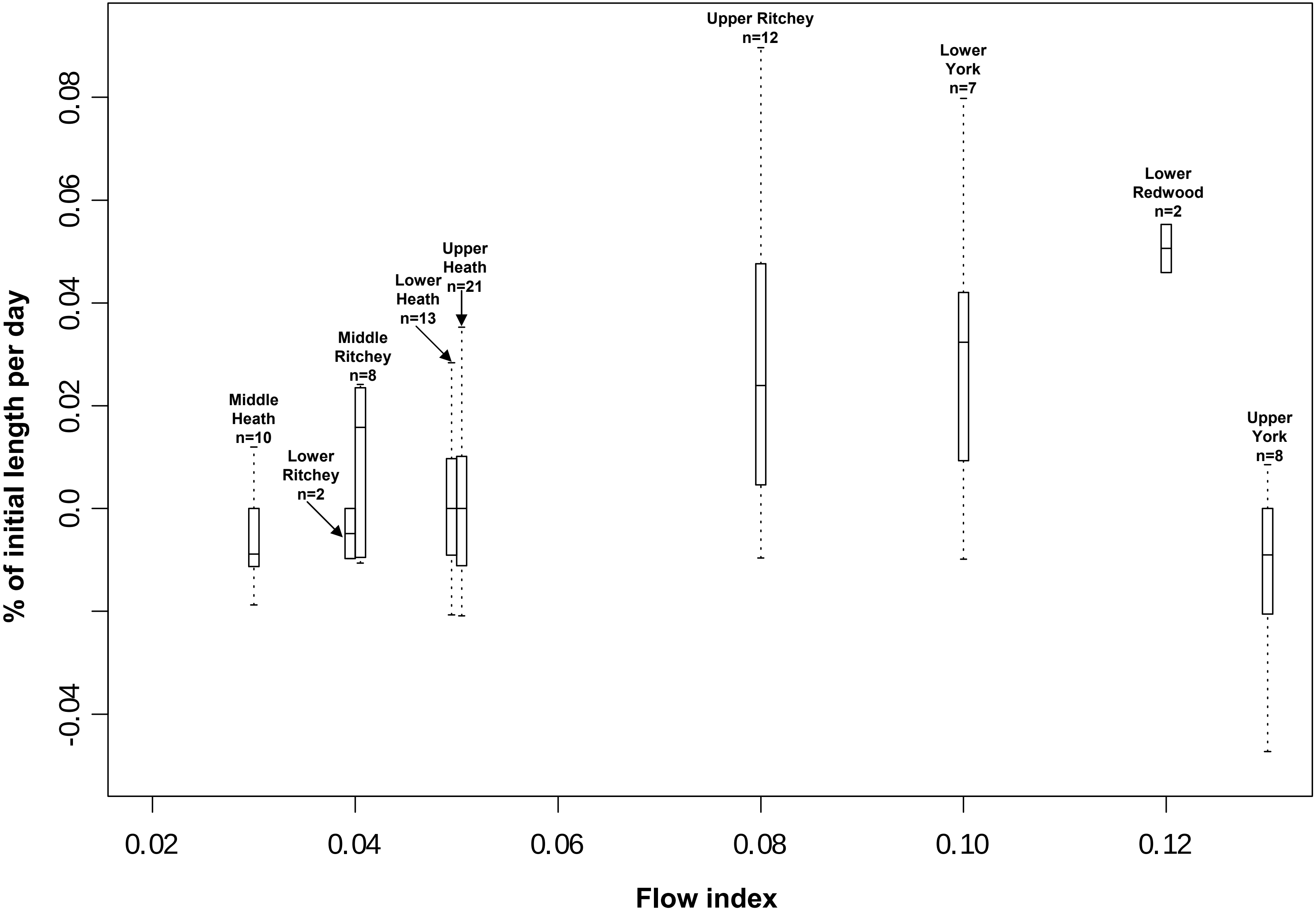

Figure 18. Relative age 1+ steelhead growth rate from August to October 2005 in all study reaches. Flow index is based on data from July 2005.

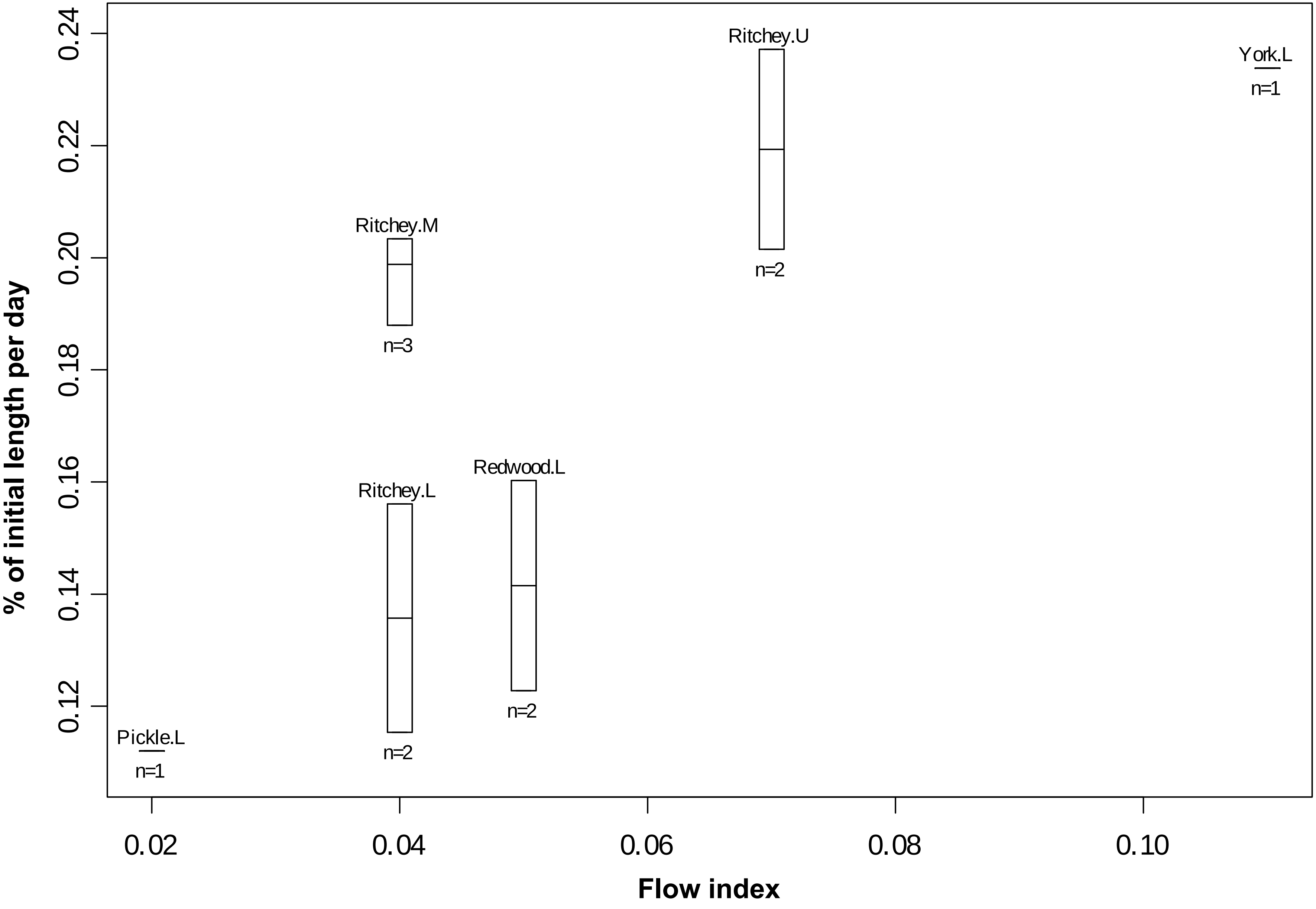

Figure 19. Relative age 0+ steelhead growth rate from October 2005 to February 2006 in all study reaches. Flow index is based on data from October 2005; used July 2005 flow index for Lower Pickle Creek as a surrogate for October, due to lack of flow in this reach.

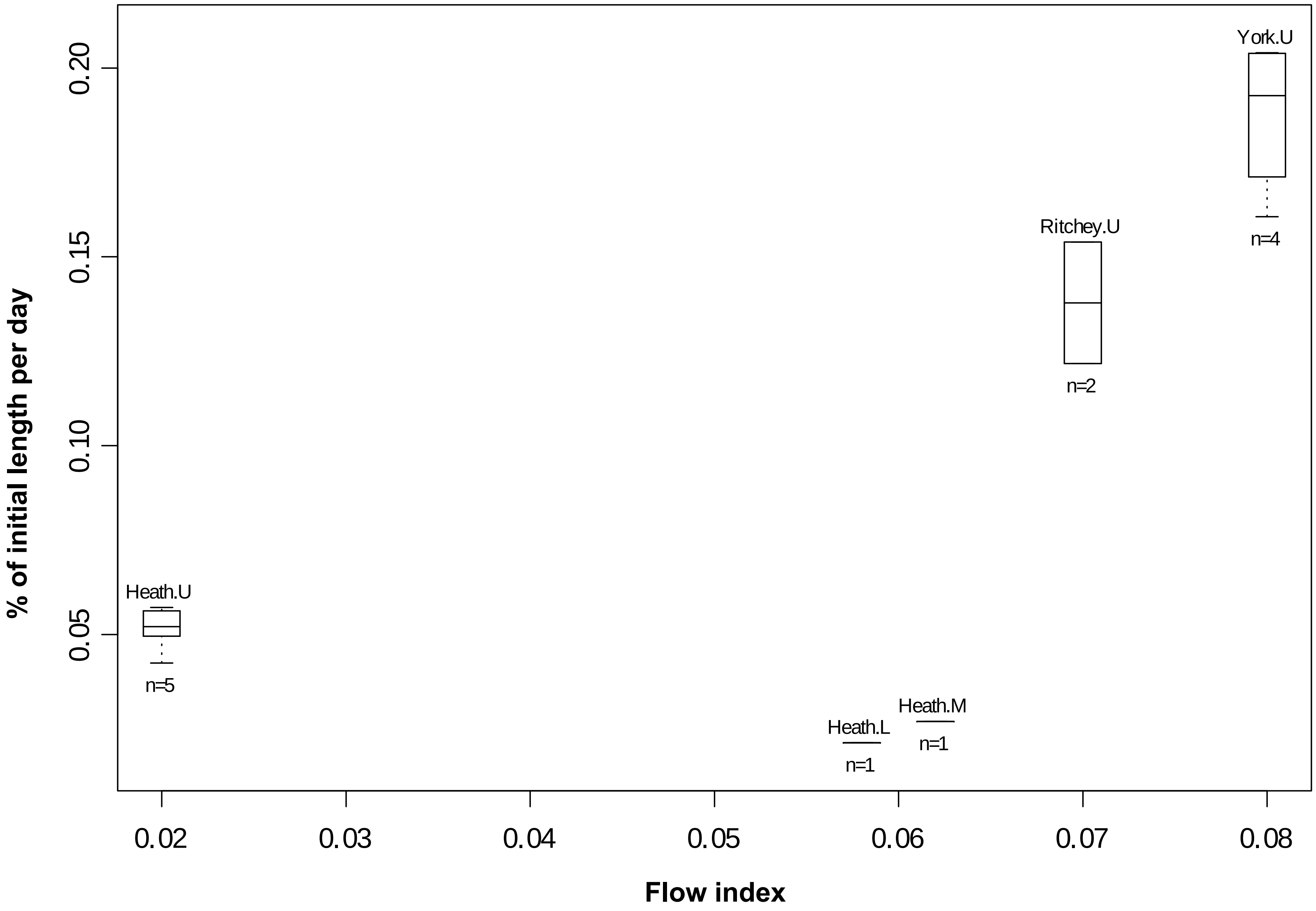

Figure 20. Relative age 1+ steelhead growth rate from October 2005 to February 2006 in all study reaches. Flow index is based on data from October 2005. Lower and Middle Heath Canyon have the same flow index (0.06), but are slightly offset for graphing purposes.

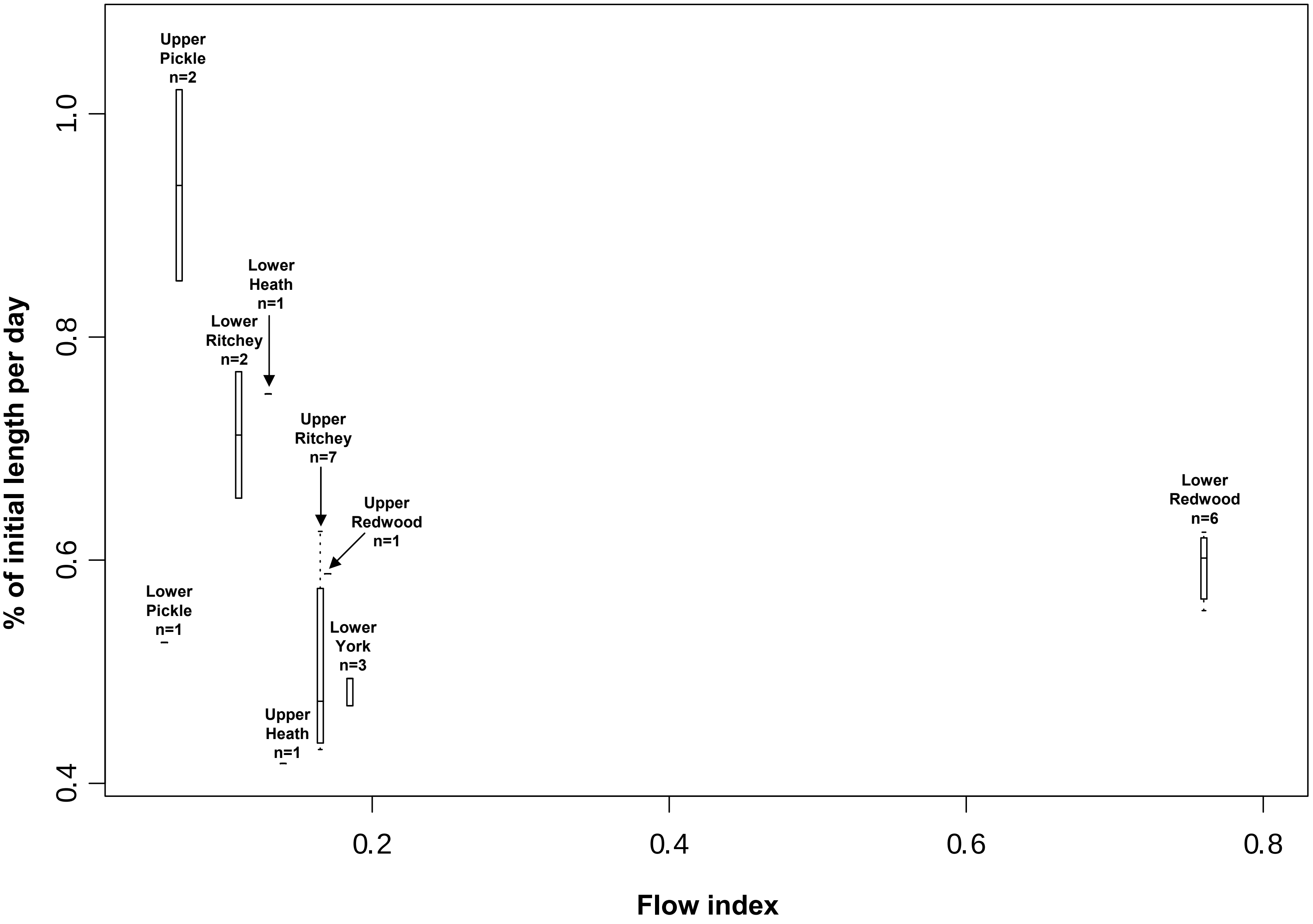

Figure 21. Relative age 0+ steelhead growth rate from February to May 2006 in all study reaches. Flow index is based on data from May 2006.

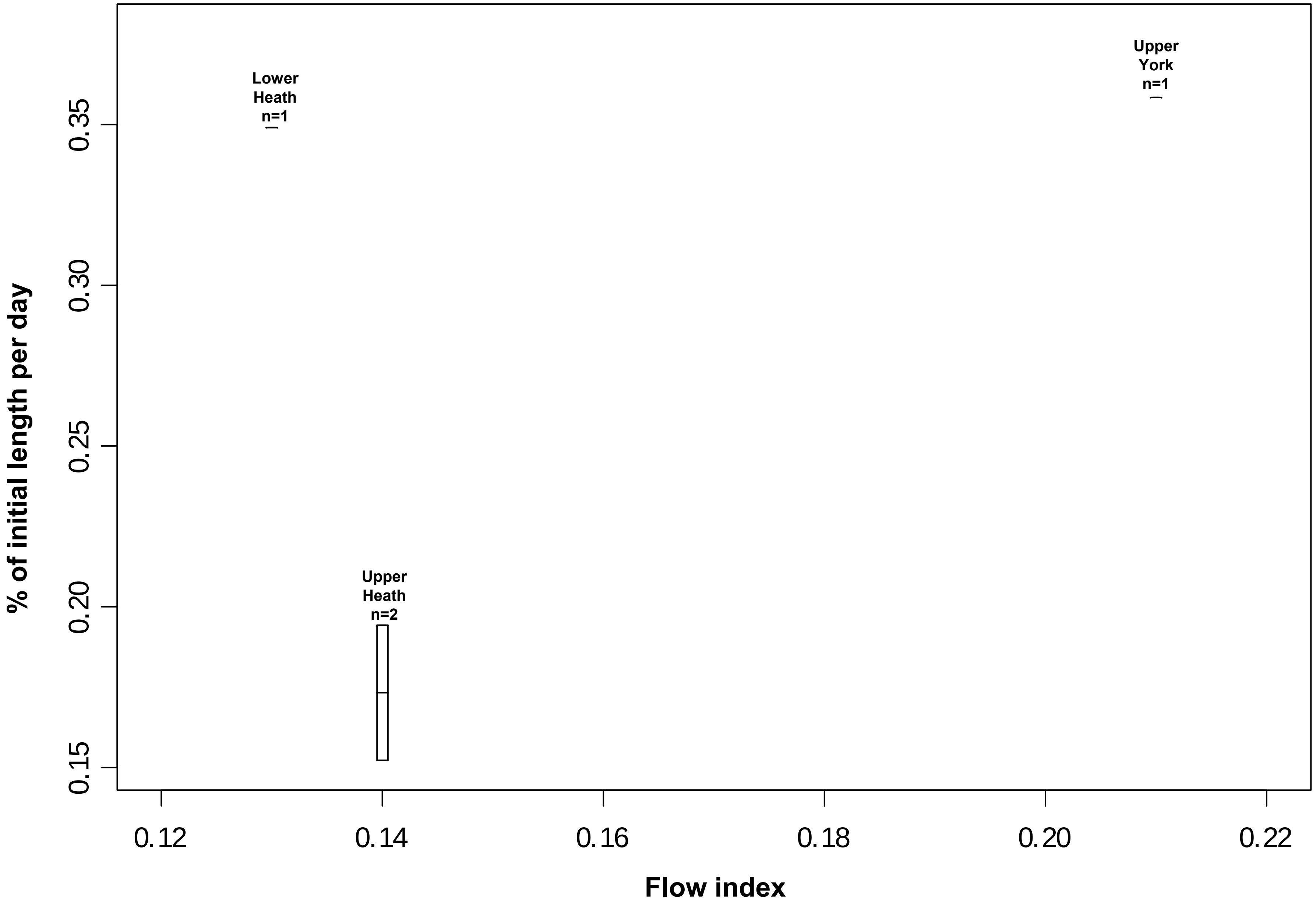

Figure 22. Relative age 1+ steelhead growth rate from February to May 2006 in all study reaches. Flow index is based on data from May 2006.

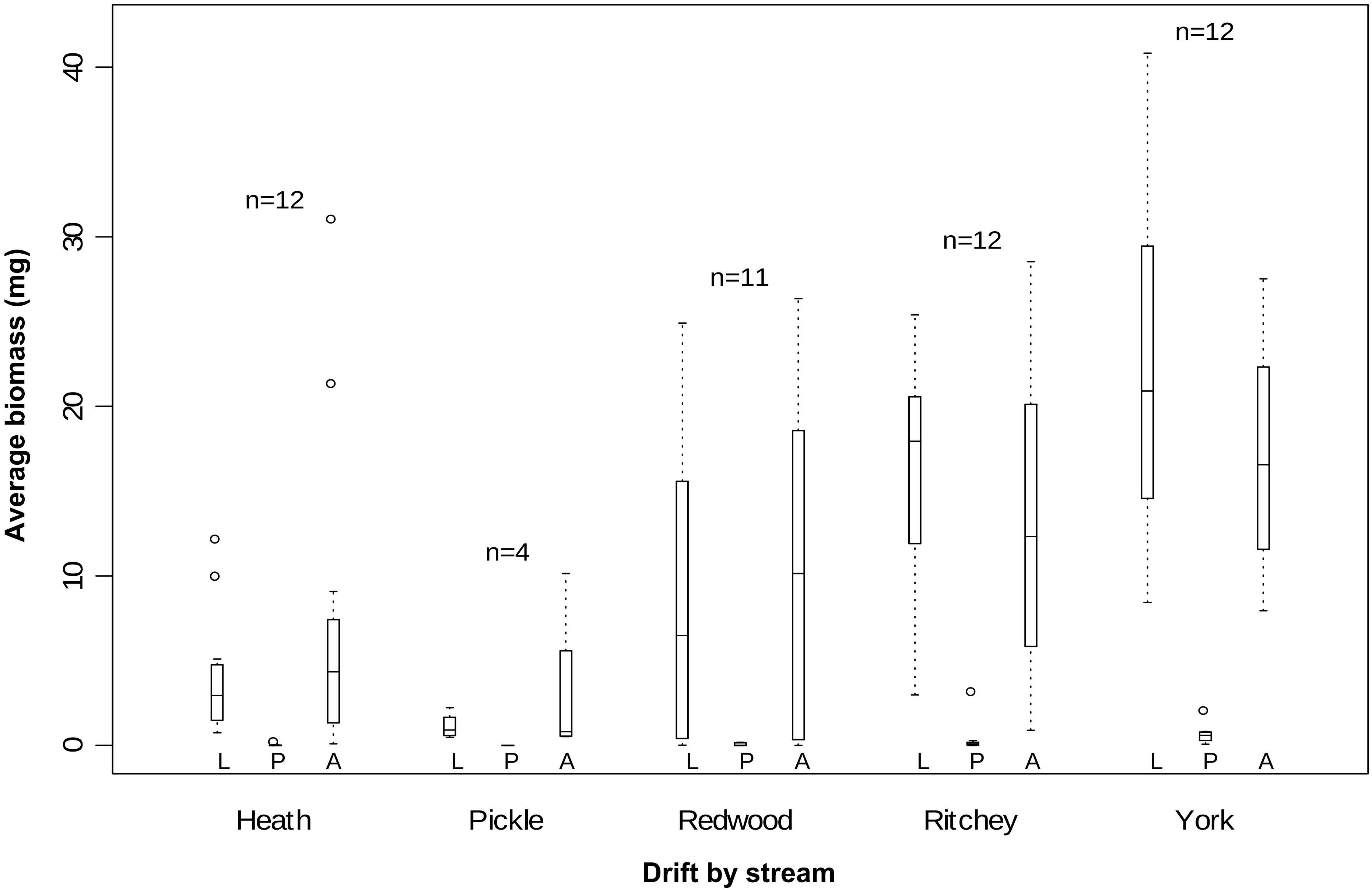

Figure 23. Average daily invertebrate drift biomass by life stage. L=larvae, P-pupae, A=adult.

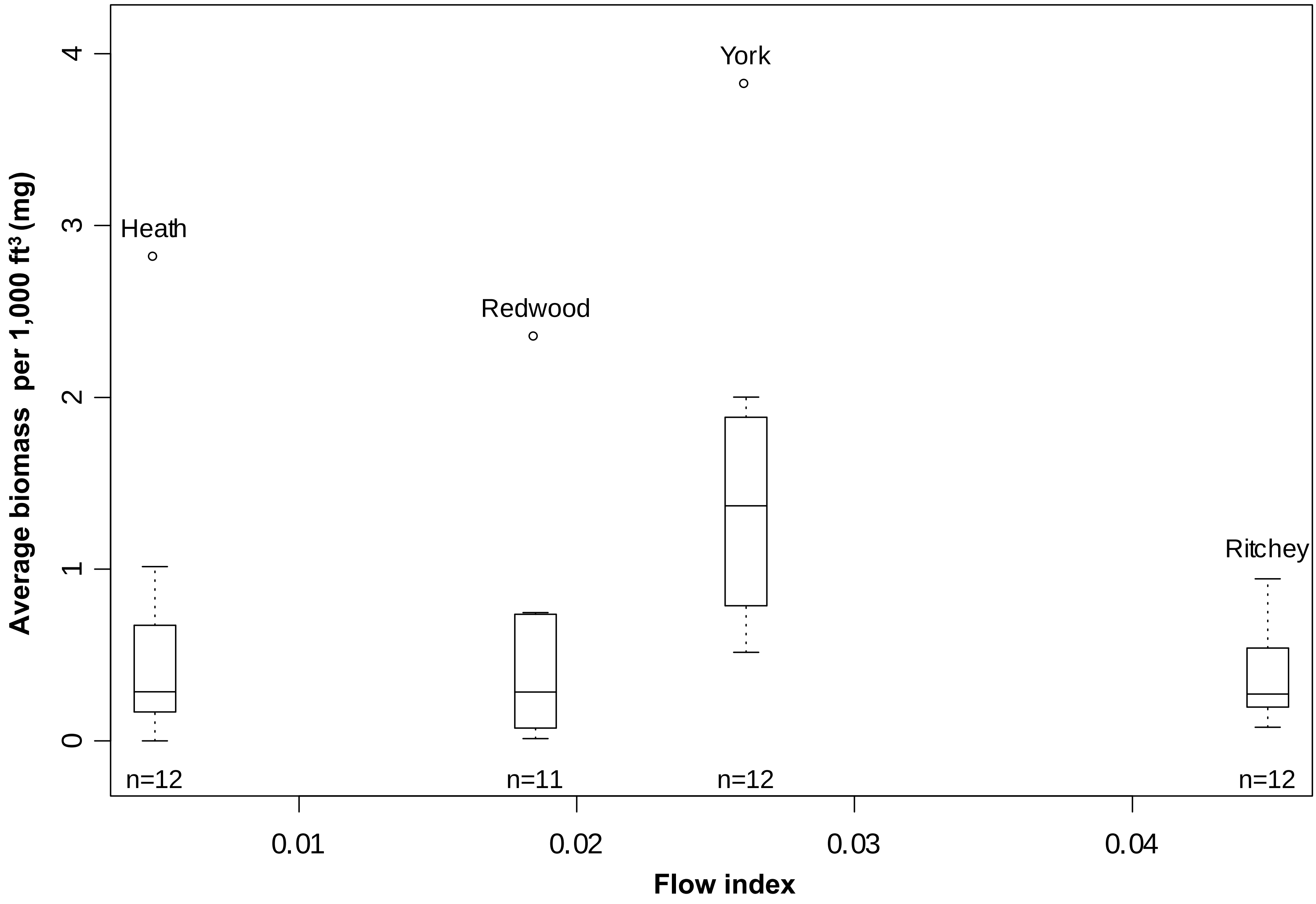

Figure 24. Relation of flow index to average daily biomass of chironomid larvae per 1,000 cubic feet of water passing through drift nets. Flow index is based on data from October 2005 during invertebrate sampling.

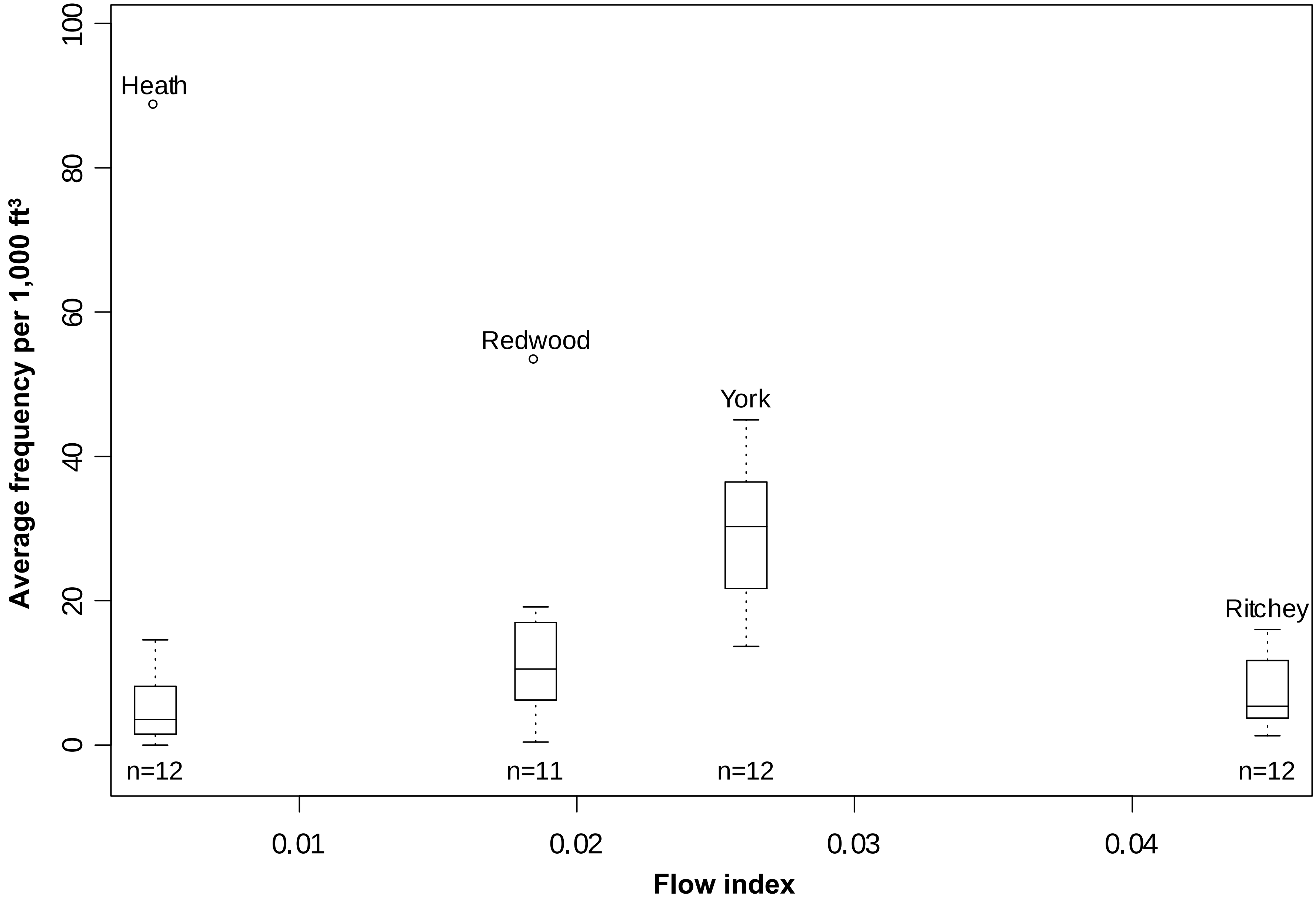

Figure 25. Relation of flow index to daily average frequency of chironomid larvae per 1,000 cubic feet of water passing through drift nets. Flow index is based on data from October 2005 during invertebrate sampling.

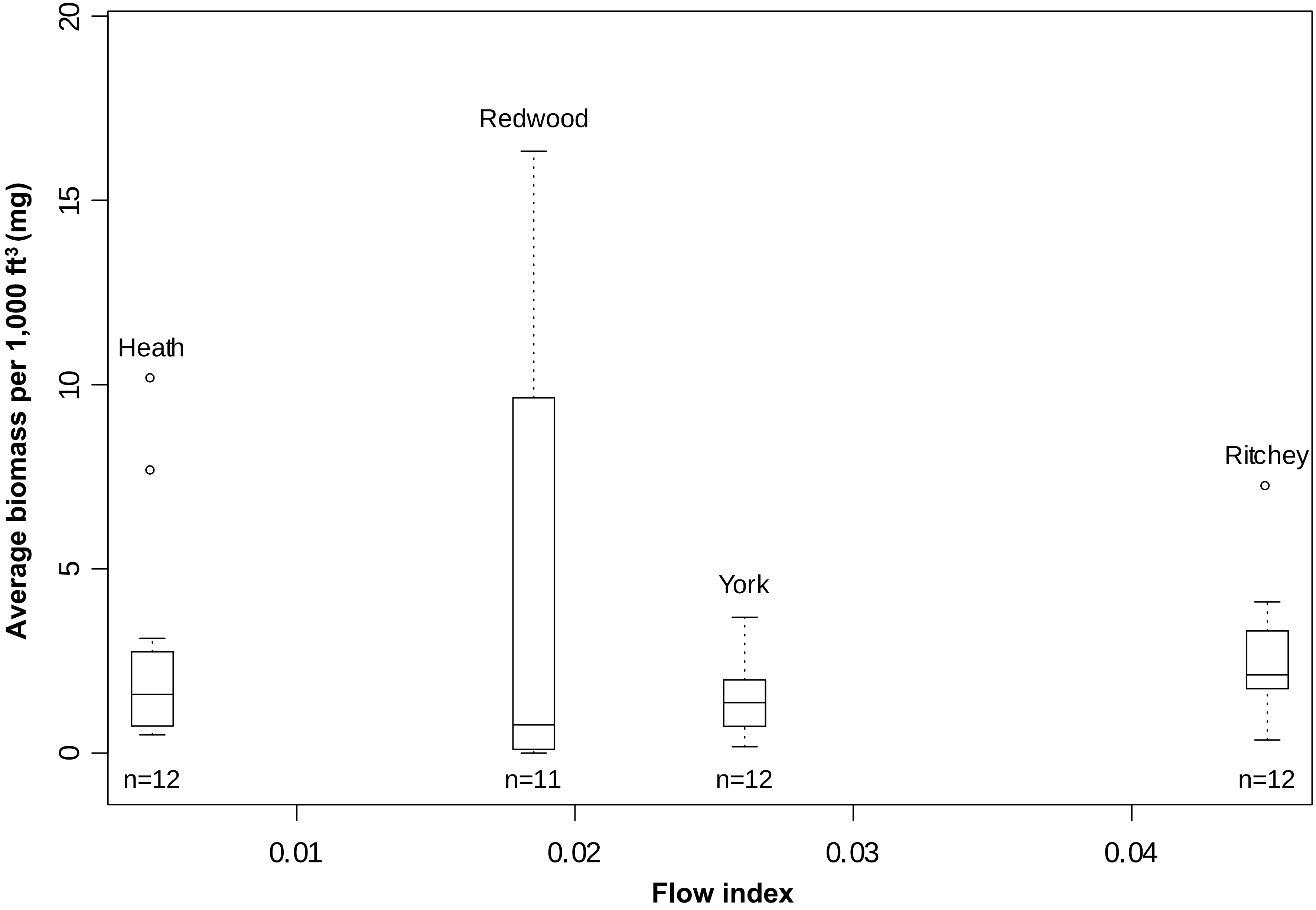

Figure 26. Relation of flow index to average biomass of mayfly larvae per 1,000 cubic feet of water passing through drift nets. Flow index is based on data from October 2005 during invertebrate sampling.

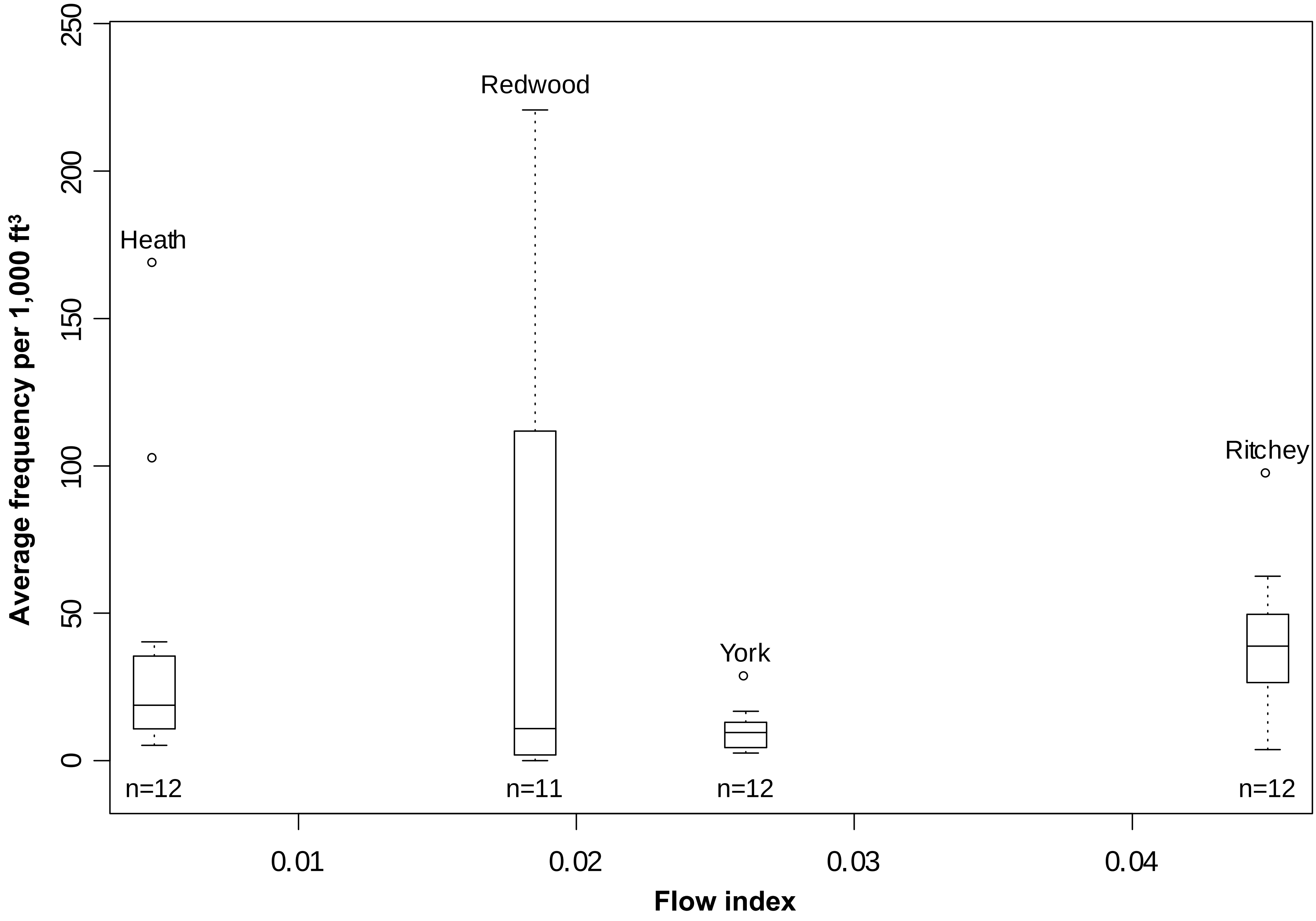

Figure 27. Relation of flow index to average frequency of mayfly larvae per 1,000 cubic feet of water passing through drift nets. Flow index is based on data from October 2005 during invertebrate sampling.

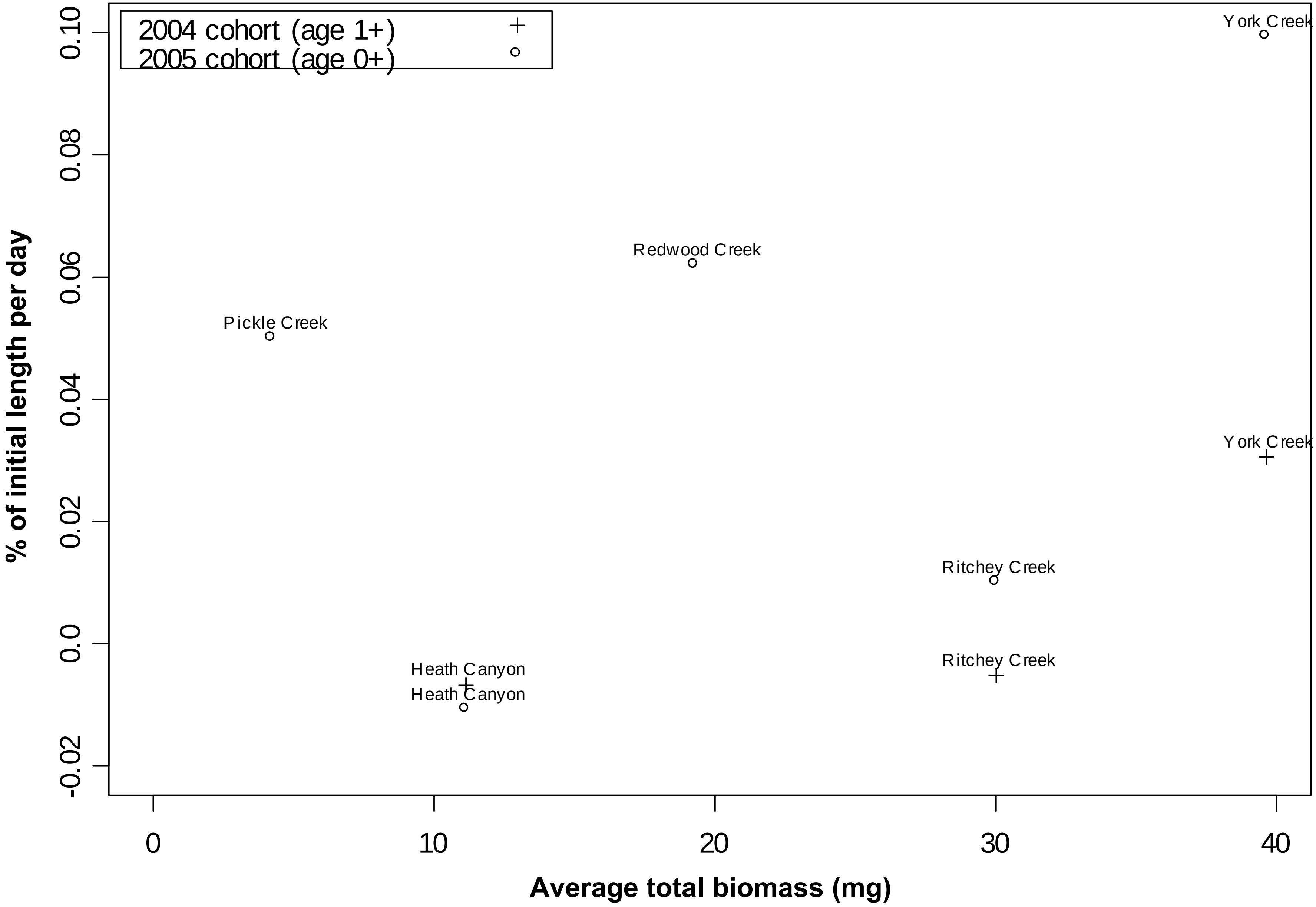

Figure 28. Relation of average total invertebrate biomass to the relative growth rate of age 0+ and 1+ steelhead from August to October 2005.

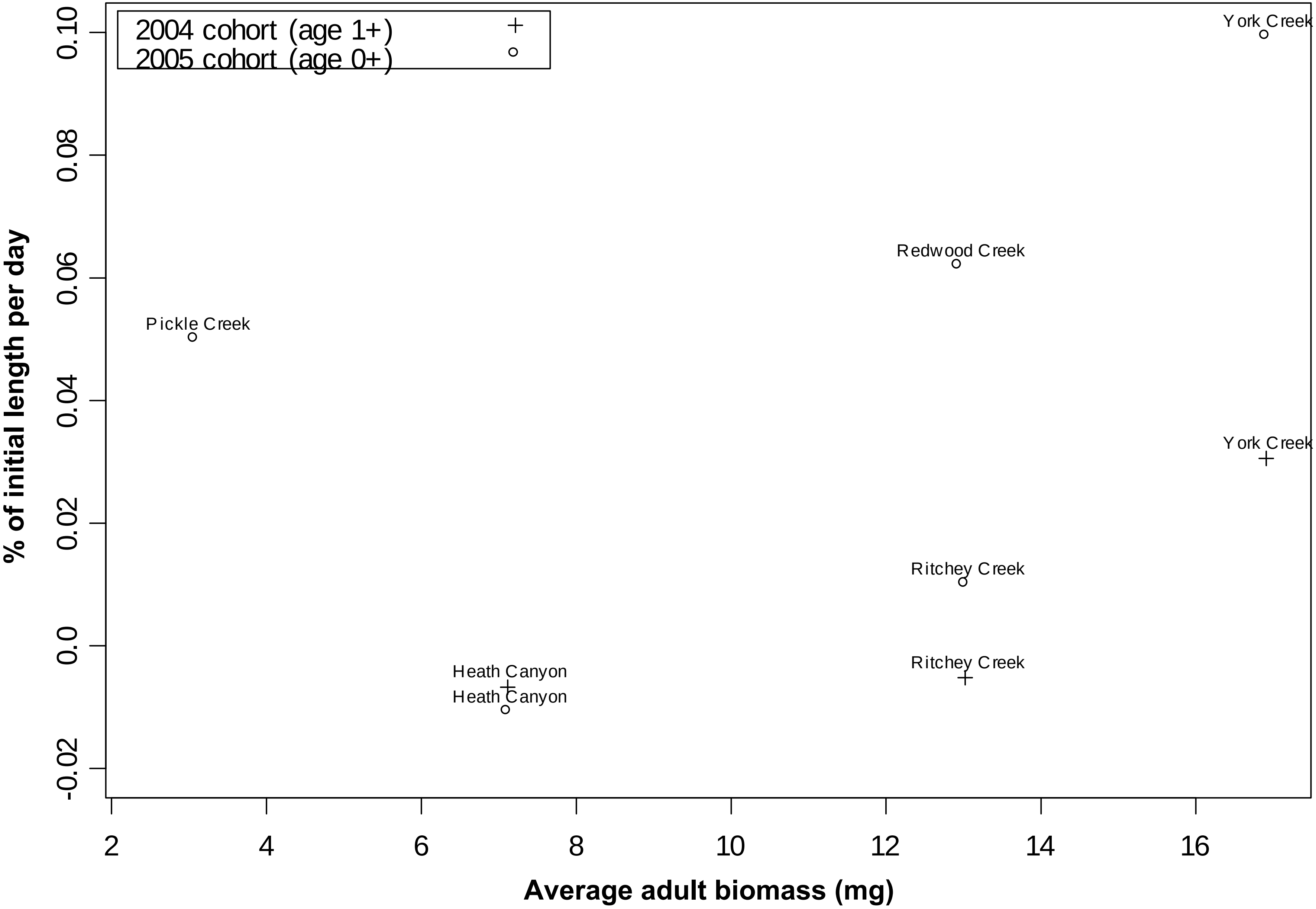

Figure 29. Relation of average adult invertebrate biomass to the relative growth rate of age 0+ and 1+ steelhead from August to October 2005.

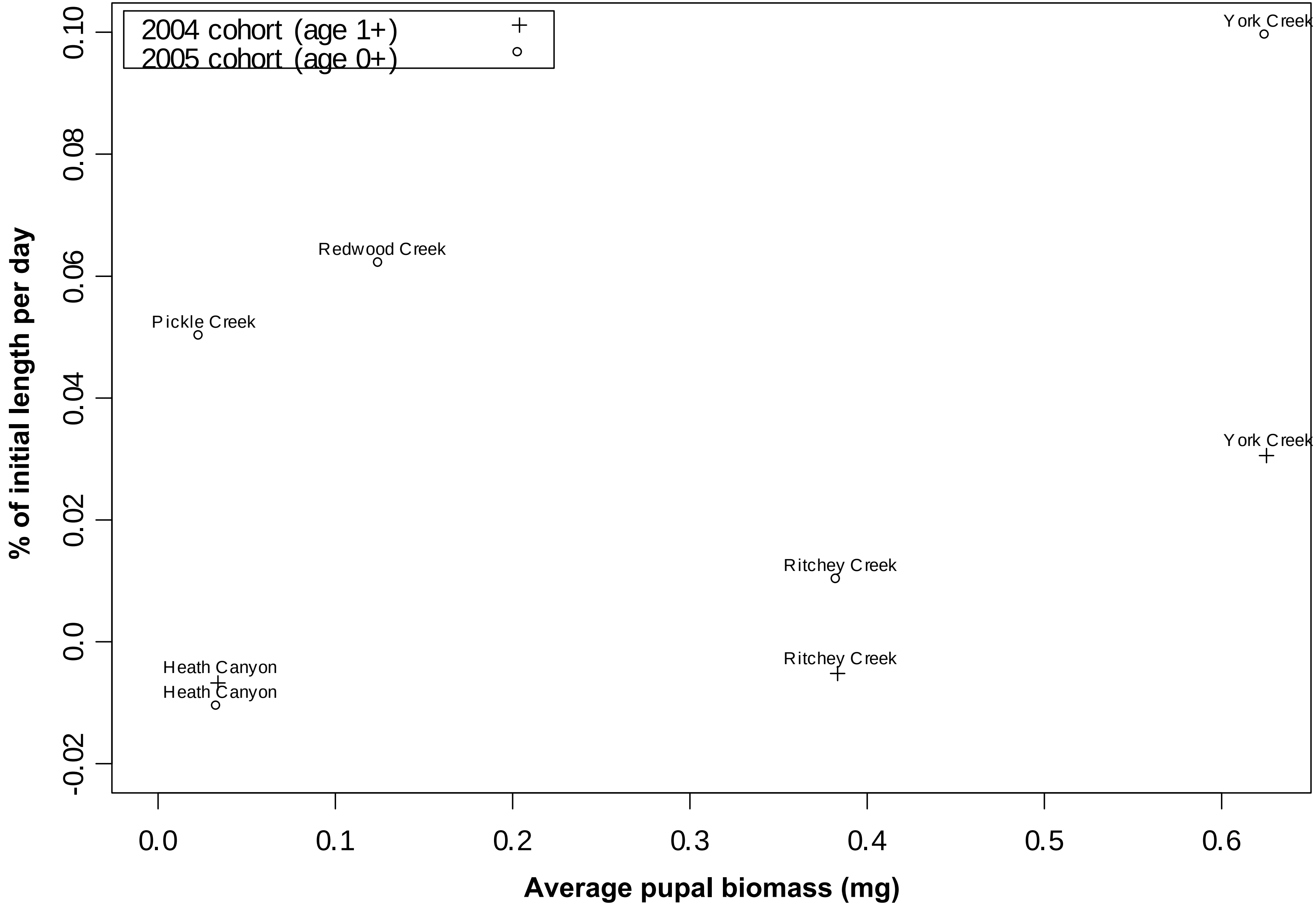

Figure 30. Relation of average biomass of invertebrate pupae to the relative growth rate of age 0+ and 1+ steelhead from August to October 2005.

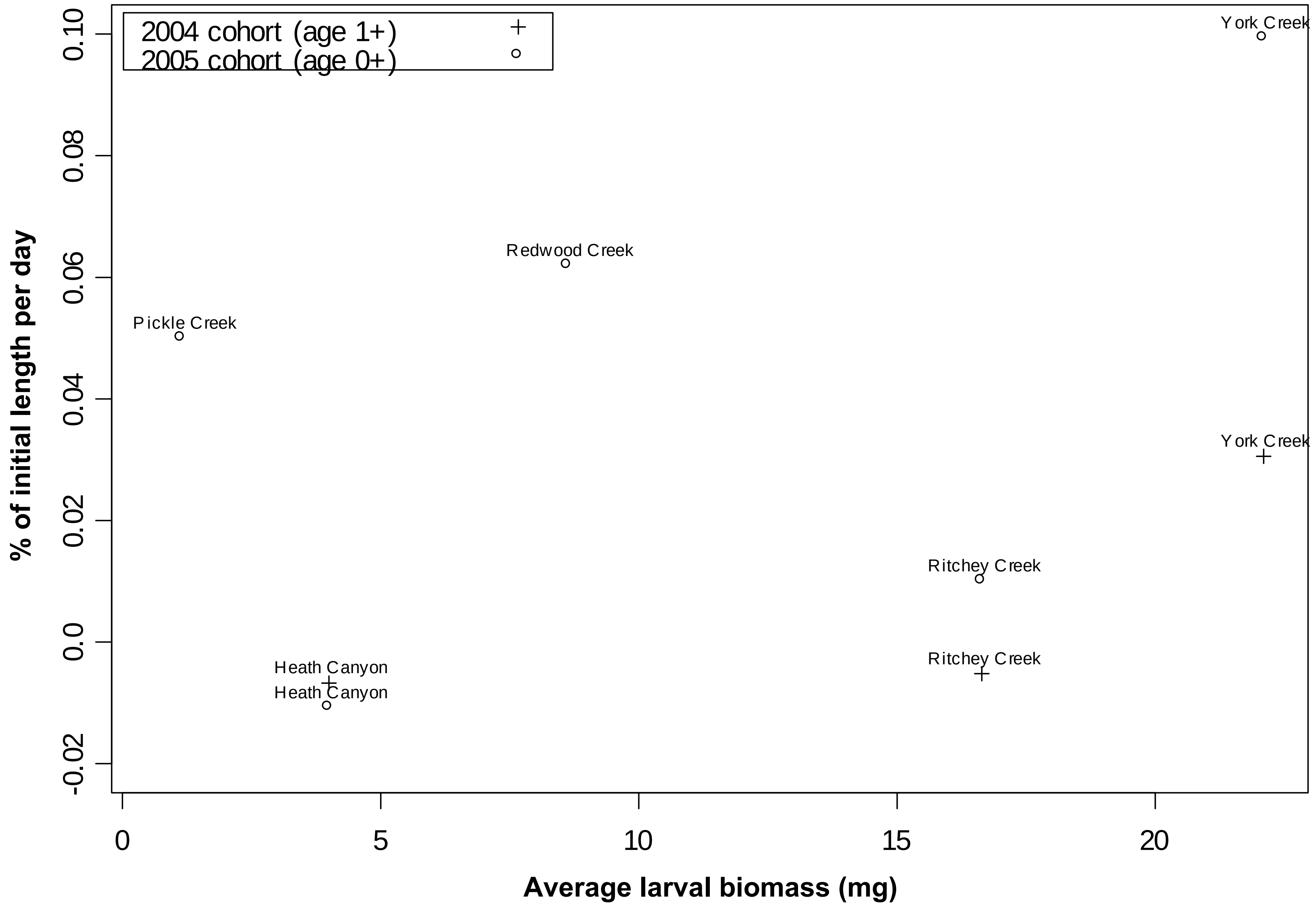

Figure 31. Relation of average biomass of larval invertebrates to the relative growth rate of age 0+ and 1+ steelhead from August to October 2005.

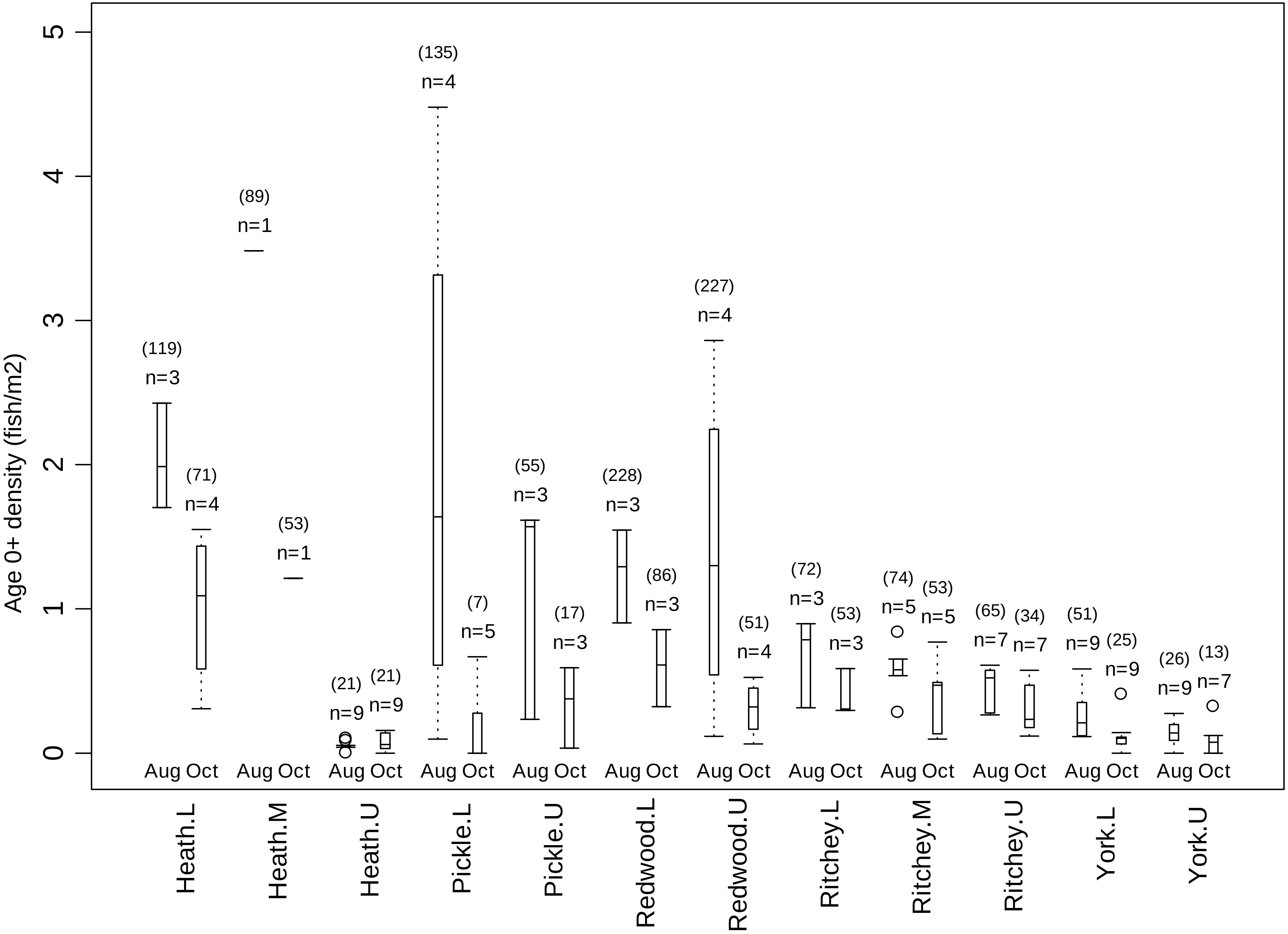

Figure 32. Density of age 0+ steelhead in August and October, 2005 in each study reach. Sample size indicates the number of habitat units sampled, and the number in parenthesis is the total estimated number of steelhead based on multiple pass electrofishing.

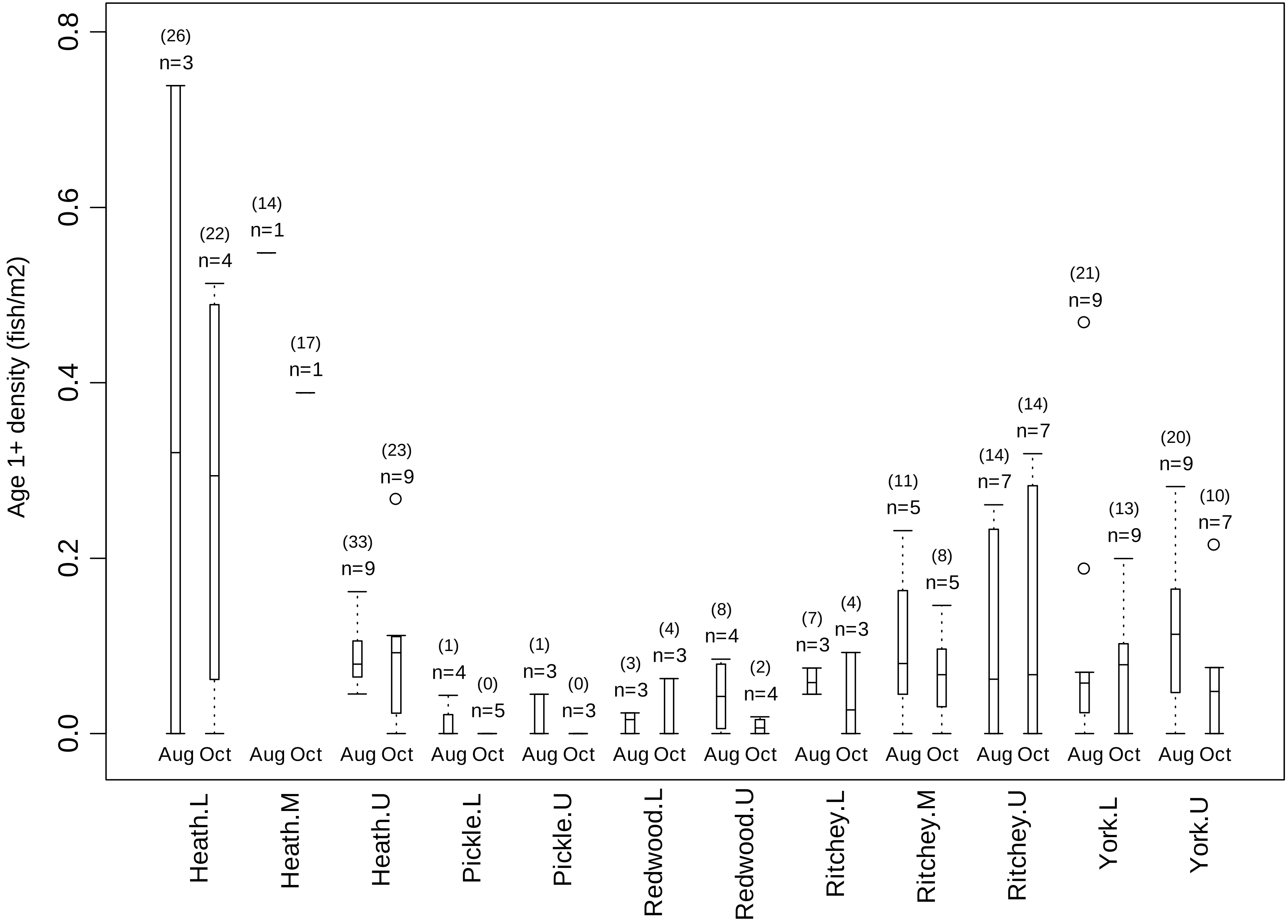

Figure 33. Density of age 1+ steelhead in August and October, 2005 in each study reach. Sample size indicates the number of habitat units sampled, and the number in parenthesis is the total estimated number of steelhead based on multiple pass electrofishing.

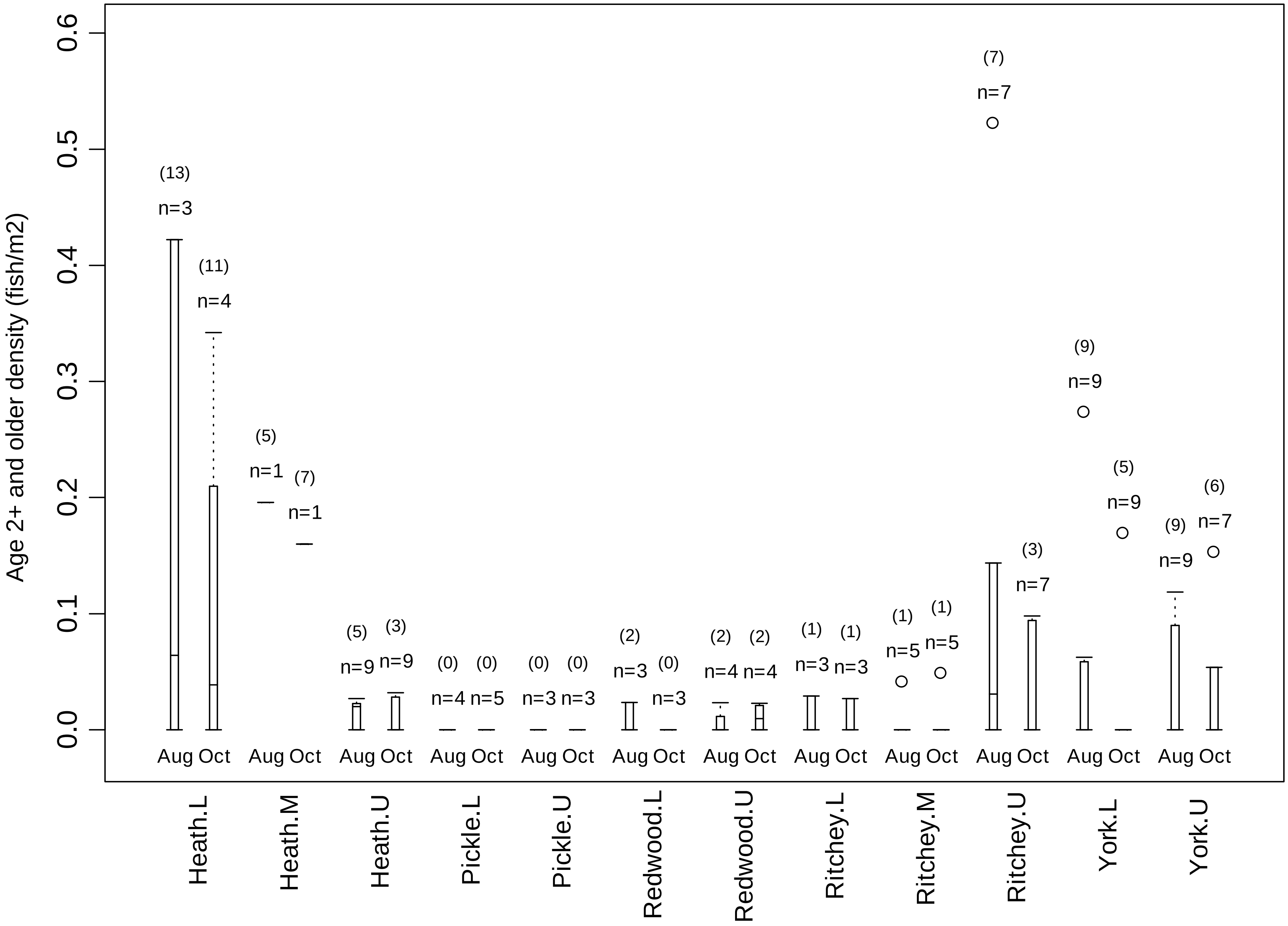

Figure 34. Density of age 2+ and older steelhead in August and October, 2005 in each study reach. Sample size indicates the number of habitat units sampled, and the number in parenthesis is the total estimated number of steelhead based on multiple pass electrofishing.

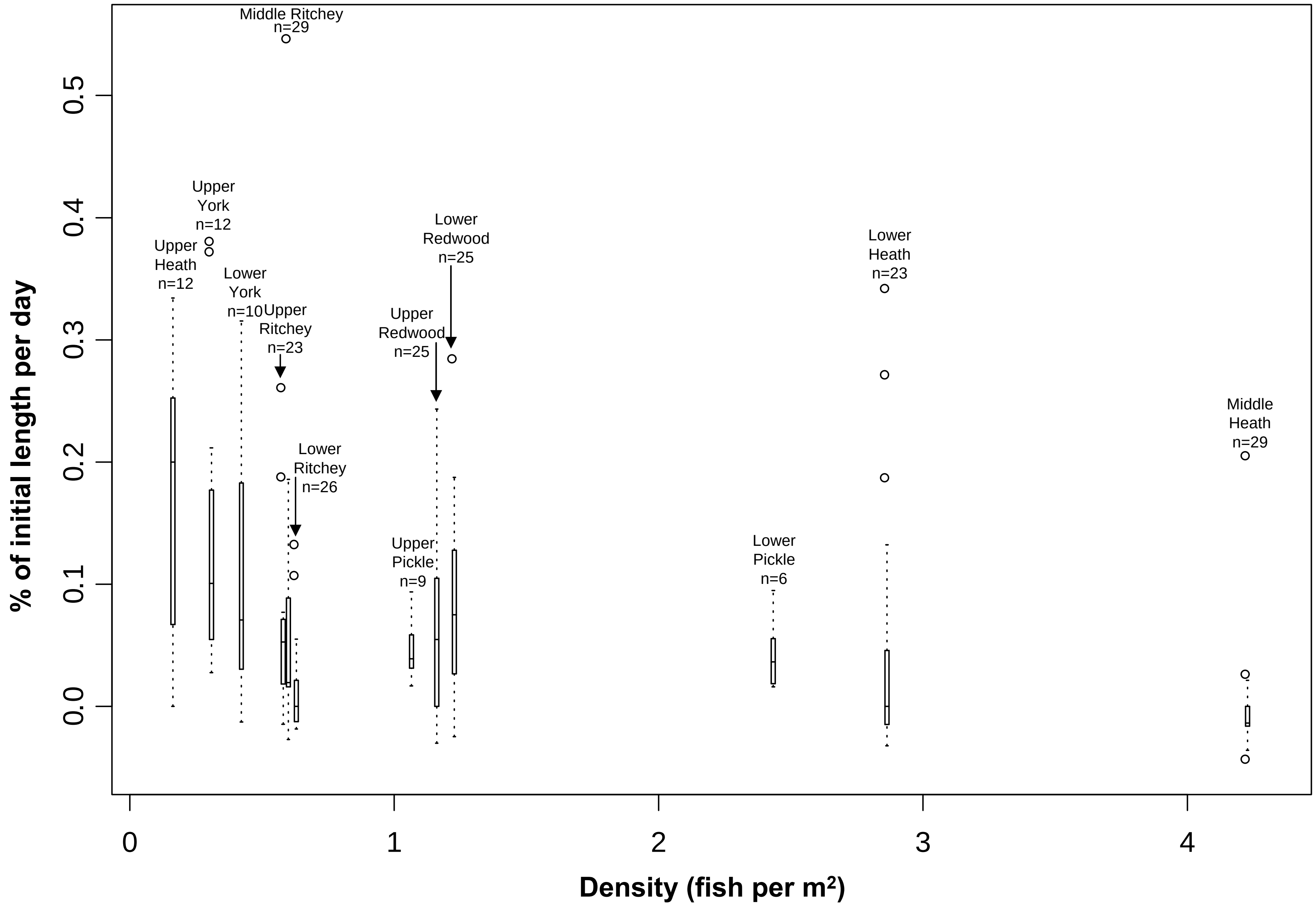

Figure 35. Relative age 0+ steelhead growth rate from August to October 2005 in all study reaches. Density is based on electrofishing data from August 2005; all steelhead.

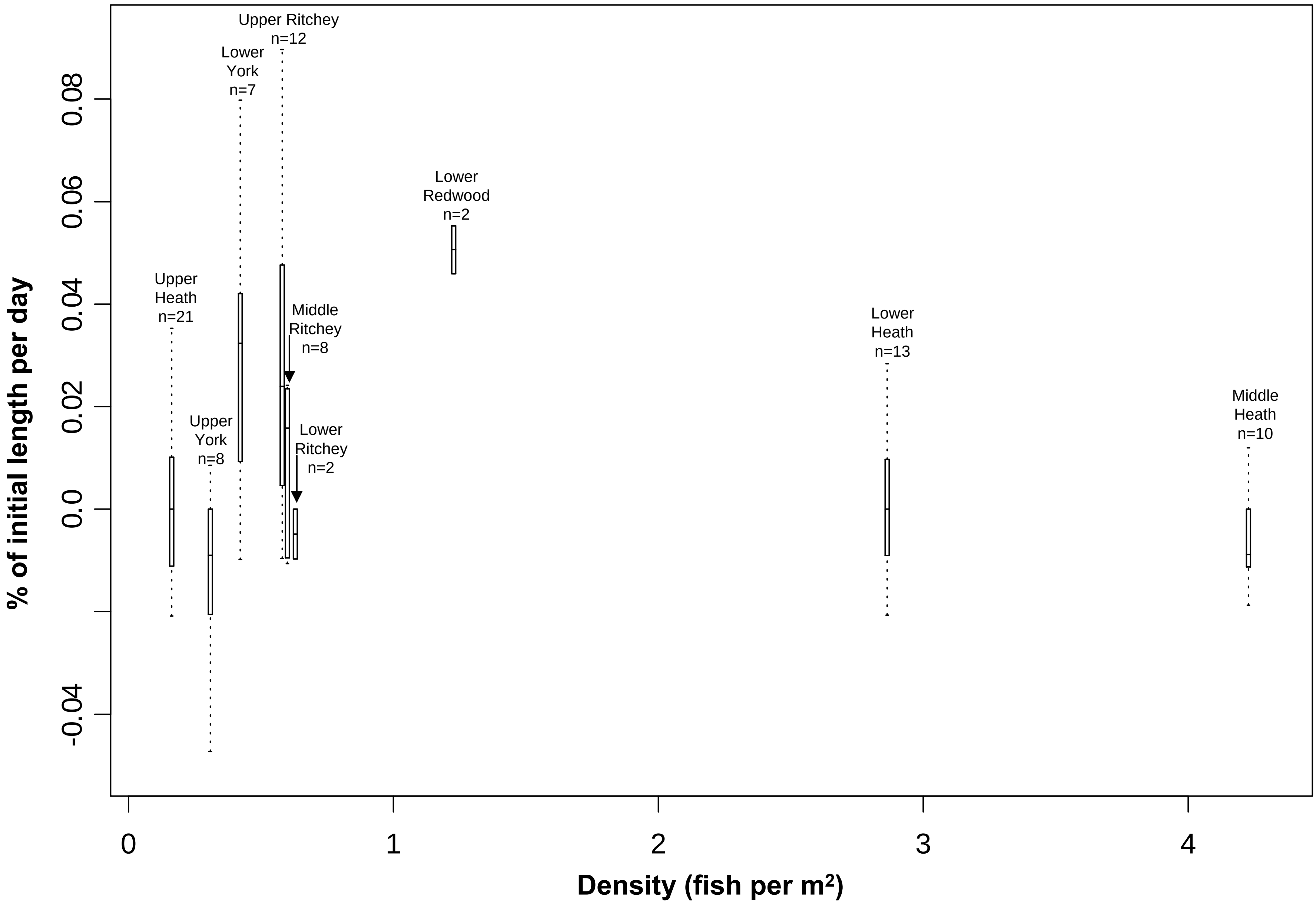

Figure 36. Relative age 1+ steelhead growth rate from August to October 2005 in all study reaches. Density is based on electrofishing data from August 2005; all steelhead.

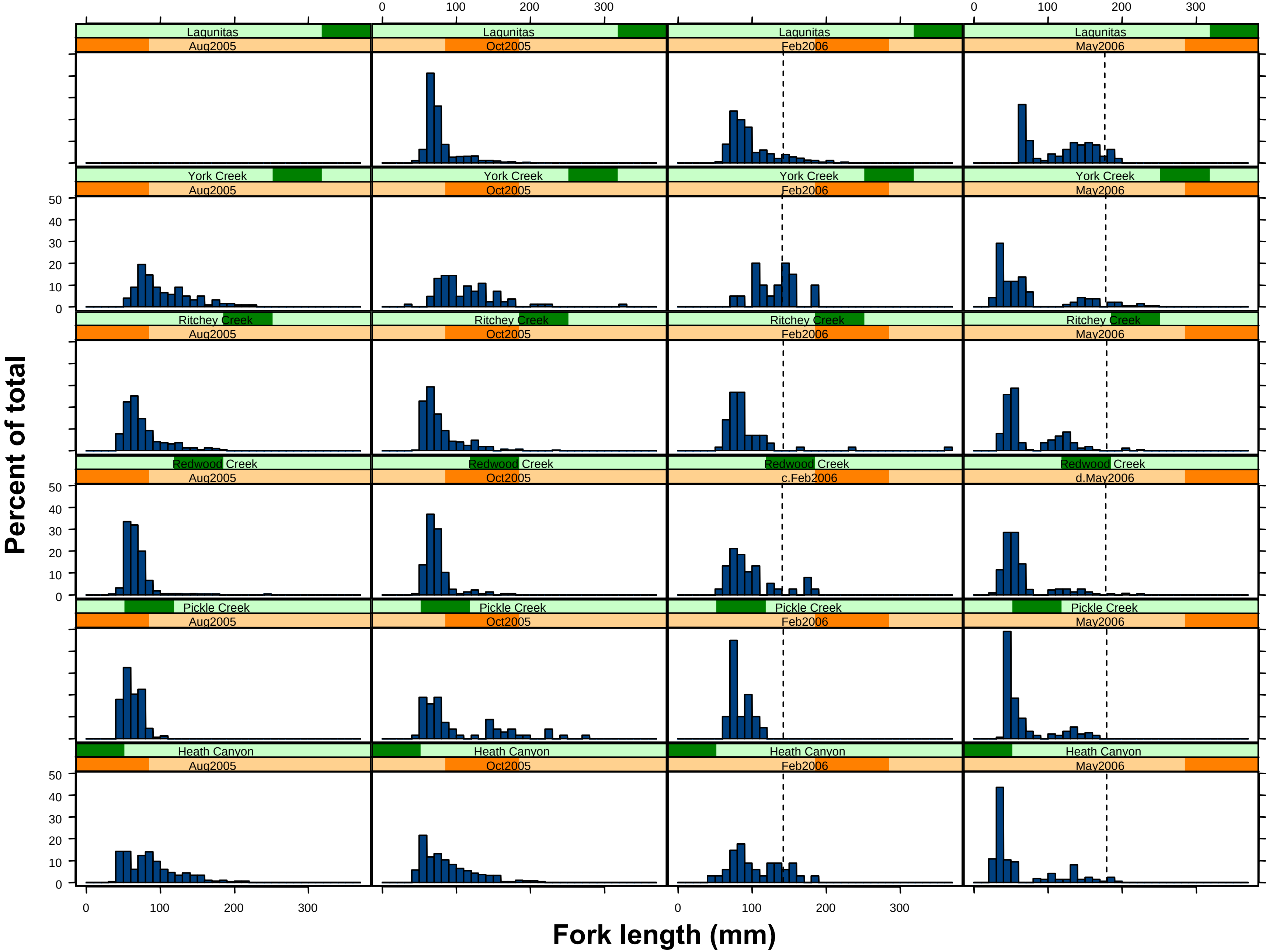

Figure 37. Length-frequency histogram by stream and survey period, including data from Lagunitas Creek (top). A dashed line is shown at 136 mm fork length for February data, and 170 mm for May data.

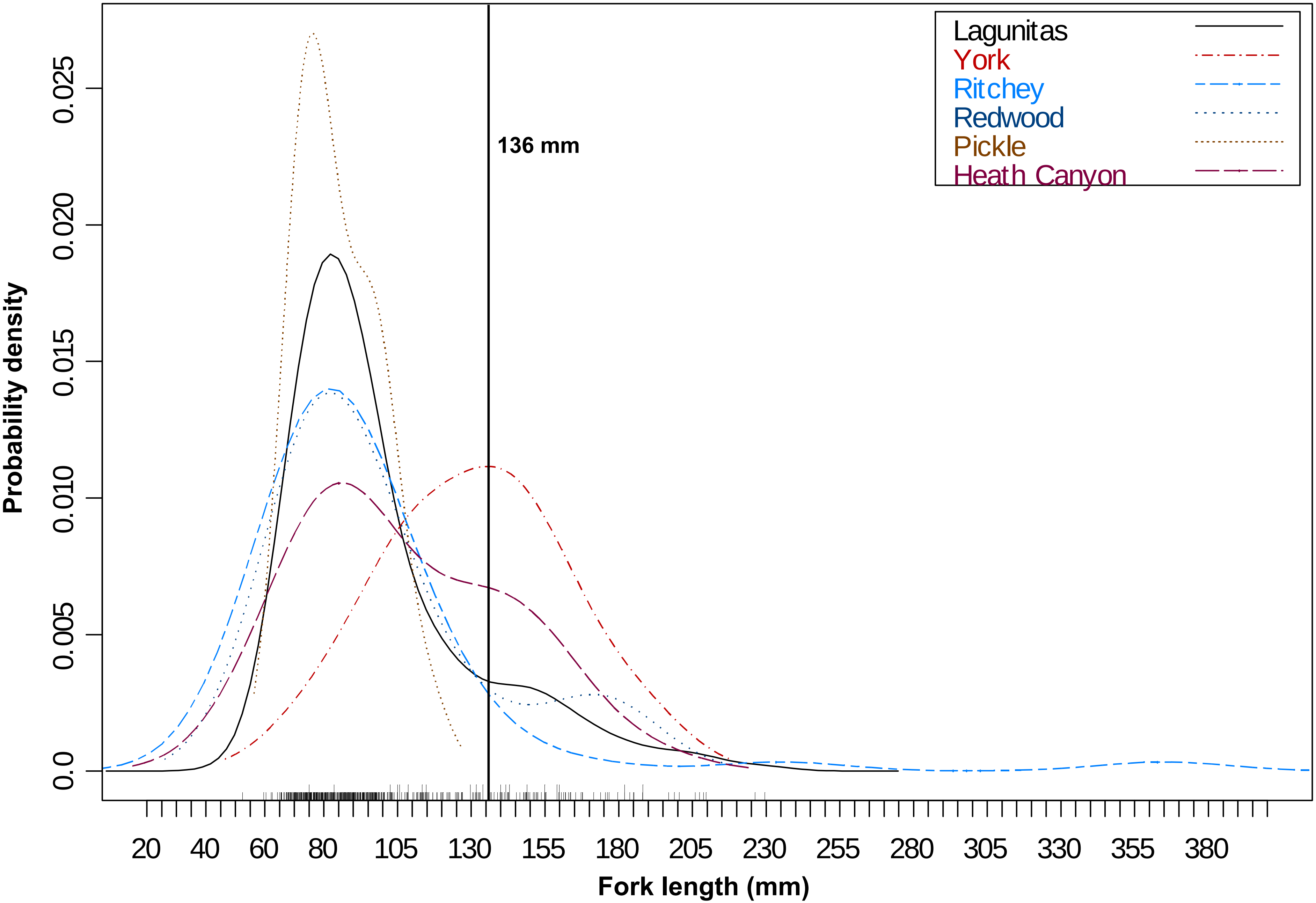

Figure 38. Probability density of steelhead length comparing all study streams and Lagunitas Creek, February 2006.

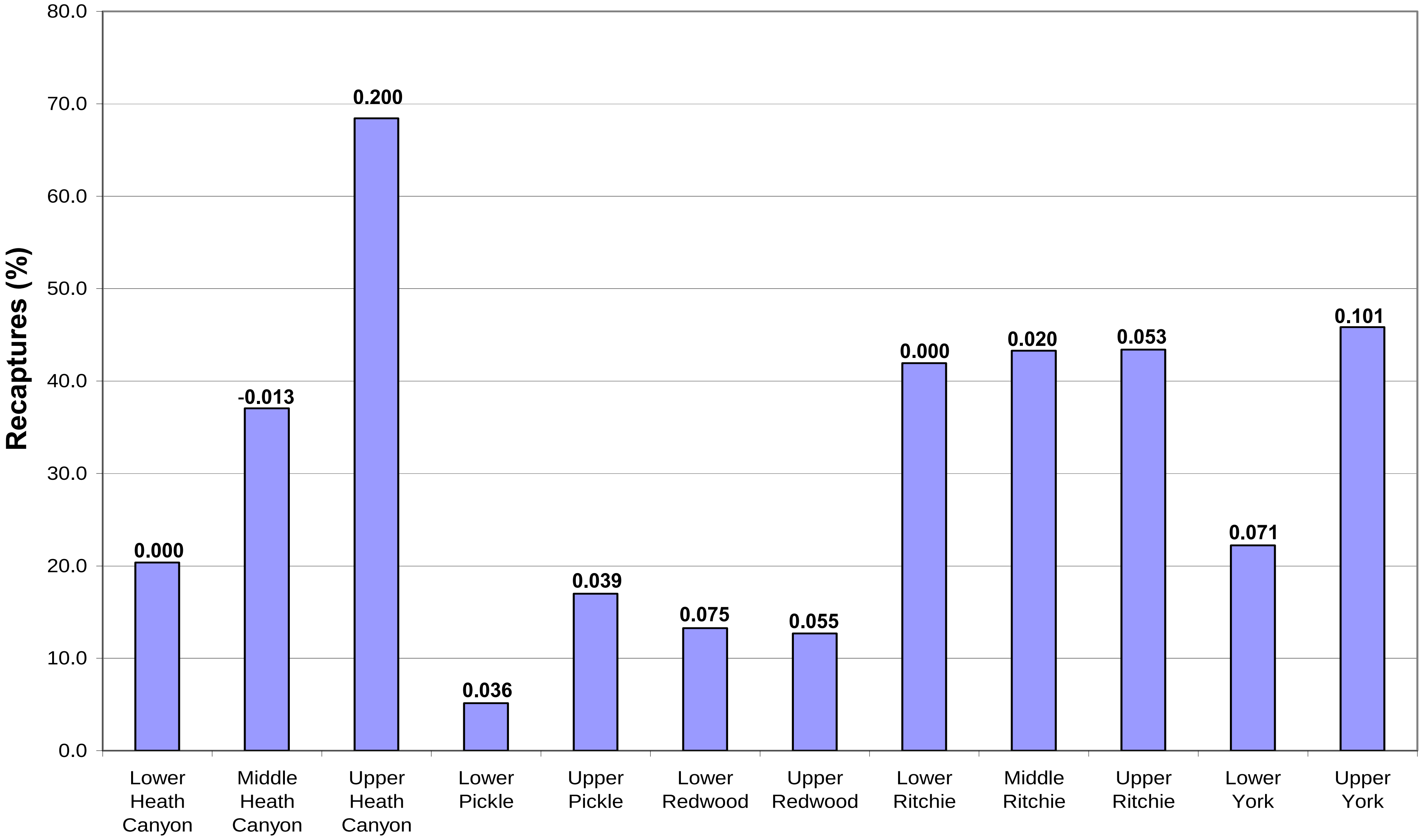

Figure 39. Percent of age 0+ steelhead recaptures based on number of fish tagged in August 2005 and recovered in October 2005. Note that the value above each bar is the median relative growth rate (% change in length per day) for that reach.

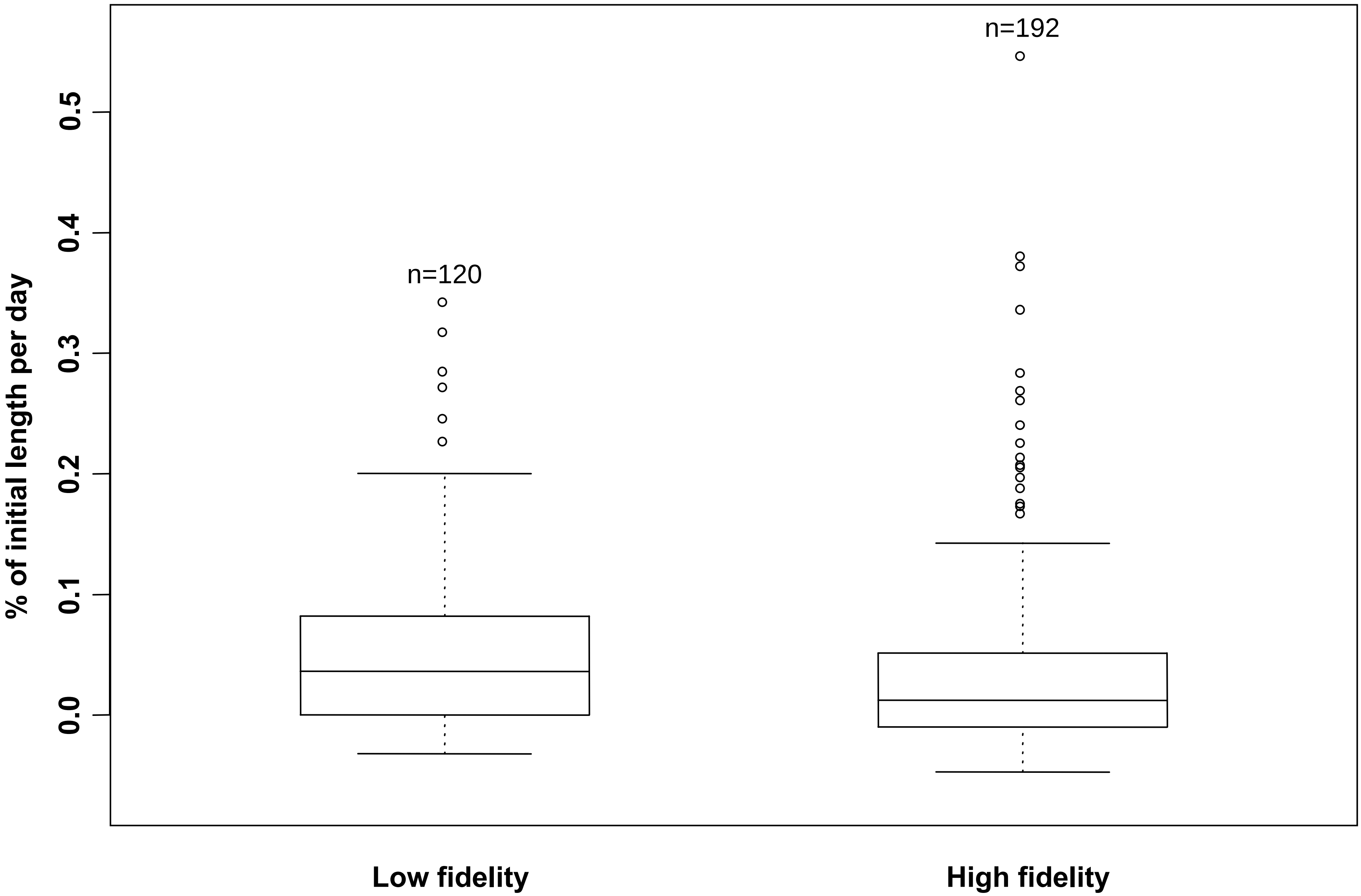

Figure 40. Relative growth rate box plots by fidelity classification; low fidelity was based on recapture rate of ≤0.35.

Appendices

Appendix A

Fish sampling results

Table A-1. Fish count totals, summer 2005 through summer 2006.

Sampling period	Stream	Reach	Species	Count	Age class	Average fork length (mm)	Minimum fork length (mm)	Maximum fork length (mm)
2–10 August 2005	Heath Canyon	Lower	Bluegill	8	NA	NA	NA	NA
			Steelhead	113	0+	69	41	98
				25	1+	130	105	151
				12	2+	173	152	213
		Middle	Bluegill	2	NA	NA	NA	NA
			Steelhead	81	0+	70	40	100
				14	1+	123	102	149
				5	2+	185	159	213
		Upper	Steelhead	19	0+	65	48	99
				29	1+	118	101	147
				5	2+	169	153	188
	Pickle Creek	Lower	Steelhead	117	0+	59	42	88
				1	1+	103	103	103
		Upper	Gambusia	2	NA	NA	NA	NA
			Steelhead	53	0+	68	52	97
				1	1+	101	101	101
	Redwood Creek	Lower	Chinook salmon	10	NA	64	56	70
			Steelhead	196	0+	65	48	95
				3	1+	122	106	142
				2	2+	161	160	161
		Upper	Roach	12	NA	NA	NA	NA
			Sculpin spp.	3	NA	NA	NA	NA
			Steelhead	187	0+	65	40	100
				6	1+	126	107	150
				2	2+	210	172	248
	Ritchey Creek	Lower	Sculpin spp.	11	NA	84	84	84
			Steelhead	62	0+	68	41	99
				5	1+	116	104	132
				1	2+	161	161	161
		Middle	Sculpin spp.	8	NA	NA	NA	NA
			Steelhead	67	0+	64	48	99
				11	1+	119	103	146
				1	2+	185	185	185
		Upper	Sculpin spp.	3	NA	NA	NA	NA
			Steelhead	54	0+	67	42	100
				14	1+	123	105	143
				5	2+	169	153	179
	York Creek	Lower	Roach	3	NA	NA	NA	NA
			Sculpin spp.	75	NA	NA	NA	NA
			Steelhead	45	0+	81	58	97
				21	1+	125	101	151
				8	2+	185	156	223
		Upper	Sculpin spp.	35	NA	NA	NA	NA
			Steelhead	24	0+	73	54	98
				17	1+	122	103	143
				9	2+	172	152	204

Sampling period	Stream	Reach	Species	Count	Age class	Average fork length (mm)	Minimum fork length (mm)	Maximum fork length (mm)
26–29 October; 1–4 November 2005	Heath Canyon	Lower	Steelhead	51	0+	65	46	100
				10	1+	119	101	141
				1	2+	154	154	154
		Middle	Steelhead	67	0+	66	45	100
				3	1+	117	106	132
		Upper	Steelhead	10	0+	75	60	98
				7	1+	122	106	144
	Pickle Creek	Lower	Steelhead	10	0+	71	49	96
				9	1+	139	105	151
				14	2+	195	155	274
		Upper	Steelhead	21	0+	68	52	99
	Redwood Creek	Lower	Steelhead	117	0+	69	50	94
				4	1+	126	119	143
		Upper	Steelhead	54	0+	71	55	95
				7	1+	126	107	144
				2	2+	167	162	171
	Ritchey Creek	Lower	Steelhead	66	0+	65	51	95
				5	1+	127	102	149
				1	2+	235	235	235
		Middle	Steelhead	51	0+	68	45	98
				6	1+	125	102	138
		Upper	Steelhead	29	0+	71	54	94
				7	1+	119	102	146
	York Creek	Lower	Steelhead	16	0+	85	38	99
				7	1+	128	109	148
				4	2+	199	153	323
		Upper	Steelhead	4	0+	80	67	100
				5	1+	122	107	138
				2	2+	161	156	166
15–20 February 2006	Heath Canyon	Lower	Steelhead	11	1+	82	60	101
		Middle	Steelhead	6	1+	80	50	101
				2	2+	154	152	155
		Upper	Steelhead	3	1+	86	78	100
				4	2+	137	122	164
	Pickle Creek	Lower	Steelhead	9	1+	83	70	101
				1	2+	115	115	115
		Upper	Steelhead	9	1+	81	68	100
	Redwood Creek	Lower	Steelhead	24	1+	81	58	108
				1	2+	160	160	160
				3	3+	179	172	186
		Upper	Roach	5	NA	65	56	75
			Sculpin spp.	1	NA	115	115	115
			Steelhead	5	1+	93	76	110
				2	2+	131	122	139
				1	3+	173	173	173

Sampling period	Stream	Reach	Species	Count	Age class	Average fork length (mm)	Minimum fork length (mm)	Maximum fork length (mm)
15–20 February 2006	Ritchey Creek	Lower	Steelhead	10	1+	74	60	91
		Middle	Sculpin spp.	3	NA	87	86	88
			Steelhead	20	1+	80	61	105
				1	2+	120	120	120
		Upper	Steelhead	9	1+	83	69	103
				3	2+	117	111	125
				2	3+	300	235	365
	York Creek	Lower	Sculpin spp.	4	NA	70	60	80
			Steelhead	3	1+	106	103	109
				5	2+	138	114	159
				2	3+	185	181	189
		Upper	Steelhead	2	1+	80	75	84
				2	2+	145	141	149
17– 22 May 2006	Heath Canyon	Lower	Steelhead	80	0+	39	27	59
				13	1+	125	89	175
		Middle	Steelhead	83	0+	38	24	55
				18	1+	129	86	191
		Upper	Steelhead	2	0+	28	27	29
				5	1+	127	106	158
	Pickle Creek	Lower	Steelhead	43	0+	55	40	75
				10	1+	128	105	165
		Upper	Steelhead	81	0+	51	41	84
				14	1+	140	127	161
	Redwood Creek	Lower	Roach	2	NA	86	81	90
			Steelhead	219	0+	51	29	78
				27	1+	129	104	210
		Upper	Roach	1	NA	81	81	81
			Sculpin spp.	2	NA	111	110	112
			Steelhead	67	0+	51	30	70
				12	1+	141	115	202
				1	2+	225	225	225
	Ritchey Creek	Lower	Sculpin spp.	6	NA	76	63	90
			Steelhead	30	0+	52	35	65
				12	1+	122	104	144
		Middle	Sculpin spp.	4	NA	93	86	106
			Steelhead	49	0+	49	31	77
				9	1+	106	91	124
		Upper	Sculpin spp.	2	NA	76	69	83
			Steelhead	30	0+	49	32	64
				12	1+	132	98	205

Sampling period	Stream	Reach	Species	Count	Age class	Average fork length (mm)	Minimum fork length (mm)	Maximum fork length (mm)
17– 22 May 2006	York Creek	Lower	Green sunfish	2	NA	107	86	127
			Sculpin spp.	42	NA	78	57	115
			Steelhead	91	0+	46	26	80
				15	1+	155	124	192
				2	2+	222	217	227
		Upper	Green sunfish	5	NA	117	108	138
			Sculpin spp.	8	NA	74	63	85
			Steelhead	55	0+	53	30	75
				15	1+	166	135	198
				3	2+	230	224	242

Table A-2. Average absolute growth rates based on recaptures of individual fish.

Stream	Reach	Average growth (mm/day)																	
		August to October (by age class)						October to February						February to May					
		2+ and older (n)	S.D.	1+ (n)	S.D.	0+ (n)	S.D.	2+ and older (n)	S.D.	1+ (n)	S.D.	0+ (n)	S.D.	2+ and older (n)	S.D.	1+ (n)	S.D.	0+ (n)	S.D.
Heath Canyon Creek	Lower	0.004 (9)	0.010	0.000 (13)	0.014	0.044 (23)	0.098	NA	NA	0.078 (1)	NA	NA	NA	NA	NA	0.349 (1)	NA	0.749 (1)	NA
	Middle	-0.012 (5)	0.010	-0.006 (10)	0.009	-0.005 (29)	0.043	NA	NA	0.128 (1)	NA	NA	NA	NA	NA	0.271 (1)	NA	NA	NA
	Upper	-0.000 (3)	0.015	0.000 (21)	0.015	0.171 (12)	0.112	NA	NA	0.106 (5)	0.013	NA	NA	NA	NA	0.173 (2)	0.030	NA	NA
Pickle Creek	Lower	NA	NA	NA	NA	0.043 (6)	0.029	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.526 (1)	NA
	Upper	NA	NA	NA	NA	0.049 (9)	0.024	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.936 (2)	0.121
Redwood Creek	Lower	NA	NA	0.051 (2)	0.007	0.086 (25)	0.075	NA	NA	NA	NA	0.315 (2)	0.075	NA	NA	NA	NA	0.595 (6)	0.030
	Upper	NA	NA	NA	NA	0.064 (25)	0.077	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.588 (1)	NA
Ritchey Creek	Lower	0.015 (1)	NA	-0.005 (2)	0.007	0.014 (26)	0.037	NA	NA	NA	NA	0.092 (2)	0.043	NA	NA	NA	NA	0.712 (2)	0.080
	Middle	-0.025 (1)	NA	0.009 (8)	0.016	0.070 (29)	0.108	NA	NA	NA	NA	0.146 (3)	0.092	NA	NA	0.303 (1)	NA	0.501 (6)	0.039
	Upper	0.011 (3)	0.011	0.027 (12)	0.030	0.056 (23)	0.060	NA	NA	0.099 (2)	0.034	0.206 (2)	0.081	NA	NA	NA	NA	0.505 (7)	0.077
York Creek	Lower	0.021 (3)	0.035	0.032 (7)	0.028	0.108 (10)	0.103	NA	NA	NA	NA	0.234 (1)	NA	NA	NA	NA	NA	0.486 (3)	0.014
	Upper	0.012 (6)	0.015	-0.012 (8)	0.017	0.139 (12)	0.121	0.035 (1)	NA	0.113 (4)	0.067	NA	NA	NA	NA	0.358 (1)	NA	NA	NA

S.D. = standard deviation.
NA indicates no recaptures or insufficient sample size to calculate standard deviation.

Appendix B

Habitat classification results

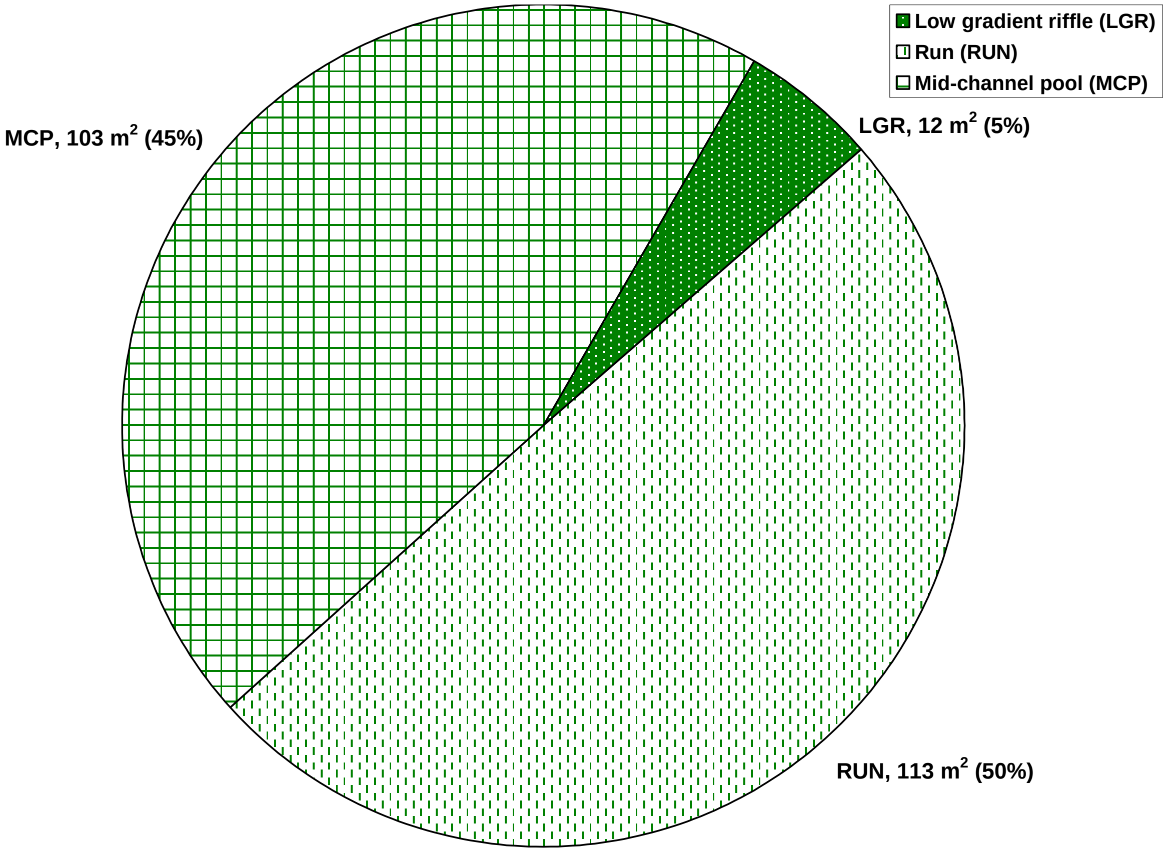

Figure B-1. Habitat area by type for steelhead sampling reaches in lower Heath Canyon Creek, August 2005.

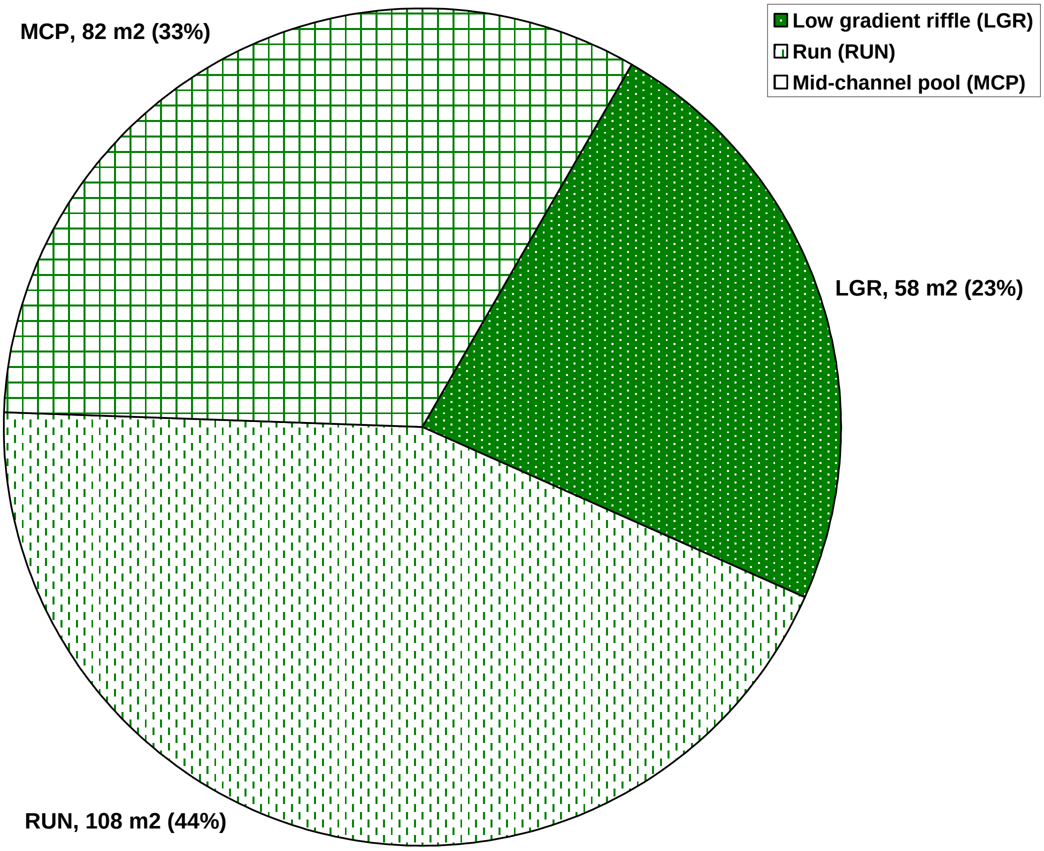

Figure B-2. Habitat area by type for steelhead sampling reaches in middle Heath Canyon Creek, August 2005.

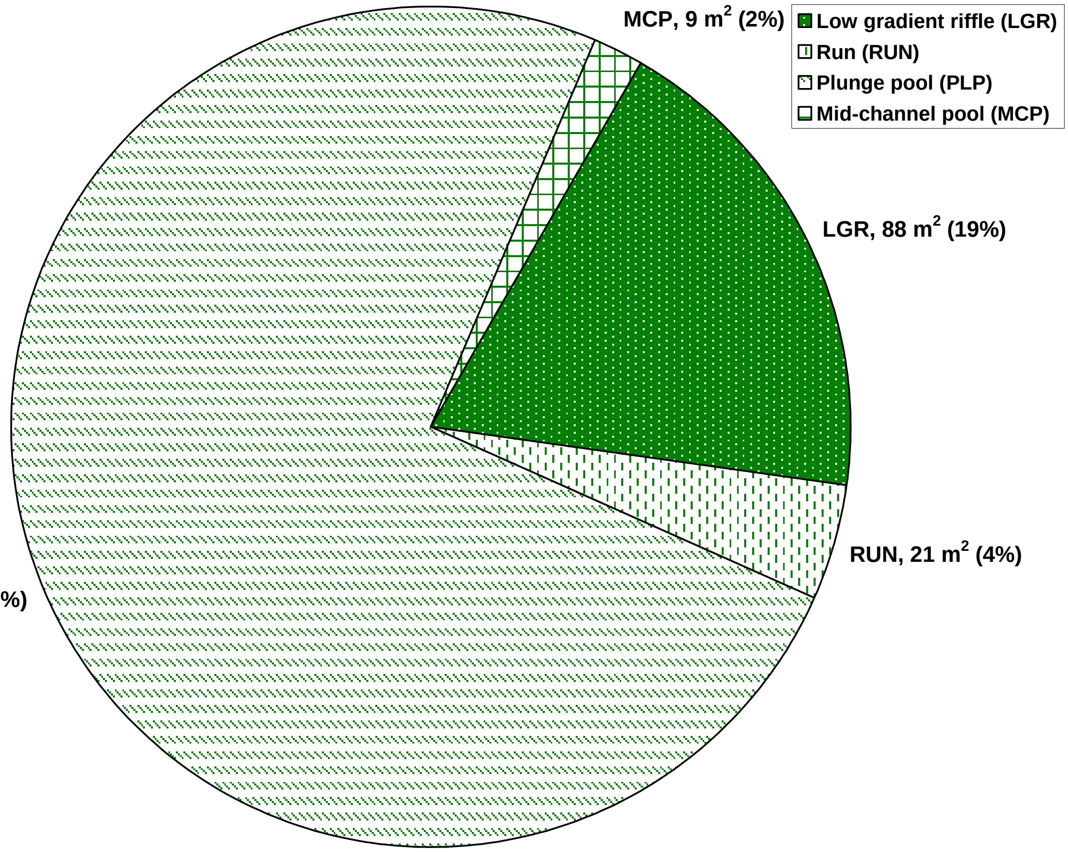

Figure B-3. Habitat area by type for steelhead sampling reaches in upper Heath Canyon Creek, August 2005.

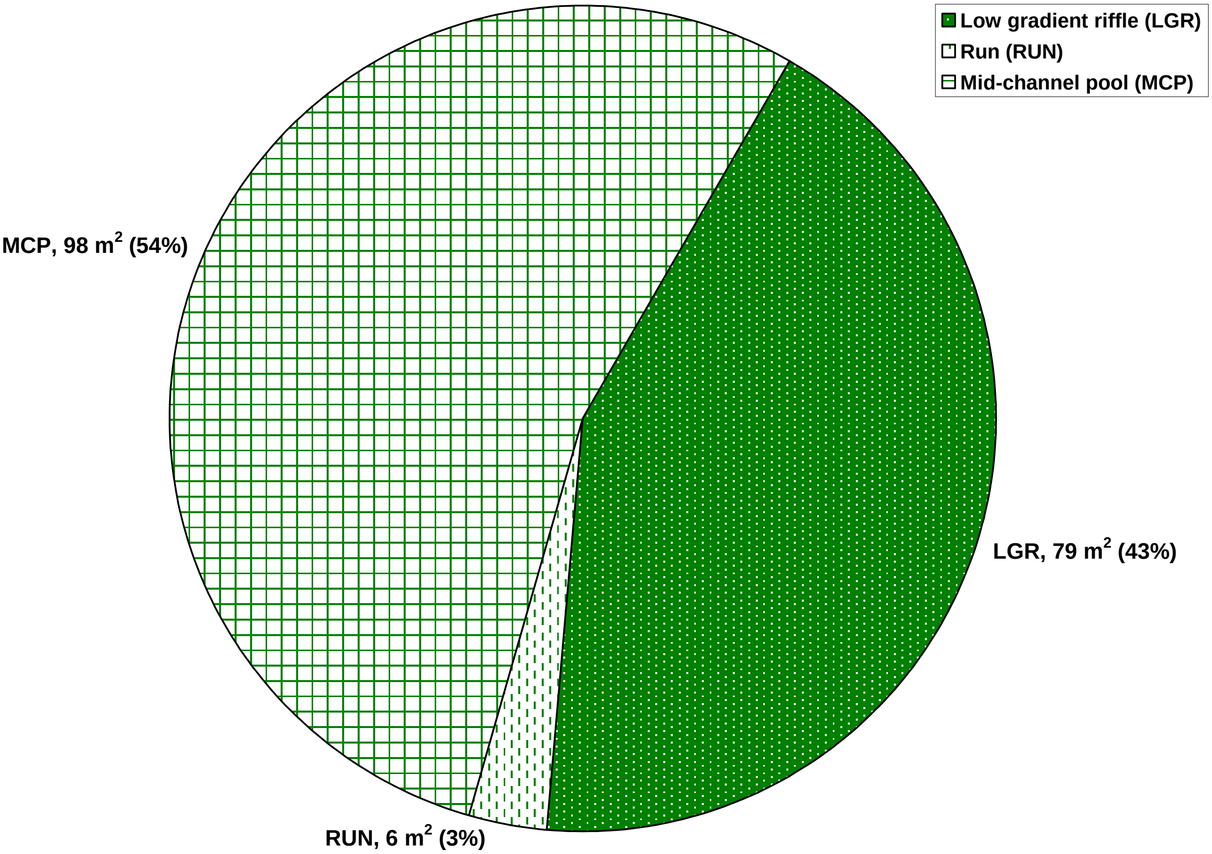

Figure B-4. Habitat area by type for steelhead sampling reaches in Pickle Creek, August 2005.

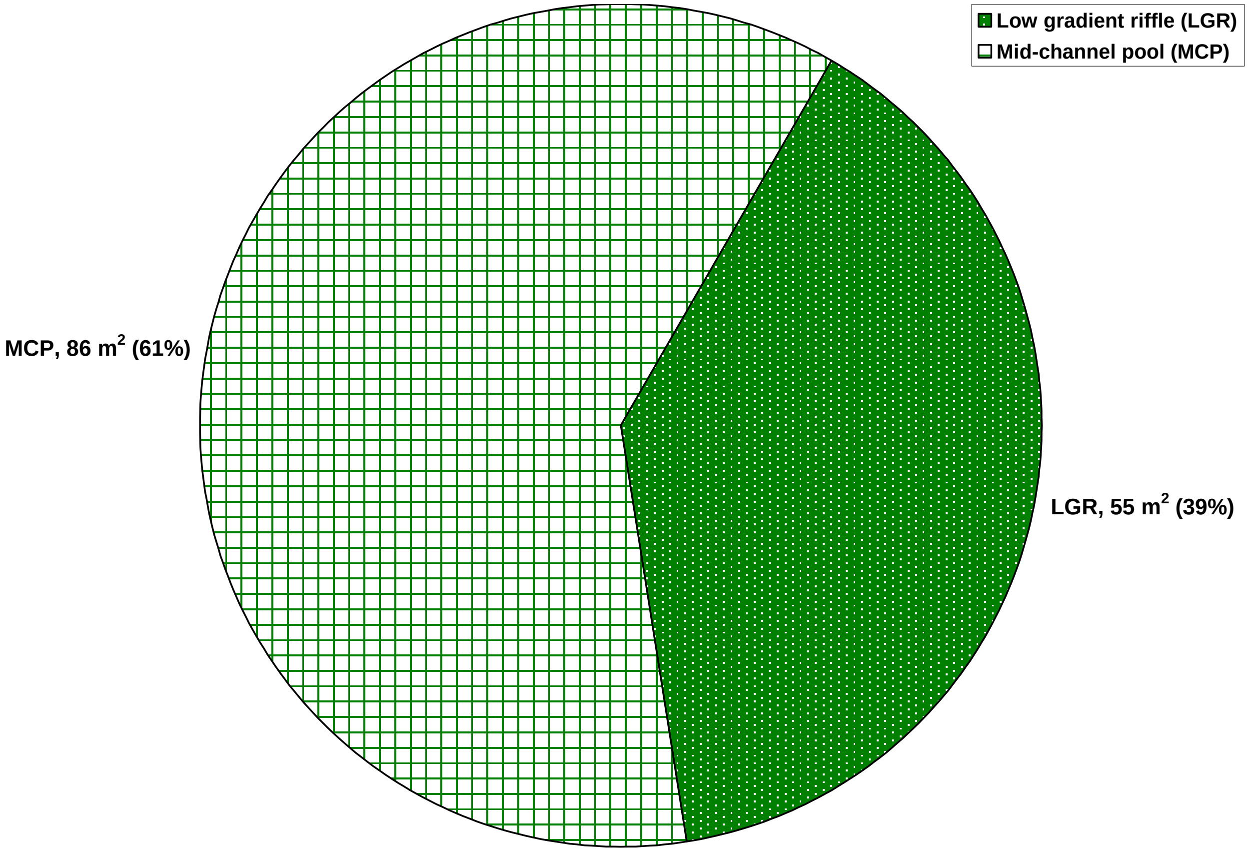

Figure B-5. Habitat area by type for steelhead sampling reaches in upper Pickle Creek, August 2005.

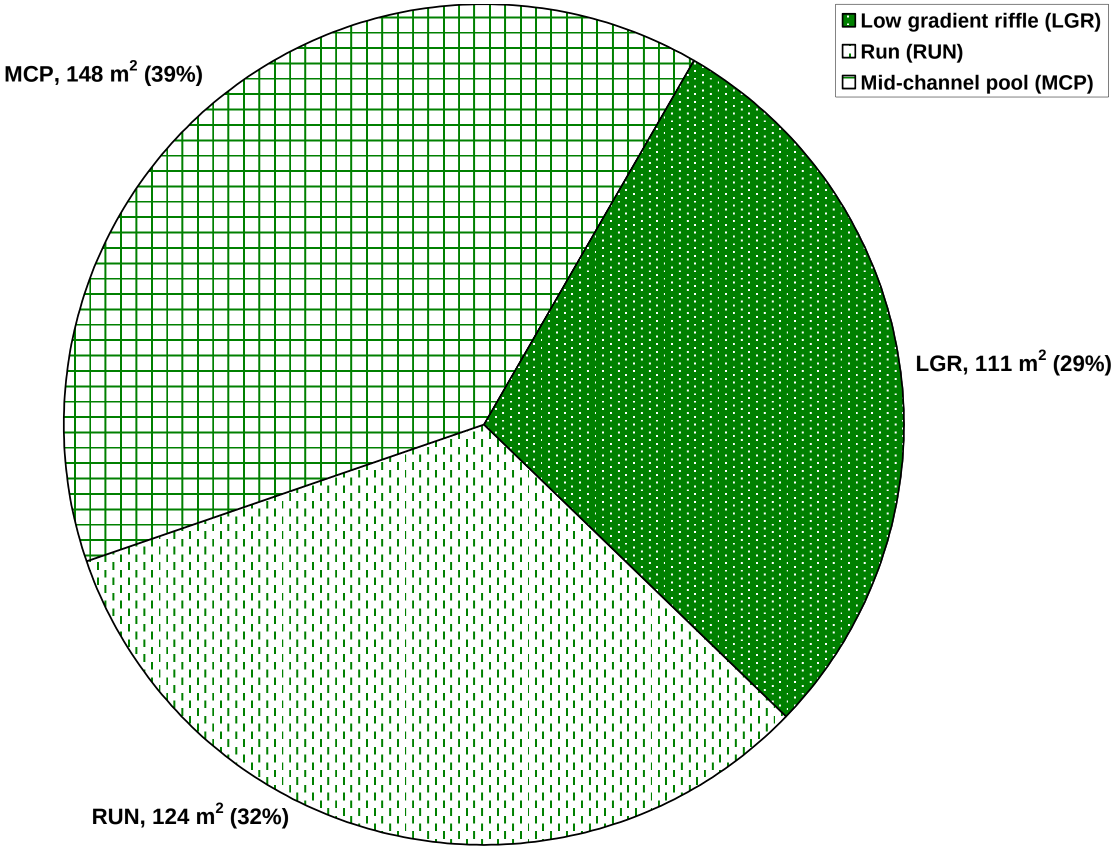

Figure B-6. Habitat area by type for steelhead sampling reaches in lower Redwood Creek, August 2005.

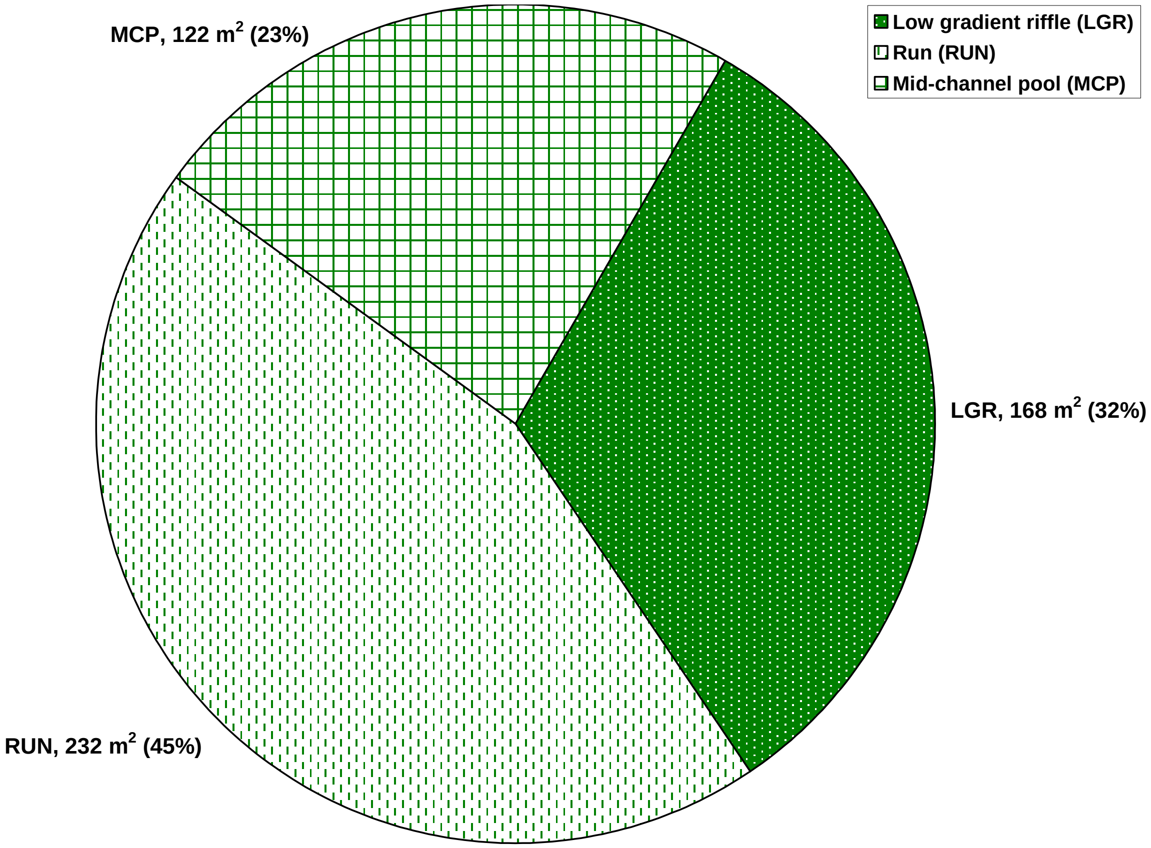

Figure B-7. Habitat area by type for steelhead sampling reaches in upper Redwood Creek, August 2005.

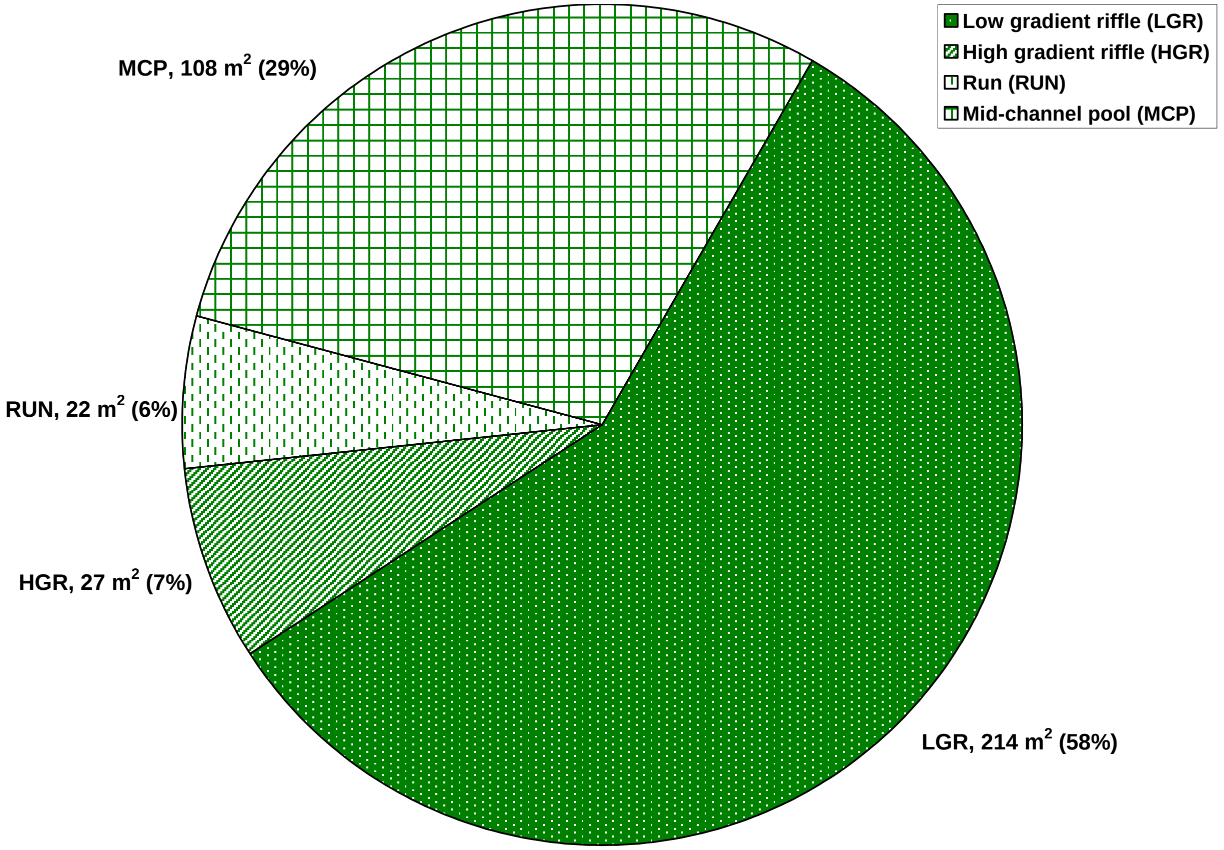

Figure B-8. Habitat area by type for steelhead sampling reaches in lower Ritchey Creek, August 2005.

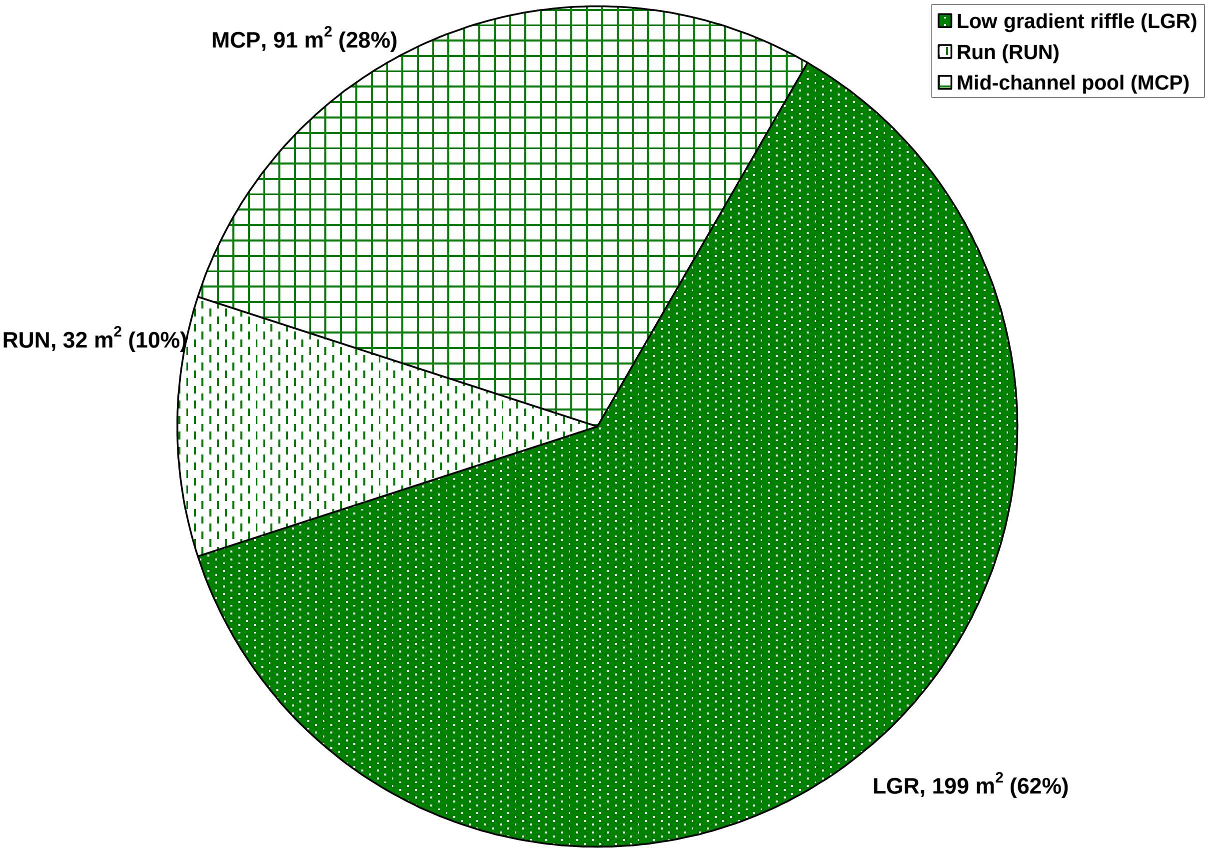

Figure B-9. Habitat area by type for steelhead sampling reaches in middle Ritchey Creek, August 2005.

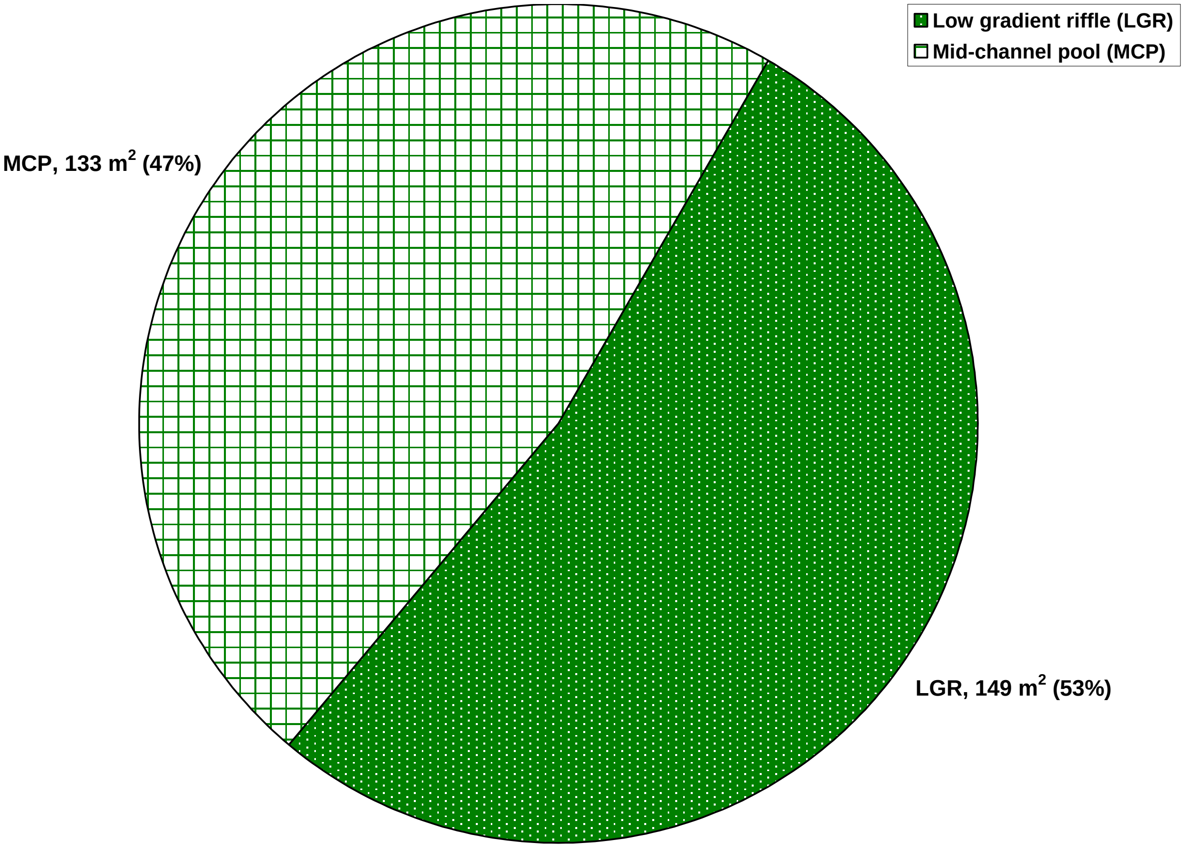

Figure B-10. Habitat area by type for steelhead sampling reaches in upper Ritchey Creek, August 2005.

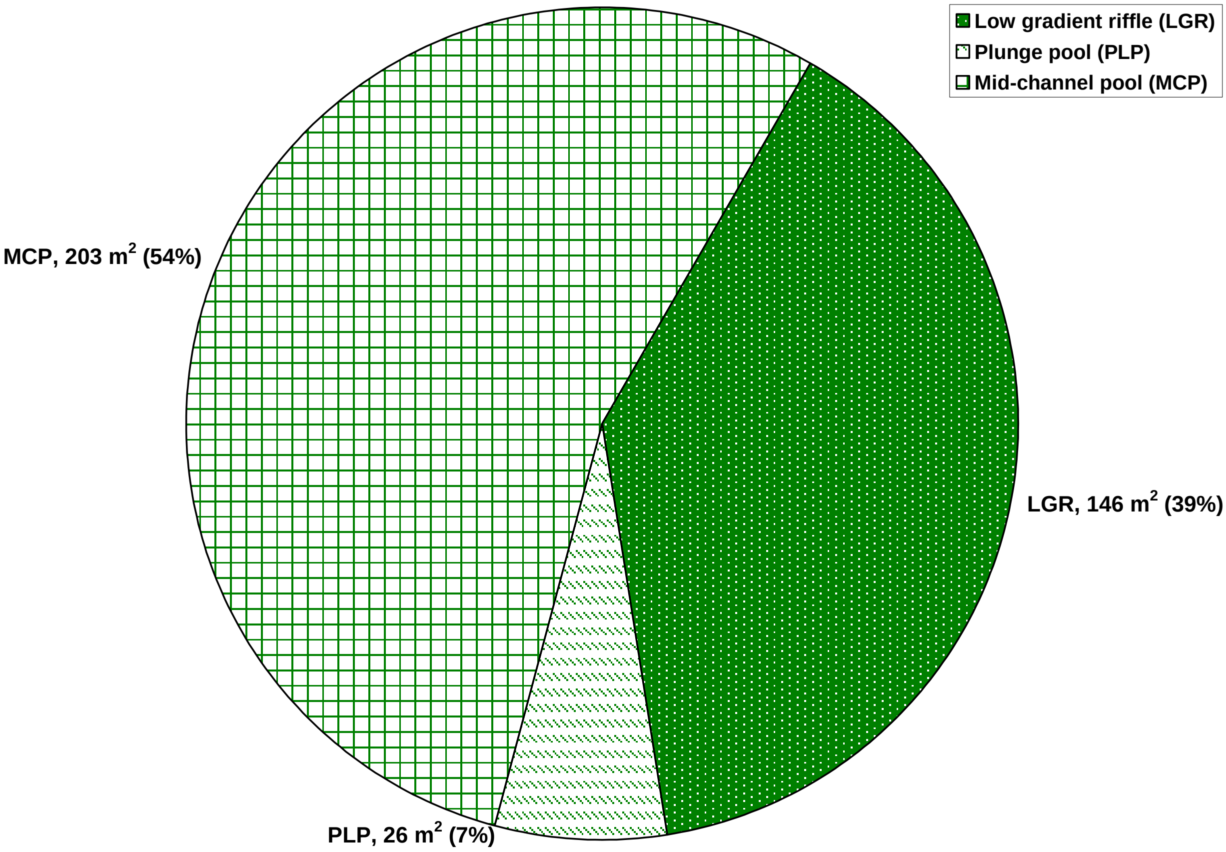

Figure B-11. Habitat area by type for steelhead sampling reaches in lower York Creek, August 2005.

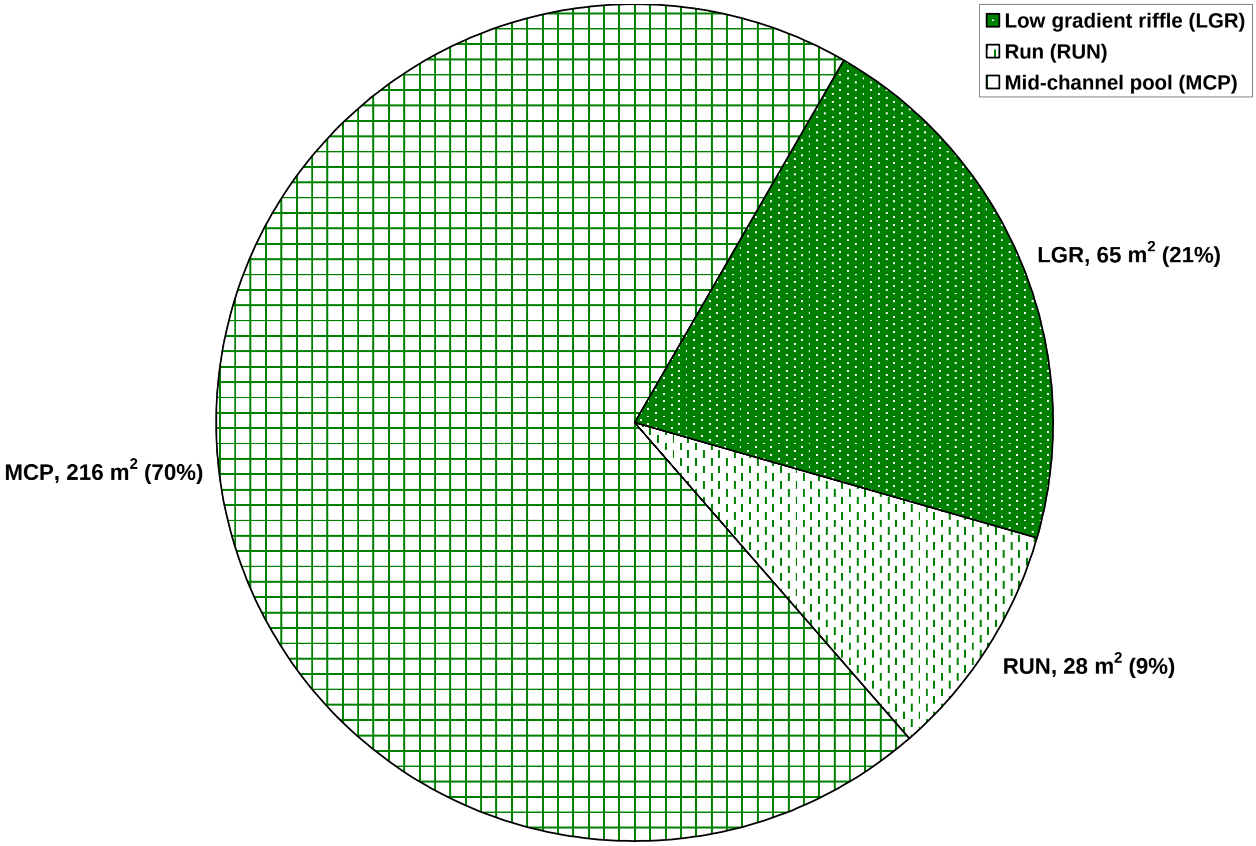

Figure B-12. Habitat area by type for steelhead sampling reaches in upper York Creek, August 2005.

Appendix C

Photographs of study sites

Figure C-1. Heath Canyon lower site. February 2005.

Figure C-2. Heath Canyon lower site. February 2005.

Figure C-3. Heath Canyon lower site. February 2005.

Figure C-4. Heath Canyon middle site. February 2005.

Figure C-5. Heath Canyon middle site. February 2005.

Figure C-6. Heath Canyon upper site. February 2005.

Figure C-7. Heath Canyon upper site. February 2005.

Figure C-8. Heath Canyon upper site. February 2005.

Figure C-9. Pickle Creek lower site. February 2005.

Figure C-10. Pickle Creek lower site. February 2005.

Figure C-11. Pickle Creek upper site. February 2005.

Figure C-12. Pickle Creek upper site. February 2005.

Figure C-13. Redwood Creek lower site. February 2005.

Figure C-14. Redwood Creek lower site. February 2005.

Figure C-15. Redwood Creek lower site. February 2005.

Figure C-16. Redwood Creek upper site. February 2005.

Figure C-17. Redwood Creek upper site. February 2005.

Figure C-18. Redwood Creek upper site. February 2005.

Figure C-19. Ritchey Creek lower site. February 2005.

Figure C-20. Ritchey Creek lower site. February 2005.

Figure C-21. Ritchey Creek lower site. February 2005.

Figure C-22. Ritchey Creek middle site. February 2005.

Figure C-23. Ritchey Creek middle site. February 2005.

Figure C-24. Ritchey Creek middle site. February 2005.

Figure C-25. Ritchey Creek upper site. February 2005.

Figure C-26. Ritchey Creek upper site. February 2005.

Figure C-27. Ritchey Creek upper site. February 2005.

Figure C-28. York Creek lower site. February 2005.

Figure C-29. York Creek lower site. February 2005.

Figure C-30. York Creek lower site. February 2005.

Figure C-31. York Creek upper site. February 2005.

Figure C-32. York Creek upper site. February 2005.

Figure C-33. York Creek upper site. February 2005.

Appendix D

Water surface level (stage) graphs

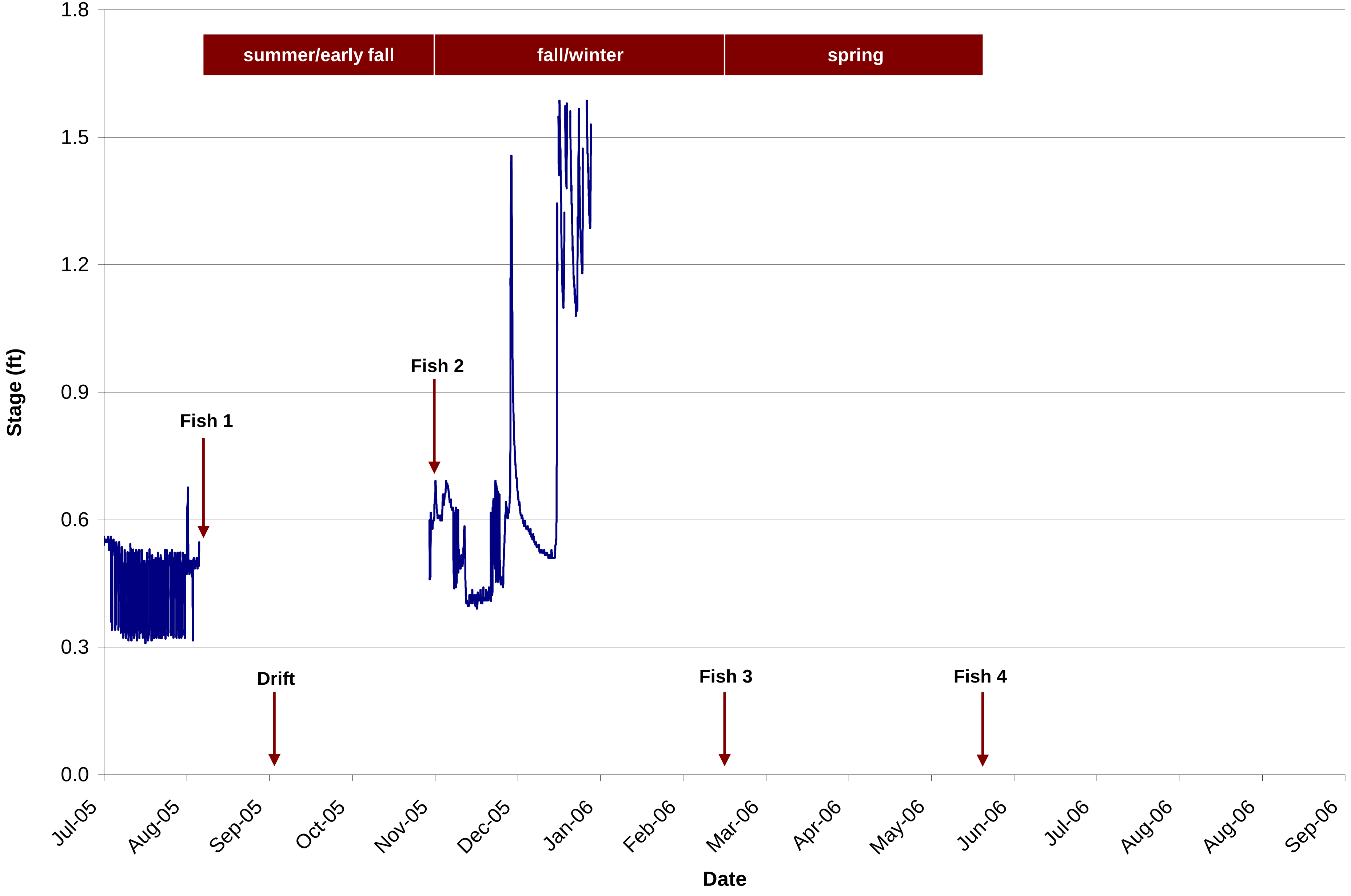

Figure D-1. Water surface level (stage) recorded in the lower reach of Heath Canyon Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

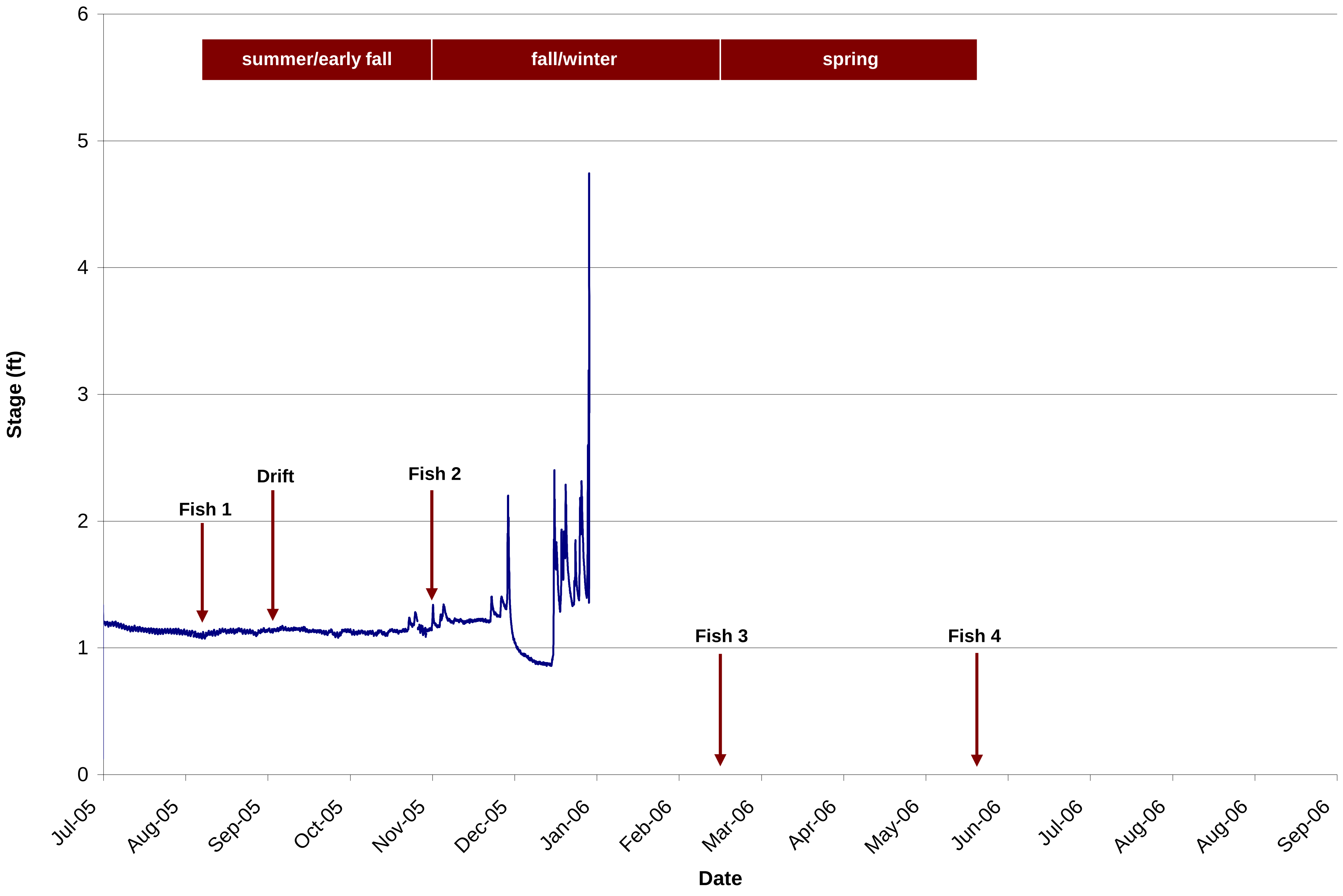

Figure D-2. Water surface level (stage) recorded in the middle reach of Heath Canyon Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

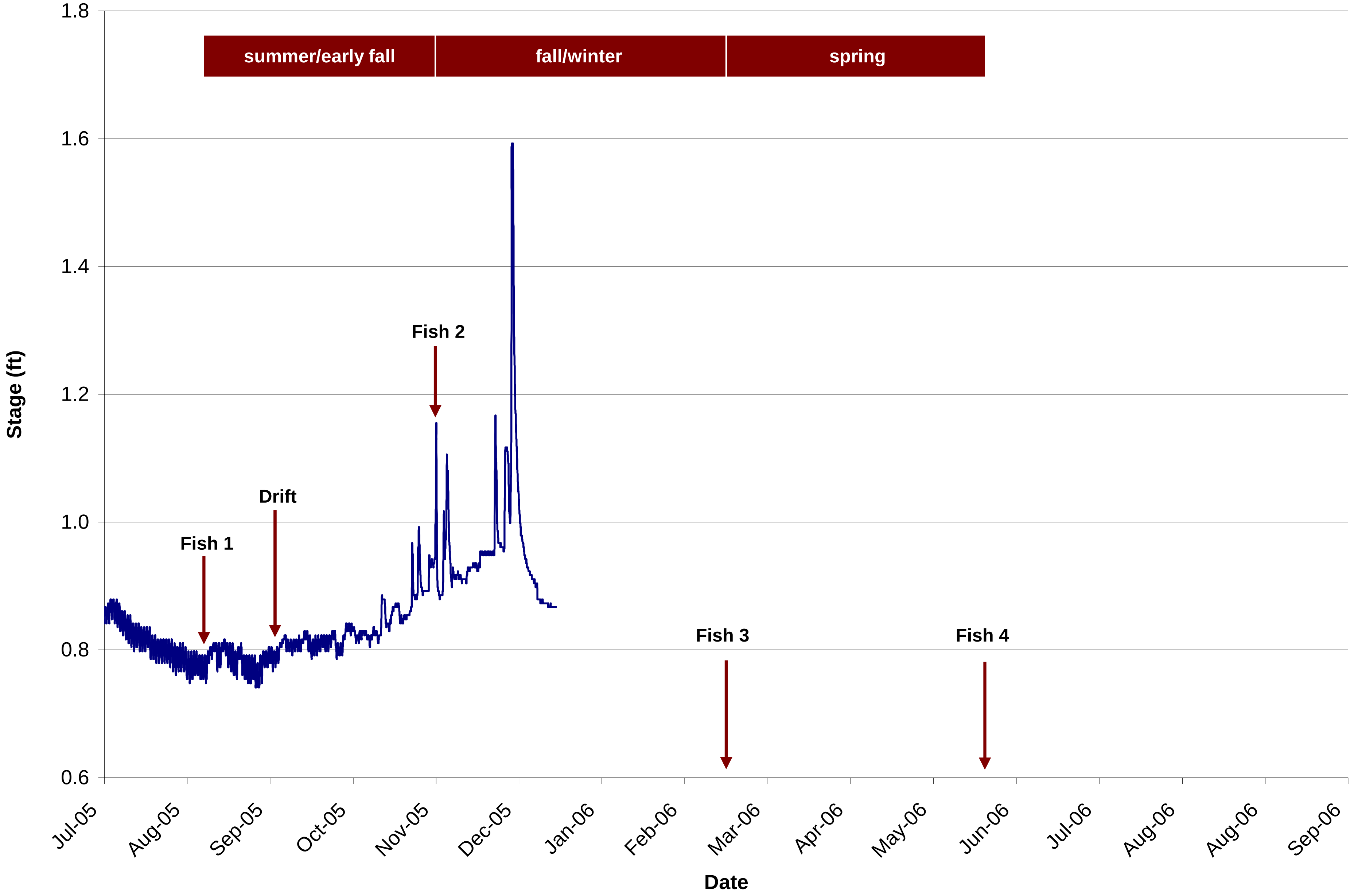

Figure D-3. Water surface level (stage) recorded in the upper reach of Heath Canyon Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

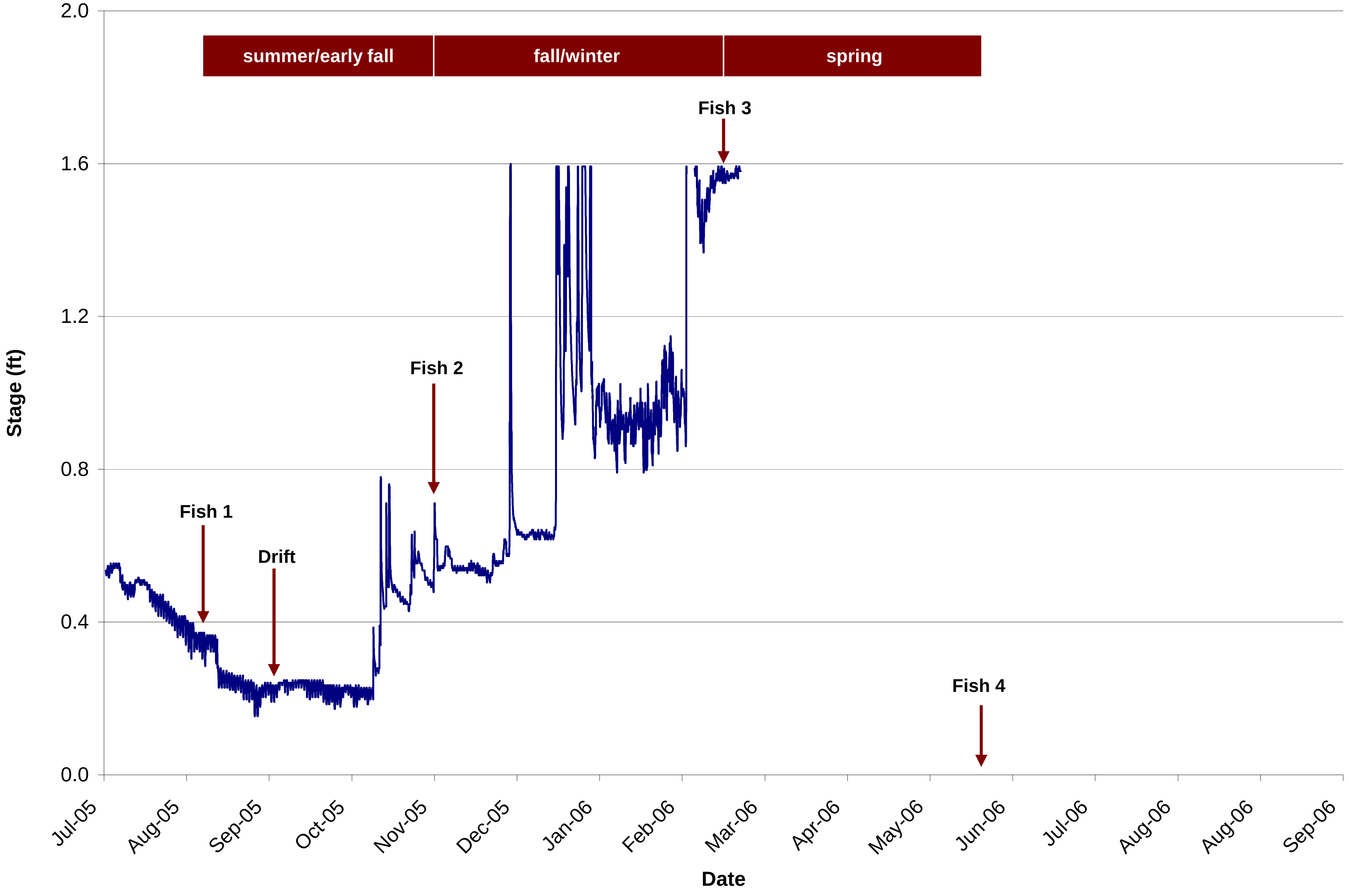

Figure D-4. Water surface level (stage) recorded in the lower reach of Pickle Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

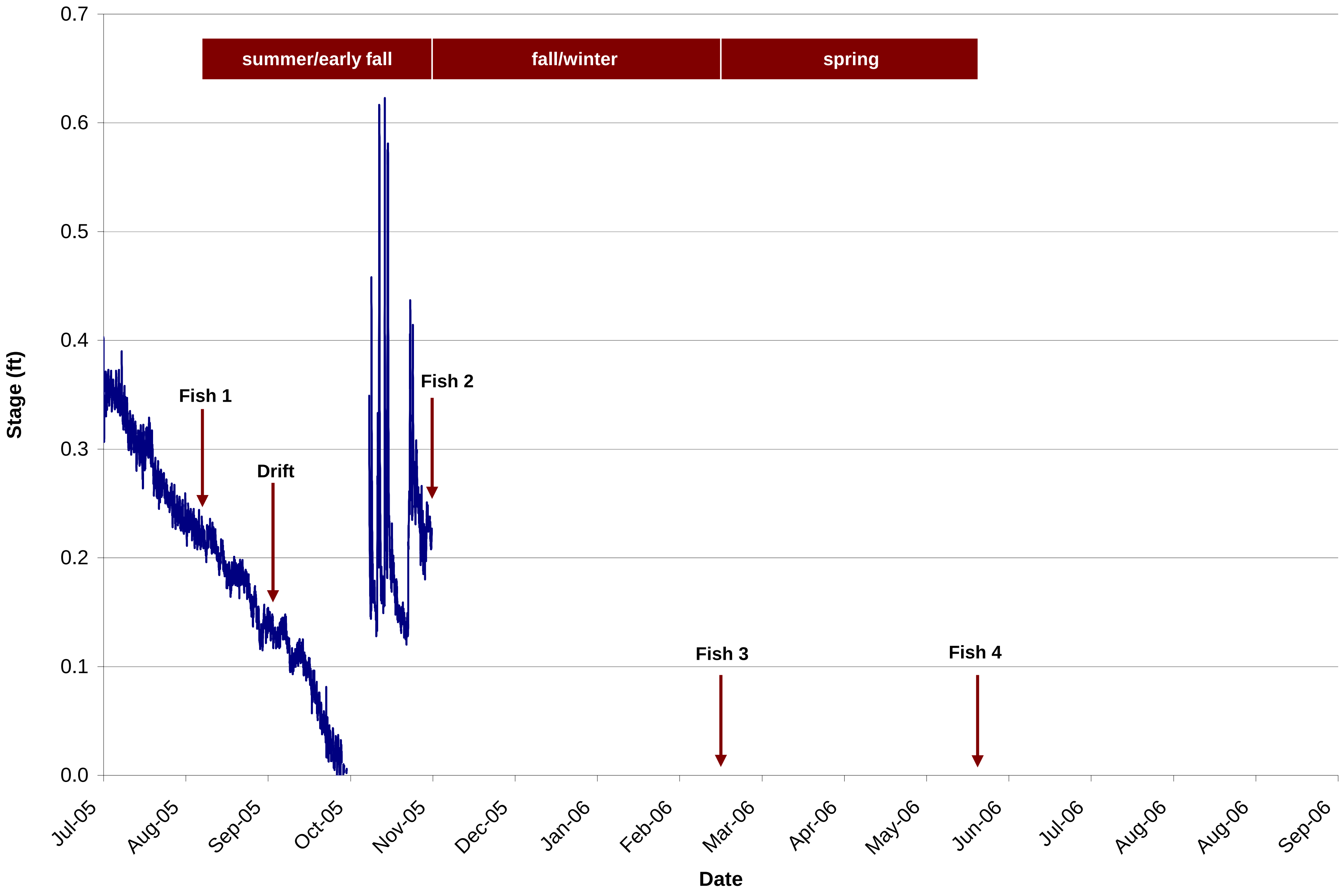

Figure D-5. **Water surface level (stage) recorded in the upper reach of Pickle Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.**

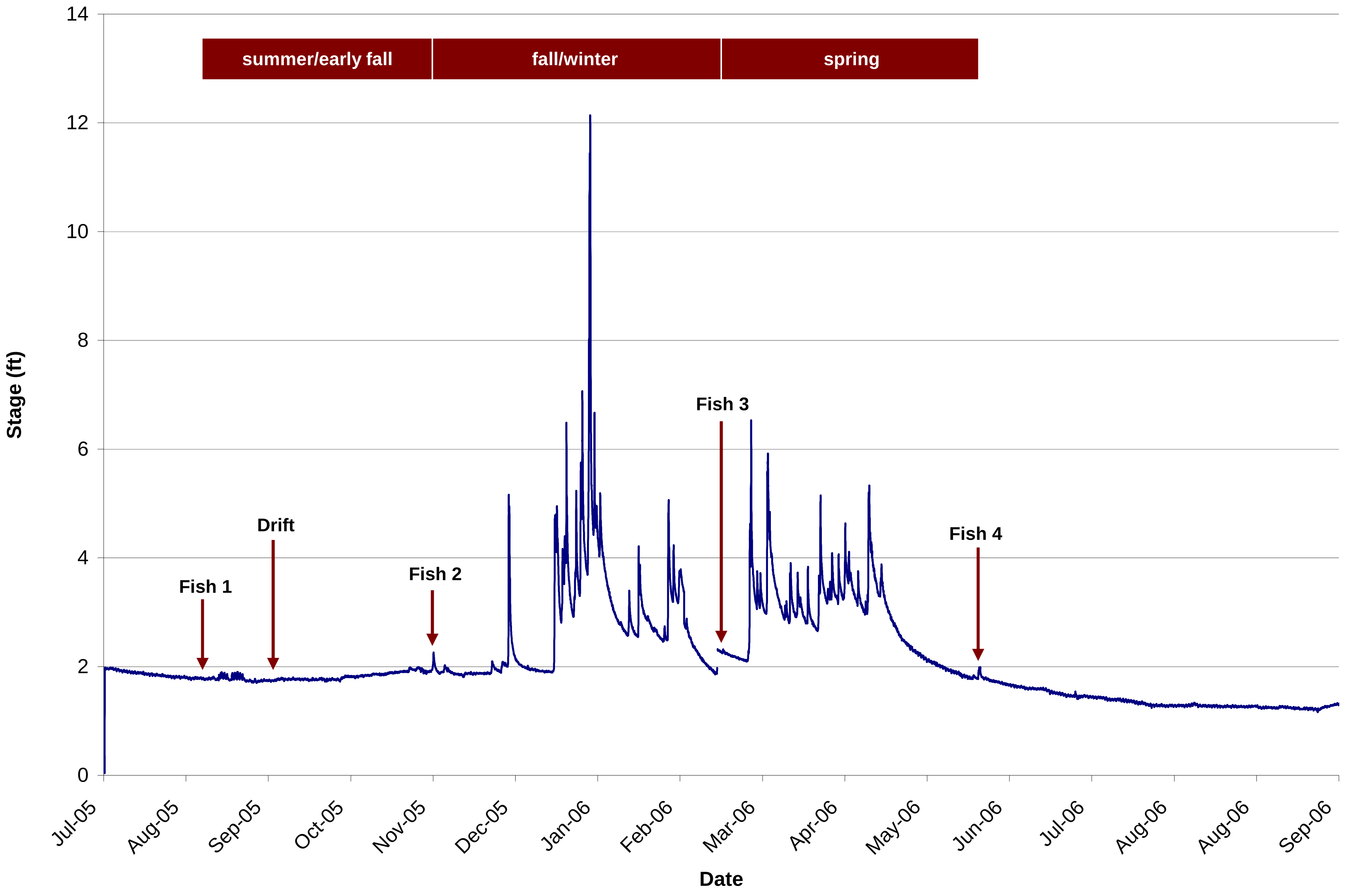

Figure D-6. Water surface level (stage) recorded in the lower reach of Redwood Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

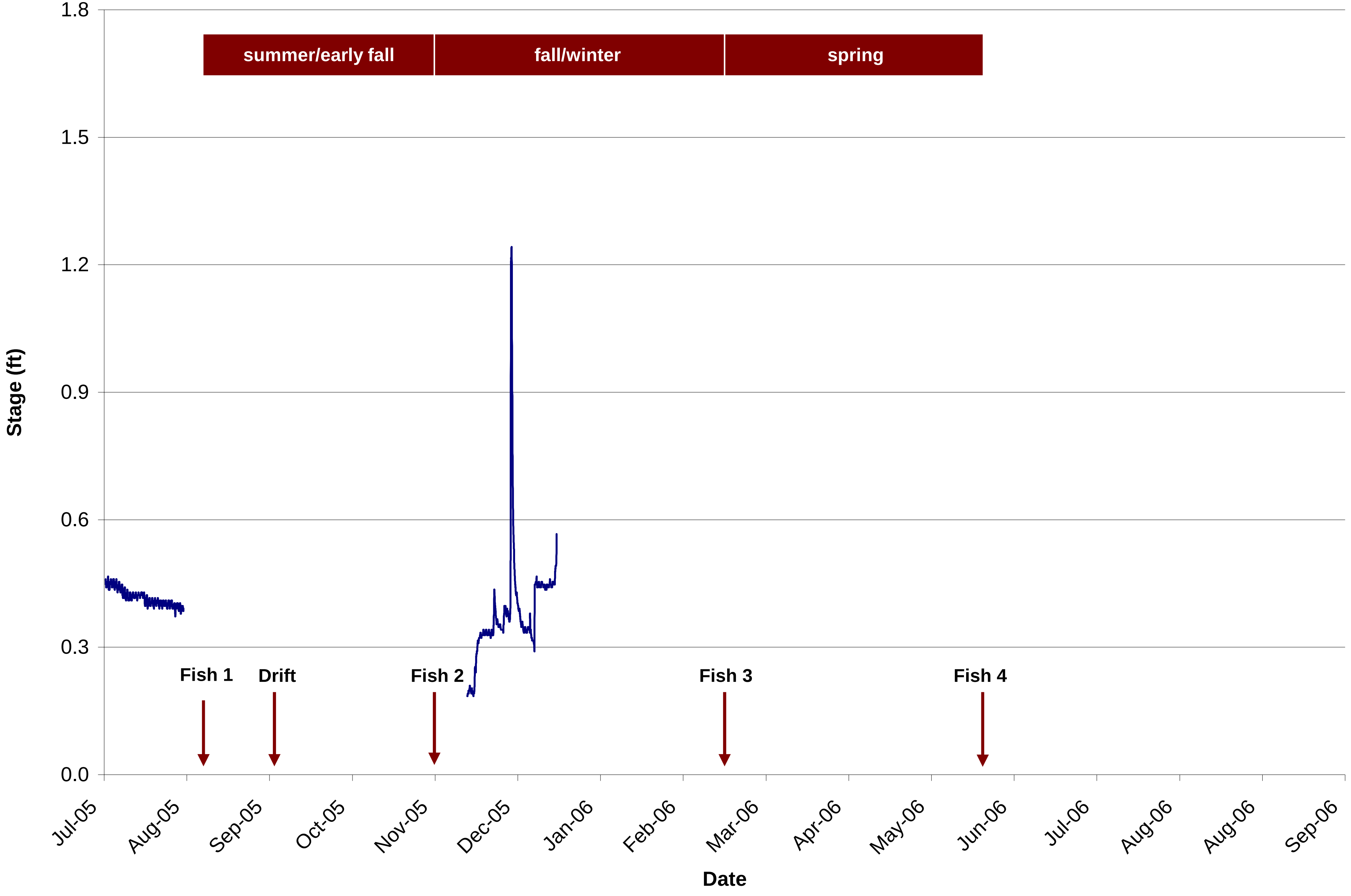

Figure D-7. Water surface level (stage) recorded in the upper reach of Redwood Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

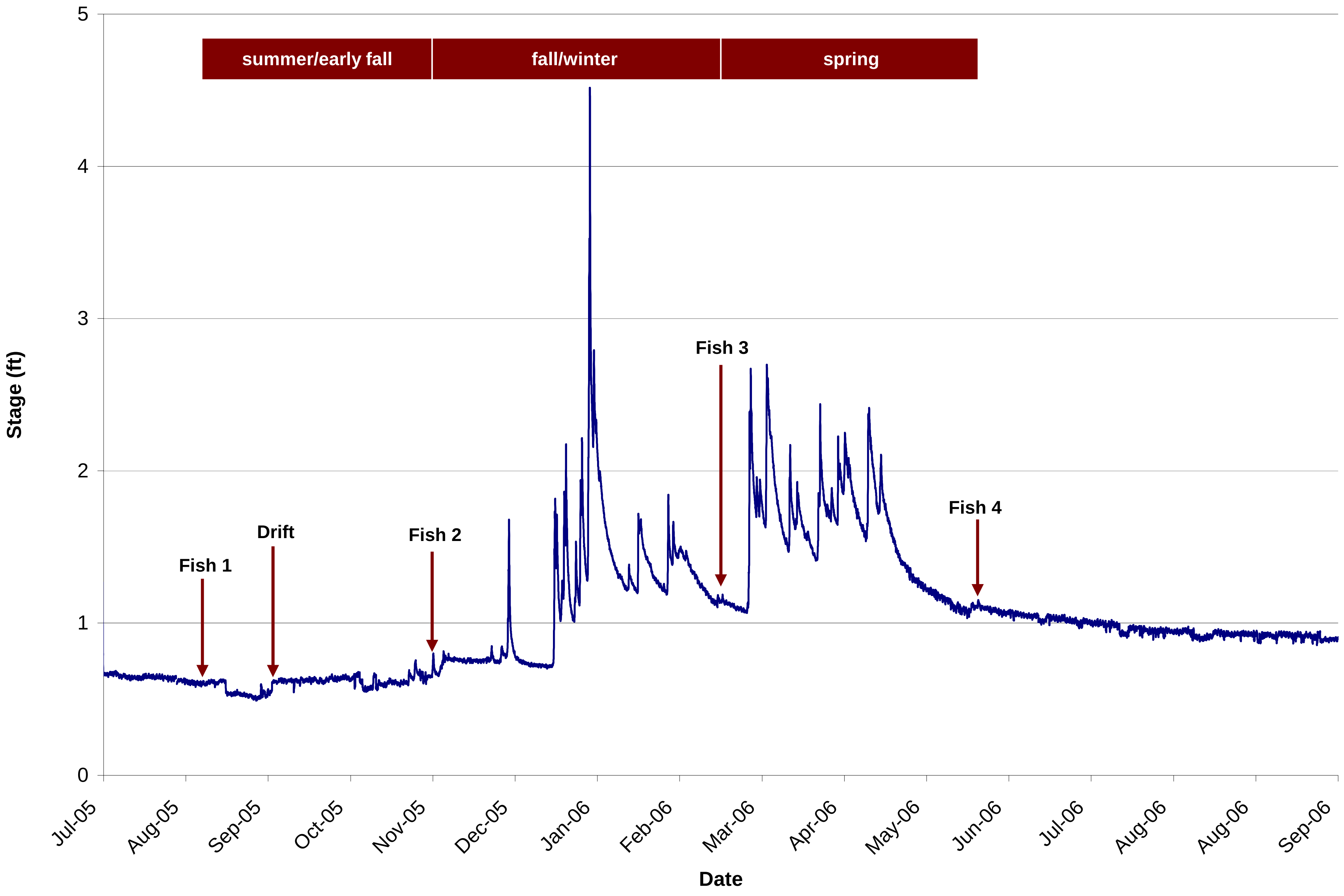

Figure D-8. **Water surface level (stage) recorded in the lower reach of Ritchey Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.**

NO DATA

Figure D-9. Water surface level (stage) recorded in the middle reach of Ritchey Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event.

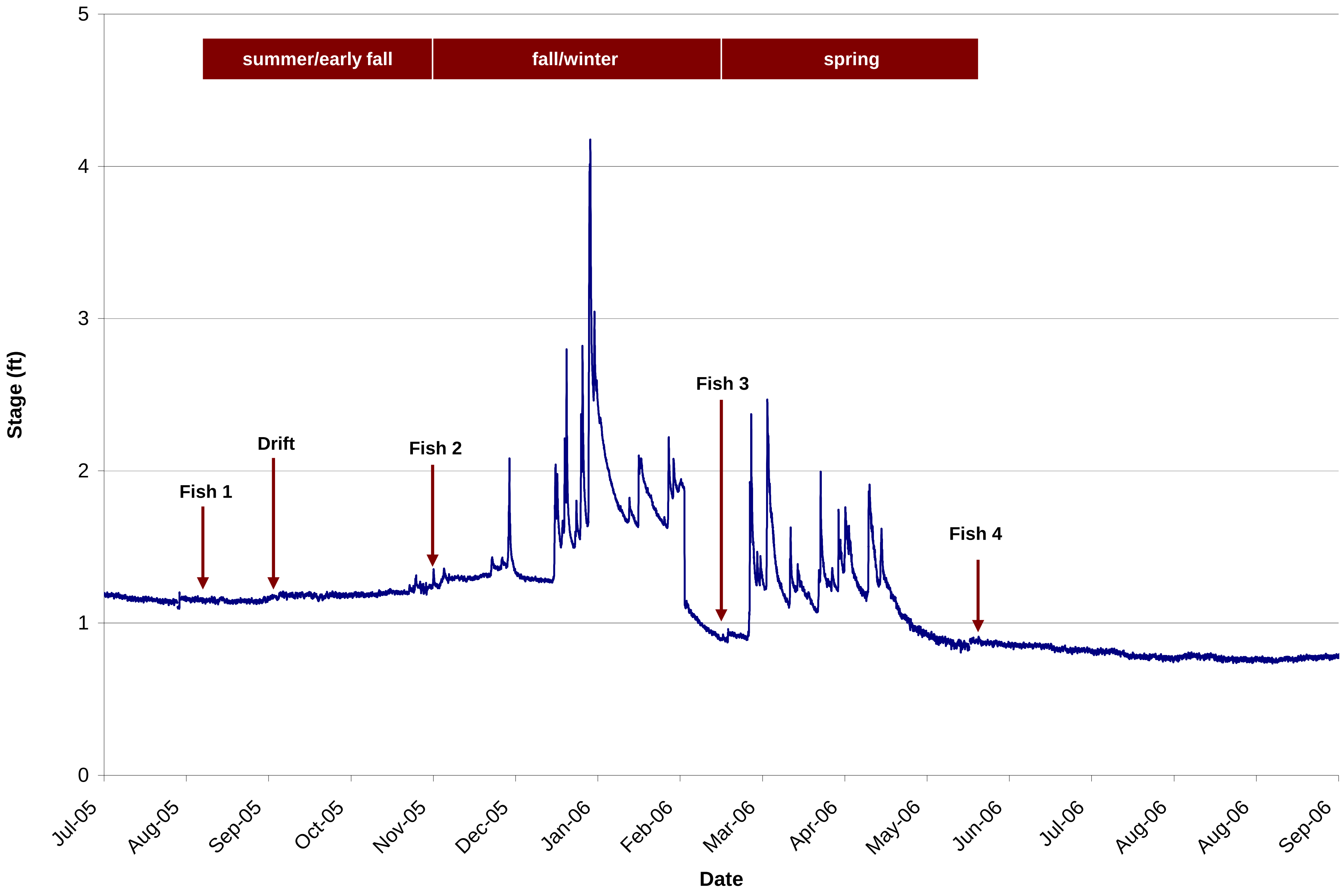

Figure D-10. Water surface level (stage) recorded in the upper reach of Ritchey Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.

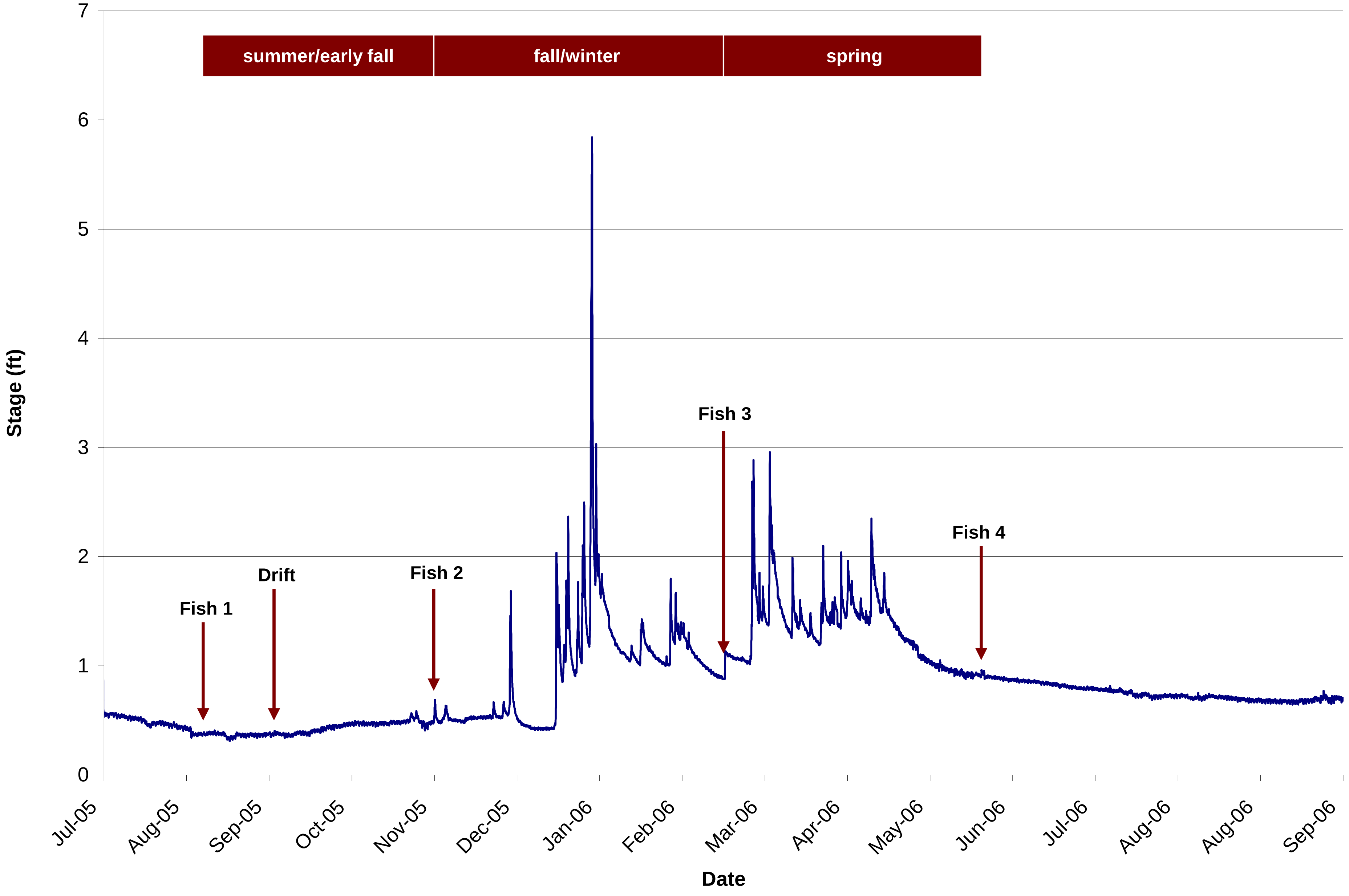

Figure D-11. **Water surface level (stage) recorded in the lower reach of York Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event. Arrows indicate fish and invertebrate drift sampling events.**

NO DATA

Figure D-12. Water surface level (stage) recorded in the upper reach of York Creek for the period 1 July 2005 to 1 September 2006. Missing data are due to data logger dewatered during low flow period and/or displacement from high flow event.

Appendix E

Frequency and biomass of larval invertebrate taxa present in drift samples

Table E-1. Total frequency of larval taxa by length class in Heath Canyon Creek for all dates sampled.

Taxa	**Length Class (mm)**							**Total**
	1	**2**	**3**	**4**	**5**	**6**	**8**	
Diphetor hageni	1	96	59	20				**176**
Baetis tricaudatus	46	55	10	1				**112**
Chironomidae	4	19	11	8	17	7		**66**
Lepidostoma pluviale group	26	30						**56**
Malenka	2	10	8	1				**21**
Simulium		14	6					**20**
Maruina	6	7						**13**
Ecdyonurus criddlei		3	3	2	1			**9**
Centroptilum/Procloeon		2	5					**7**
Dixa		2	3	1	1			**7**
Glossosoma	3	3	1					**7**
Hydropsyche	2	4					1	**7**
Coleoptera	1	4						**5**
Homoptera	1	3						**4**
Meringodixa		1	1					**2**
Microvelia	1	1						**2**
Paraleptophlebia			1		1			**2**
Tricorythodes minutus	2							**2**
Ameletus		1						**1**
Aphidae	1							**1**
Calineuria californica						1		**1**
Capniidae			1					**1**
Eubrianax edwardsi			1					**1**
Ironodes		1						**1**
Psocoptera	1							**1**
Rhyacophila betteni group					1			**1**
Wormaldia				1				**1**
Total	**97**	**256**	**110**	**34**	**21**	**8**	**1**	**527**

Table E-2. Total biomass (mg) of larval taxa by length class in Heath Canyon Creek for all dates sampled.

Taxa	Length Class (mm)							Total
	1	**2**	**3**	**4**	**5**	**6**	**8**	
Diphetor hageni	0.01	3.73	7.36	5.70				**16.80**
Chironomidae	0.01	0.21	0.35	0.54	2.07	1.37		**4.55**
Baetis tricaudatus	0.24	2.14	1.25	0.29				**3.91**
Ecdyonurus criddlei		0.22	0.67	0.98	0.91			**2.78**
Hydropsyche	0.01	0.14					2.02	**2.17**
Calineuria californica						1.72		**1.72**
Lepidostoma pluviale group	0.21	1.49						**1.69**
Malenka	0.01	0.38	0.93	0.26				**1.58**
Centroptilum/Procloeon		0.08	0.62					**0.70**
Simulium		0.23	0.33					**0.55**
Rhyacophila betteni group					0.54			**0.54**
Paraleptophlebia			0.11		0.42			**0.53**
Dixa		0.03	0.14	0.10	0.19			**0.47**
Glossosoma	0.02	0.19	0.21					**0.43**
Eubrianax edwardsi			0.30					**0.30**
Microvelia	0.05	0.24						**0.29**
Wormaldia				0.16				**0.16**
Homoptera	0.01	0.15						**0.16**
Maruina	0.02	0.11						**0.13**
Capniidae			0.08					**0.08**
Coleoptera	0.00	0.07						**0.08**
Ironodes		0.07						**0.07**
Meringodixa		0.02	0.05					**0.06**
Psocoptera	0.05							**0.05**
Ameletus		0.05						**0.05**
Tricorythodes minutus	0.02							**0.02**
Aphidae	0.01							**0.01**
Total	**0.66**	**9.55**	**12.40**	**8.04**	**4.12**	**3.09**	**2.02**	**39.87**

Table E-3. Total frequency of larval taxa by length class in Pickle Creek for all dates sampled.

Taxa	Length Class (mm)					Total
	1	2	3	4	5	
Chironomidae		12	6	3	1	**22**
Diphetor hageni	2	5	8	1		**16**
Baetis tricaudatus	2	4	1			**7**
Simulium	1	3	2			**6**
Centroptilum/Procloeon		2	1	1	1	**5**
Microvelia	3	1				**4**
Meringodixa		1	1		1	**3**
Caloparyphus		2				**2**
Forcipomyiinae	1					**1**
Ecdyonurus criddlei			1			**1**
Total	**9**	**30**	**20**	**5**	**3**	**67**

Table E-4. Total biomass (mg) of larval taxa by length class in Pickle Creek for all dates sampled.

Taxa	Length Class (mm)					Total
	1	2	3	4	5	
Diphetor hageni	0.01	0.19	1.00	0.29		**1.49**
Centroptilum/Procloeon		0.08	0.12	0.29	0.54	**1.03**
Chironomidae		0.13	0.19	0.20	0.12	**0.65**
Microvelia	0.15	0.24				**0.39**
Baetis tricaudatus	0.01	0.16	0.12			**0.29**
Meringodixa		0.02	0.05		0.19	**0.25**
Ecdyonurus criddlei			0.22			**0.22**
Simulium	0.00	0.05	0.11			**0.16**
Caloparyphus		0.06				**0.06**
Forcipomyiinae	0.00					**0.00**
Total	**0.18**	**0.93**	**1.82**	**0.77**	**0.85**	**4.55**

Table E-5. Total frequency of larval taxa by length class in Redwood Creek for all dates sampled.

Taxa	**Length Class (mm)**							**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	
Diphetor hageni	7	210	192	26				**435**
Baetis tricaudatus	74	185	37	9				**305**
Chironomidae	20	138	32	16	12	11	1	**230**
Simulium	10	77	60	26	8			**181**
Centroptilum/Procloeon	7	46	3	2				**58**
Ecdyonurus criddlei		3	7	6				**16**
Hydropsyche	1	10	4	1				**16**
Microvelia	7	2	1					**10**
Meringodixa		2	5	1				**8**
Psocoptera	6	1						**7**
Aphidae	2	4						**6**
Tricorythodes minutus	3	3						**6**
Rhyacophila betteni group		2	1				1	**4**
Isoperla	2	1						**3**
Lepidostoma-panel case		1	2					**3**
Paraleptophlebia		2	1					**3**
Amiocentrus aspilus	2							**2**
Dixa		1		1				**2**
Hydroptila	1	1						**2**
Ironodes						2		**2**
Lepidostoma pluviale group	2							**2**
Brachycera		1						**1**
Caloparyphus		1						**1**
Capniidae	1							**1**
Chelifera/Metachela		1						**1**
Epeorus	1							**1**
Homoptera	1							**1**
Malenka	1							**1**
Total	**148**	**692**	**345**	**88**	**20**	**13**	**2**	**1,308**

Table E-6. Total biomass (mg) of larval taxa by length class in Redwood Creek for all dates sampled.

Taxa	Length Class (mm)							Total
	1	2	3	4	5	6	7	
Diphetor hageni	0.04	8.17	23.95	7.42				**39.57**
Baetis tricaudatus	0.39	7.19	4.62	2.57				**14.77**
Simulium	0.02	1.24	3.28	3.38	2.04			**9.96**
Chironomidae	0.04	1.52	1.02	1.08	1.46	2.15	0.29	**7.57**
Ecdyonurus criddlei		0.22	1.56	2.95				**4.73**
Ironodes						3.00		**3.00**
Centroptilum/Procloeon	0.04	1.79	0.37	0.57				**2.77**
Rhyacophila betteni group		0.11	0.15				1.23	**1.50**
Microvelia	0.35	0.48	0.60					**1.43**
Hydropsyche	0.00	0.35	0.46	0.27				**1.08**
Psocoptera	0.30	0.26						**0.56**
Meringodixa		0.03	0.24	0.10				**0.38**
Lepidostoma-panel case		0.05	0.29					**0.34**
Tricorythodes minutus	0.03	0.20						**0.23**
Aphidae	0.01	0.20						**0.21**
Paraleptophlebia		0.08	0.11					**0.18**
Dixa		0.02		0.10				**0.12**
Isoperla	0.02	0.05						**0.06**
Hydroptila	0.01	0.04						**0.05**
Brachycera		0.03						**0.03**
Caloparyphus		0.03						**0.03**
Chelifera/Metachela		0.03						**0.03**
Amiocentrus aspilus	0.02							**0.02**
Lepidostoma pluviale group	0.02							**0.02**
Epeorus	0.01							**0.01**
Malenka	0.01							**0.01**
Homoptera	0.01							**0.01**
Capniidae	0.00							**0.00**
Total	**1.30**	**22.09**	**36.65**	**18.44**	**3.49**	**5.16**	**1.53**	**88.65**

Table E-7. Total frequency of larval taxa by length class in Ritchey Creek for all dates sampled.

Taxa	Length Class (mm)								Total
	1	2	3	4	5	6	7	8	
Baetis tricaudatus	667	708	209	72	19				**1,675**
Simulium	3	229	186	51	8				**477**
Chironomidae	14	128	111	67	45	25	2		**392**
Diphetor hageni	24	156	155	41					**376**
Isoperla	48	4							**52**
Meringodixa	1	17	13	15	5	1			**52**
Maruina	22	25	1						**48**
Paraleptophlebia	3	5	21	11	2				**42**
Capniidae	9	20	3						**32**
Psocoptera	15	12	1						**28**
Centroptilum/Procloeon	5	14	2	1					**22**
Coleoptera	2	13	5						**20**
Aphidae	17	1	1						**19**
Acari	14								**14**
Tricorythodes minutus	10	3							**13**
Microvelia	7	4							**11**
Ironodes	3	5				1			**9**
Lepidostoma pluviale group	6	3							**9**
Soyedina	3	6							**9**
Zapada frigida	4	5							**9**
Ameletus		6							**6**
Ecdyonurus criddlei	3		2	1					**6**
Glossosoma	3	2	1						**6**
Hydropsyche		4	1						**5**
Lepidostoma-panel case		1	3	1					**5**
Micrasema	3	1	1						**5**
Copepoda	4								**4**
Dixa		2	1	1					**4**
Ephemerella excrusians	3	1							**4**
Malenka		4							**4**
Amiocentrus aspilus	2	1							**3**
Epeorus	1			1	1				**3**
Forcipomyiinae	2	1							**3**
Homoptera	2	1							**3**
Rhithrogena	3								**3**
Caloparyphus		2							**2**
Oligochaeta	1	1							**2**
Rhyacophila betteni group		2							**2**
Ceratopogoninae					1				**1**
Chelifera/Metachela	1								**1**
Chydoridae	1								**1**
Eubrianax edwardsi		1							**1**
Hydroptila	1								**1**
Optioservus				1					**1**
Thysanoptera	1								**1**
Wormaldia								1	**1**
Total	**908**	**1,388**	**717**	**263**	**81**	**27**	**2**	**1**	**3,387**

Table E-8. Total biomass (mg) of larval taxa by length class in Ritchey Creek for all dates sampled.

Taxa	**Length Class (mm)**								**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Baetis tricaudatus	3.54	27.53	26.07	20.54	10.29				**87.96**
Diphetor hageni	0.13	6.07	19.33	11.69					**37.22**
Simulium	0.01	3.69	10.17	6.63	2.04				**22.53**
Chironomidae	0.03	1.41	3.54	4.54	5.47	4.89	0.59		**20.47**
Paraleptophlebia	0.02	0.19	2.29	2.55	0.83				**5.88**
Psocoptera	0.75	3.17	0.70						**4.62**
Meringodixa	0.00	0.27	0.63	1.57	0.95	0.31			**3.73**
Ironodes	0.03	0.36				1.50			**1.90**
Acari	1.86								**1.86**
Epeorus	0.01			0.49	0.91				**1.41**
Microvelia	0.35	0.96							**1.31**
Centroptilum/Procloeon	0.03	0.54	0.25	0.29					**1.11**
Ecdyonurus criddlei	0.03		0.45	0.49					**0.97**
Wormaldia								0.93	**0.93**
Capniidae	0.04	0.58	0.25						**0.87**
Lepidostoma-panel case		0.05	0.44	0.31					**0.80**
Isoperla	0.36	0.18							**0.55**
Maruina	0.06	0.40	0.05						**0.51**
Coleoptera	0.01	0.24	0.25						**0.49**
Micrasema	0.05	0.10	0.26						**0.41**
Optioservus				0.40					**0.40**
Glossosoma	0.02	0.13	0.21						**0.36**
Aphidae	0.09	0.05	0.19						**0.33**
Tricorythodes minutus	0.10	0.20							**0.30**
Ameletus		0.28							**0.28**
Hydropsyche		0.14	0.11						**0.25**
Soyedina	0.02	0.23							**0.24**
Zapada frigida	0.02	0.19							**0.21**
Lepidostoma pluviale group	0.05	0.15							**0.20**
Dixa		0.03	0.05	0.10					**0.18**
Malenka		0.15							**0.15**
Ceratopogoninae					0.13				**0.13**
Rhyacophila betteni group		0.11							**0.11**
Ephemerella excrusians	0.03	0.07							**0.10**
Eubrianax edwardsi		0.09							**0.09**
Amiocentrus aspilus	0.02	0.06							**0.08**
Caloparyphus		0.06							**0.06**
Homoptera	0.01	0.05							**0.06**
Rhithrogena	0.03								**0.03**
Copepoda	0.03								**0.03**
Chydoridae	0.02								**0.02**
Forcipomyiinae	0.01	0.01							**0.02**
Thysanoptera	0.01								**0.01**
Hydroptila	0.01								**0.01**
Chelifera/Metachela	0.01								**0.01**
Oligochaeta	0.00	0.00							**0.00**
Total	**7.76**	**47.75**	**65.22**	**49.60**	**20.62**	**6.71**	**0.59**	**0.93**	**199.16**

Table E-9. Total frequency of larval taxa by length class in York Creek for all dates sampled.

Taxa	Length Class (mm)									Total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Chironomidae	30	647	314	183	129	87	15	2	1	**1,408**
Simulium	12	147	165	114	56	5		1		**500**
Diphetor hageni	1	73	149	65	1					**289**
Dixa	3	34	34	18	12	13	4	2		**120**
Lepidostoma-panel case	5	15	30	23	12	1				**86**
Meringodixa	2	18	29	15	16	3				**83**
Baetis tricaudatus	8	39	22	8	4					**81**
Centroptilum/Procloeon	1	7	17	13	1					**39**
Wormaldia		7	8	7	2	2		1	1	**28**
Microvelia	12	12	3							**27**
Hydropsyche	2	5	8	5			1			**21**
Malenka		1	11	8						**20**
Ironodes	5	5			1	2	1			**14**
Acari	11									**11**
Psocoptera	3	7								**10**
Maruina	2	6								**8**
Zapada cinctipes	3	5								**8**
Lepidostoma pluviale group	5	2								**7**
Chelifera/Metachela		4	1							**5**
Homoptera	1	2		1						**4**
Isoperla	3	1								**4**
Capniidae		3								**3**
Mystacides		1	2							**3**
Paraleptophlebia				1	1	1				**3**
Rhyacophila betteni group	2		1							**3**
Coleoptera	1	1								**2**
Brachycera		2								**2**
Thysanoptera	1	1								**2**
Aphidae	1									**1**
Caloparyphus			1							**1**
Cleptelmis addenda			1							**1**
Culicidae			1							**1**
Diphetor hageni	1									**1**
Epeorus	1									**1**
Eubrianax edwardsi			1							**1**
Glossosoma						1				**1**
Hydroptila		1								**1**
Lepidoptera								1		**1**
Optioservus		1								**1**
Rhithrogena		1								**1**
Total	**116**	**1,048**	**798**	**461**	**235**	**115**	**21**	**7**	**2**	**2,803**

Table E-10. Total biomass (mg) of larval taxa by length class in York Creek for all dates sampled.

Taxa	Length Class (mm)									Total (mg)
	1	2	3	4	5	6	7	8	9	
Chironomidae	0.05	7.14	10.02	12.40	15.67	17.03	4.40	0.83	0.57	**68.11**
Simulium	0.02	2.37	9.02	14.82	14.25	2.20		1.05		**43.73**
Diphetor hageni	0.01	2.84	18.59	18.54	0.54					**40.51**
Lepidostoma-panel case	0.04	0.74	4.35	7.15	6.74	0.91				**19.93**
Dixa	0.01	0.55	1.64	1.88	2.28	4.04	1.88	1.35		**13.63**
Baetis tricaudatus	0.04	1.52	2.74	2.28	2.17					**8.75**
Meringodixa	0.01	0.29	1.40	1.57	3.05	0.93				**7.24**
Centroptilum/Procloeon	0.01	0.27	2.12	3.71	0.54					**6.65**
Ironodes	0.05	0.36			0.91	3.00	2.30			**6.62**
Wormaldia		0.20	0.63	1.14	0.57	0.90		0.93	1.24	**5.61**
Microvelia	0.60	2.89	1.81							**5.30**
Hydropsyche	0.01	0.17	0.92	1.33			1.37			**3.79**
Malenka		0.04	1.28	2.06						**3.38**
Lepidoptera								2.02		**2.02**
Psocoptera	0.15	1.85								**2.00**
Glossosoma						1.64				**1.64**
Acari	1.46									**1.46**
Paraleptophlebia				0.23	0.42	0.67				**1.32**
Mystacides		0.18	1.07							**1.25**
Homoptera	0.01	0.10		0.51						**0.61**
Eubrianax edwardsi			0.30							**0.30**
Chelifera/Metachela		0.13	0.09							**0.21**
Zapada cinctipes	0.02	0.19								**0.21**
Cleptelmis addenda			0.17							**0.17**
Rhyacophila betteni group	0.02		0.15							**0.17**
Lepidostoma pluviale group	0.04	0.10								**0.14**
Maruina	0.01	0.10								**0.10**
Caloparyphus			0.09							**0.09**
Capniidae		0.09								**0.09**
Rhithrogena		0.07								**0.07**
Isoperla	0.02	0.05								**0.07**
Brachycera		0.06								**0.06**
Culicidae			0.05							**0.05**
Optioservus		0.05								**0.05**
Thysanoptera	0.01	0.04								**0.05**
Hydroptila		0.04								**0.04**
Coleoptera	0.00	0.02								**0.02**
Epeorus	0.01									**0.01**
Diphetor hageni	0.01									**0.01**
Aphidae	0.01									**0.01**
Total (mg)	**2.60**	**22.46**	**56.44**	**67.60**	**47.13**	**31.33**	**9.94**	**6.18**	**1.81**	**245.48**

Appendix F

Water temperature graphs

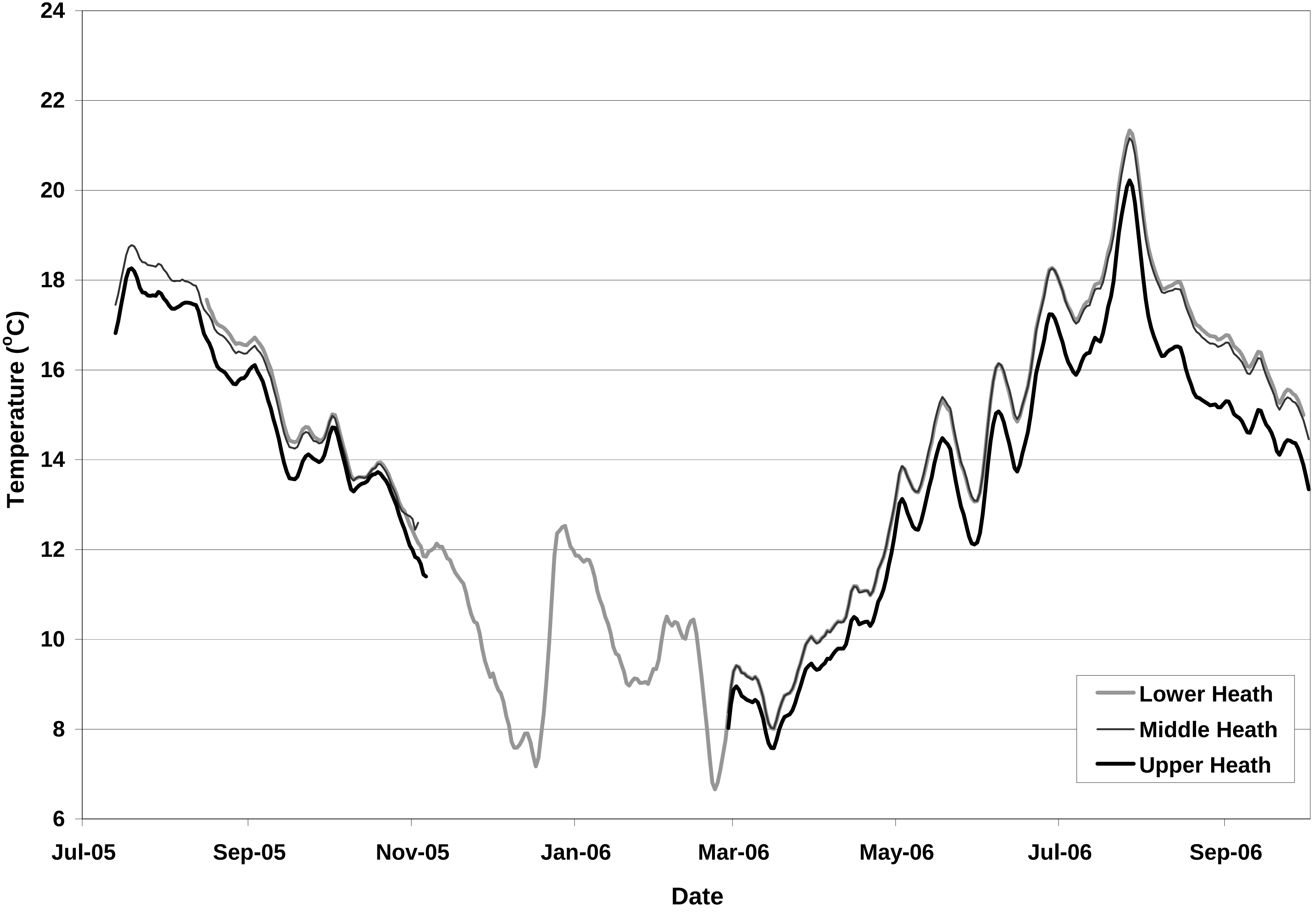

Figure F-1. Continuous record of 7-day average temperature for reaches of Heath Canyon Creek for the period 7 July 2005 to 2 October 2006. Missing data due to thermograph displacement from high flow event.

Figure F-5. Continuous record of 7-day average temperature for reaches of York Creek for the period 8 August 2005 to 2 October 2006. Missing data due to thermograph displacement from high flow event.

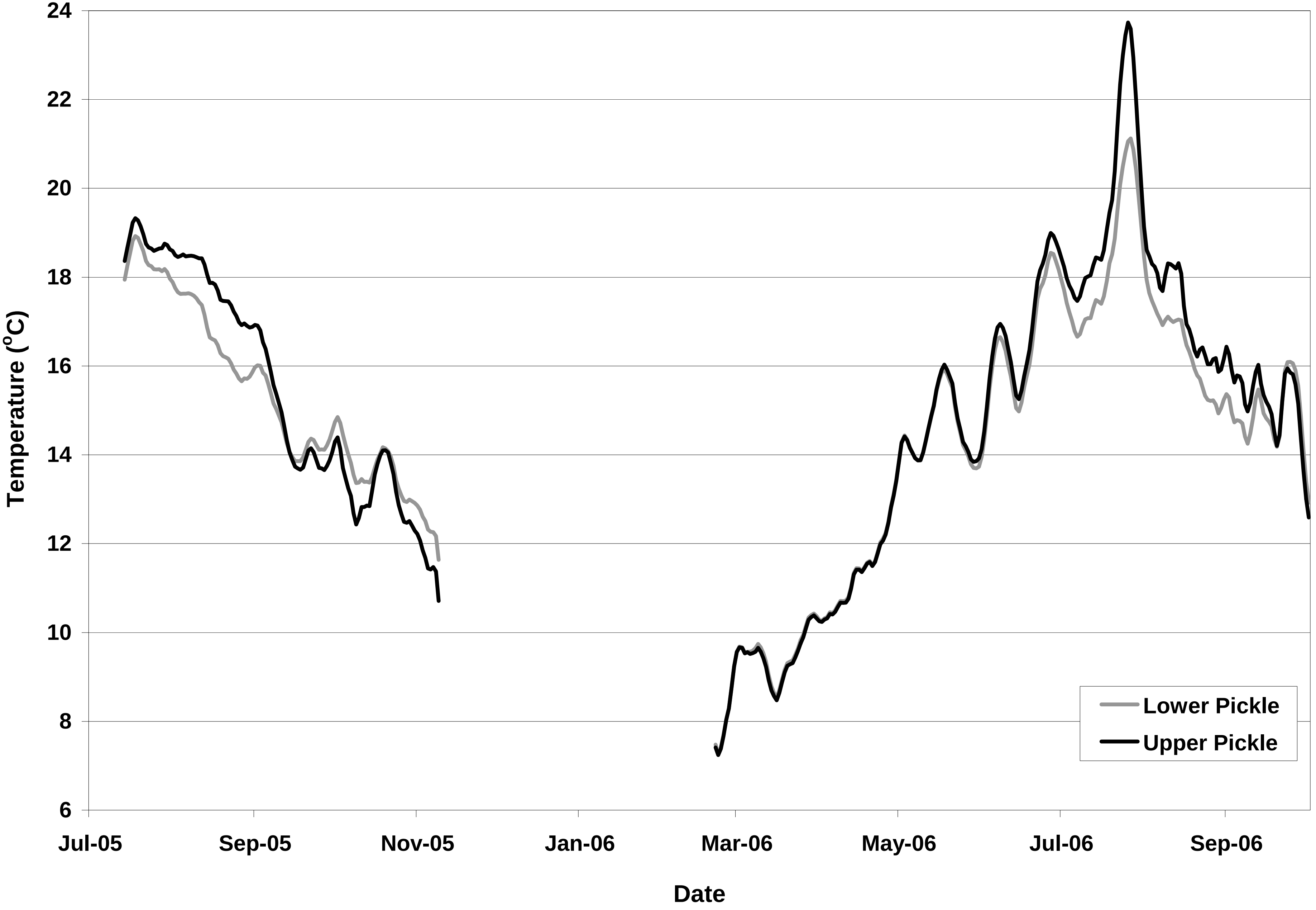

Figure F-2. Continuous record of 7-day average temperature for reaches of Pickle Creek for the period 7 July 2005 to 2 October 2006. Missing data due to thermograph displacement from high flow event.

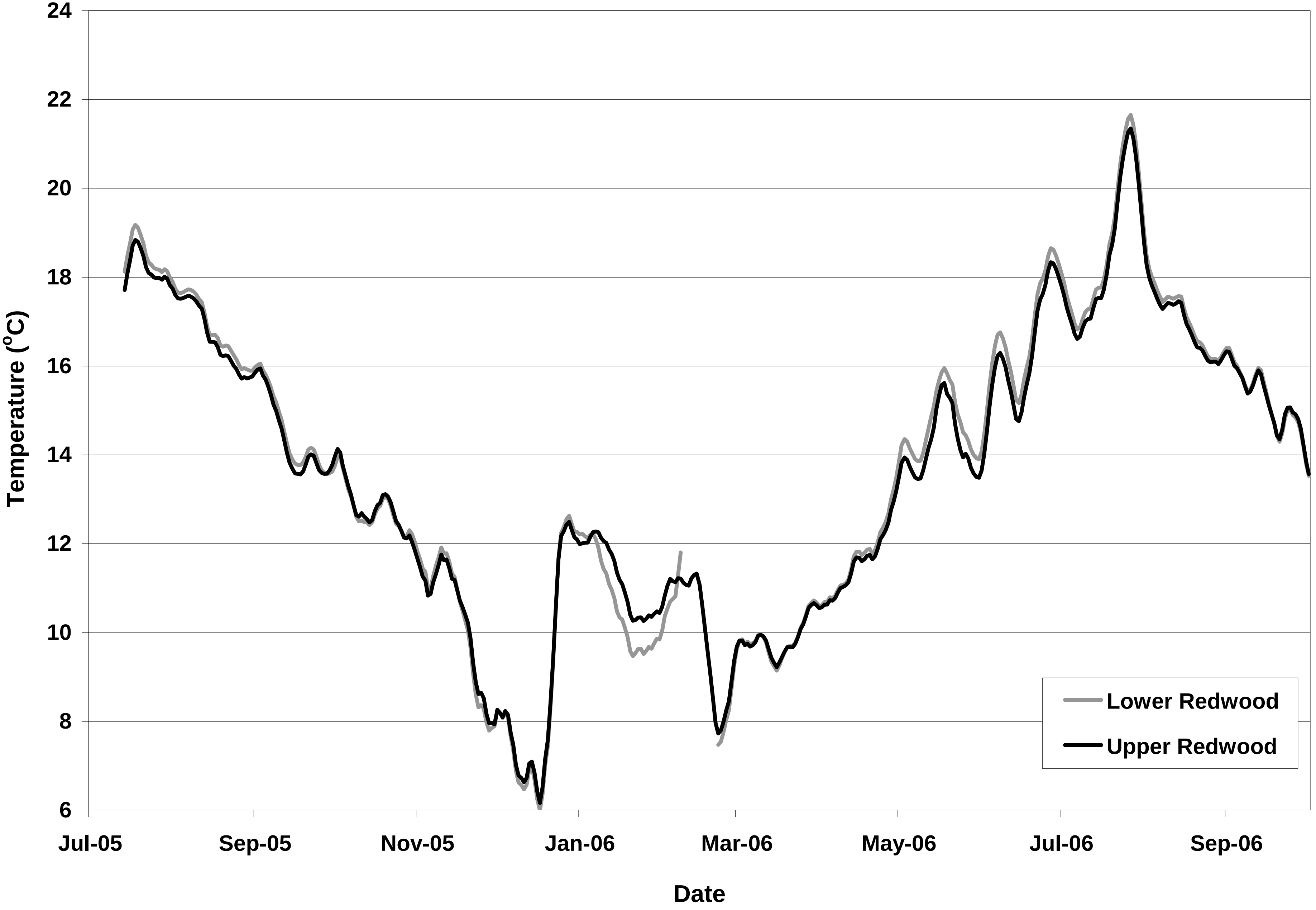

Figure F-3. Continuous record of 7-day average temperature for reaches of Redwood Creek for the period 7 July 2005 to 2 October 2006. Missing data due to thermograph displacement from high flow event.

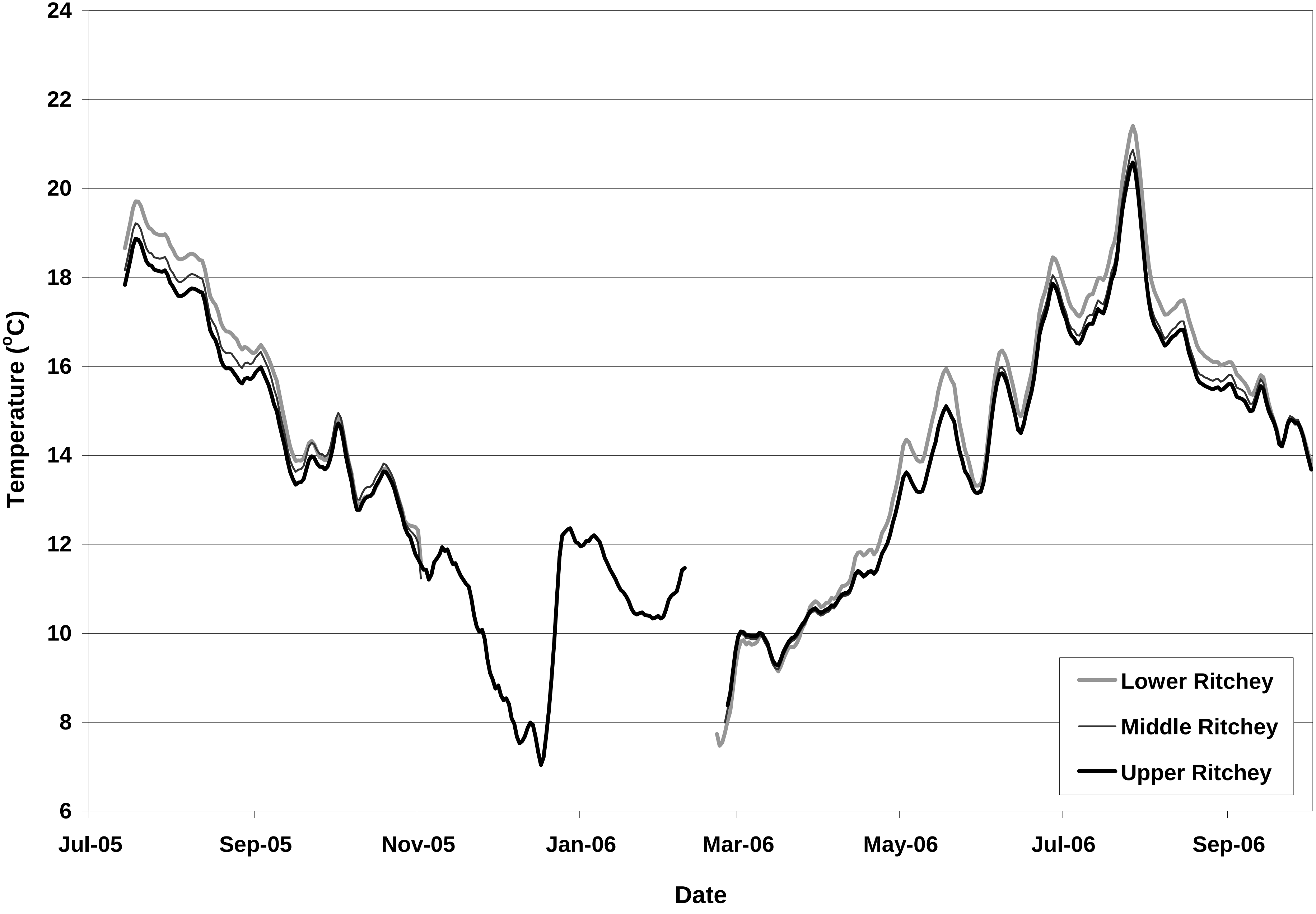

Figure F-4. Continuous record of 7-day average temperature for reaches of Ritchey Creek for the period 7 July 2005 to 2 October 2006. Missing data due to thermograph displacement from high flow event.

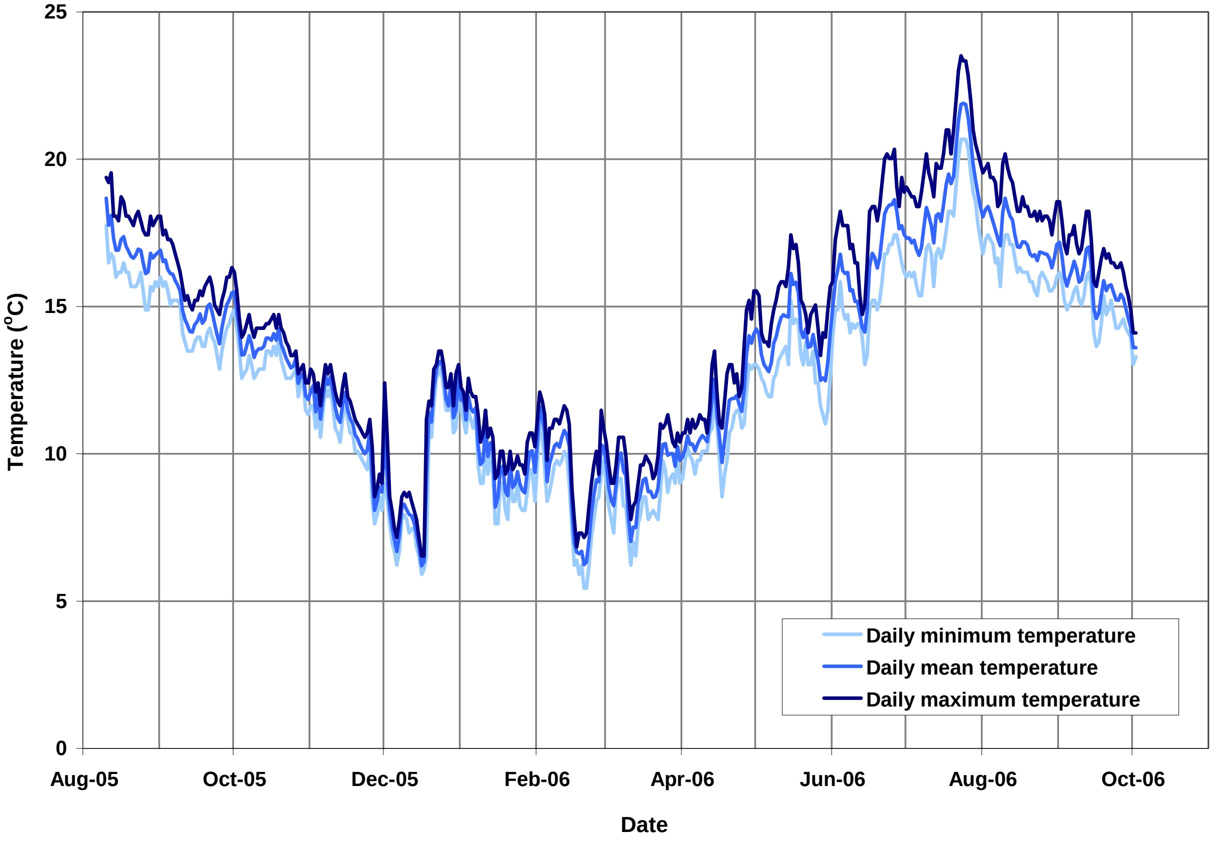

Figure F-6. Daily mean, minimum, and maximum water temperatures in the lower reach of Heath Canyon Creek for the period 8 August 2005 to 2 October 2006.

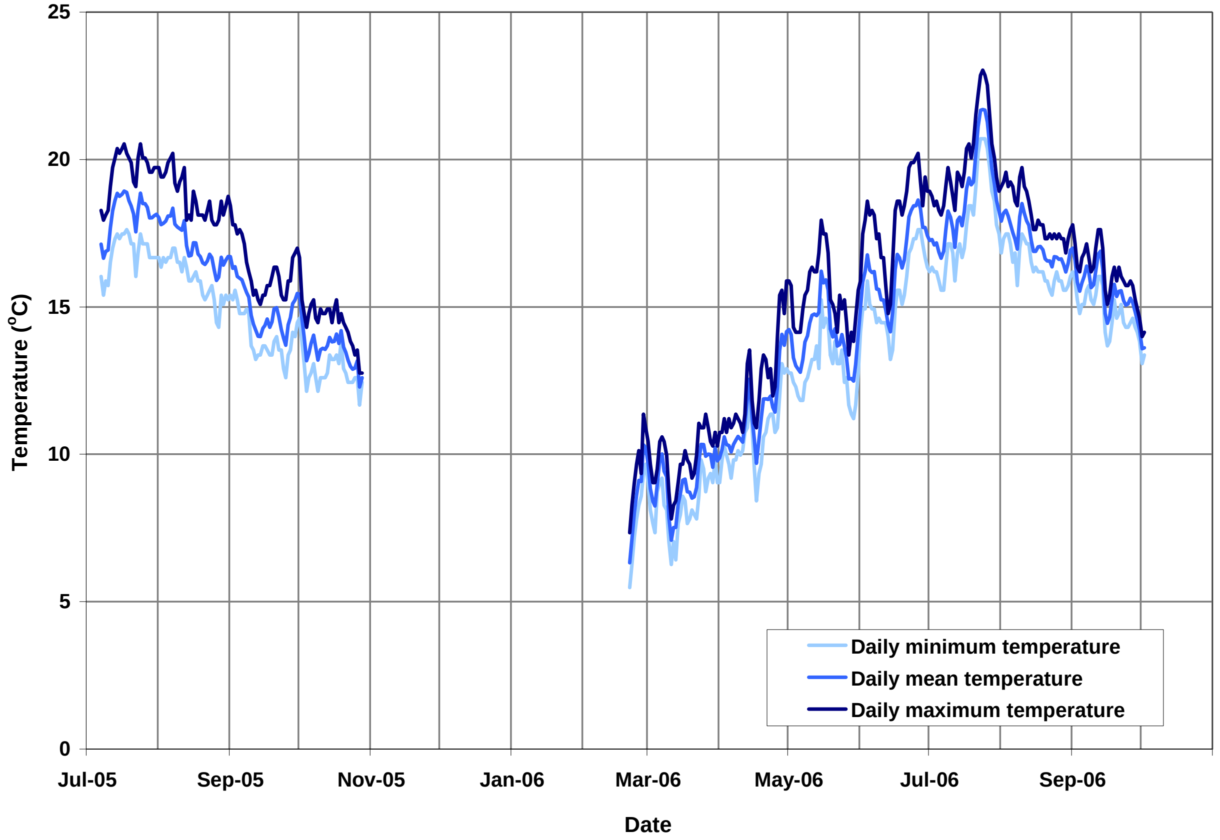

Figure F-7. Daily mean, minimum, and maximum water temperatures in the middle reach of Heath Canyon Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

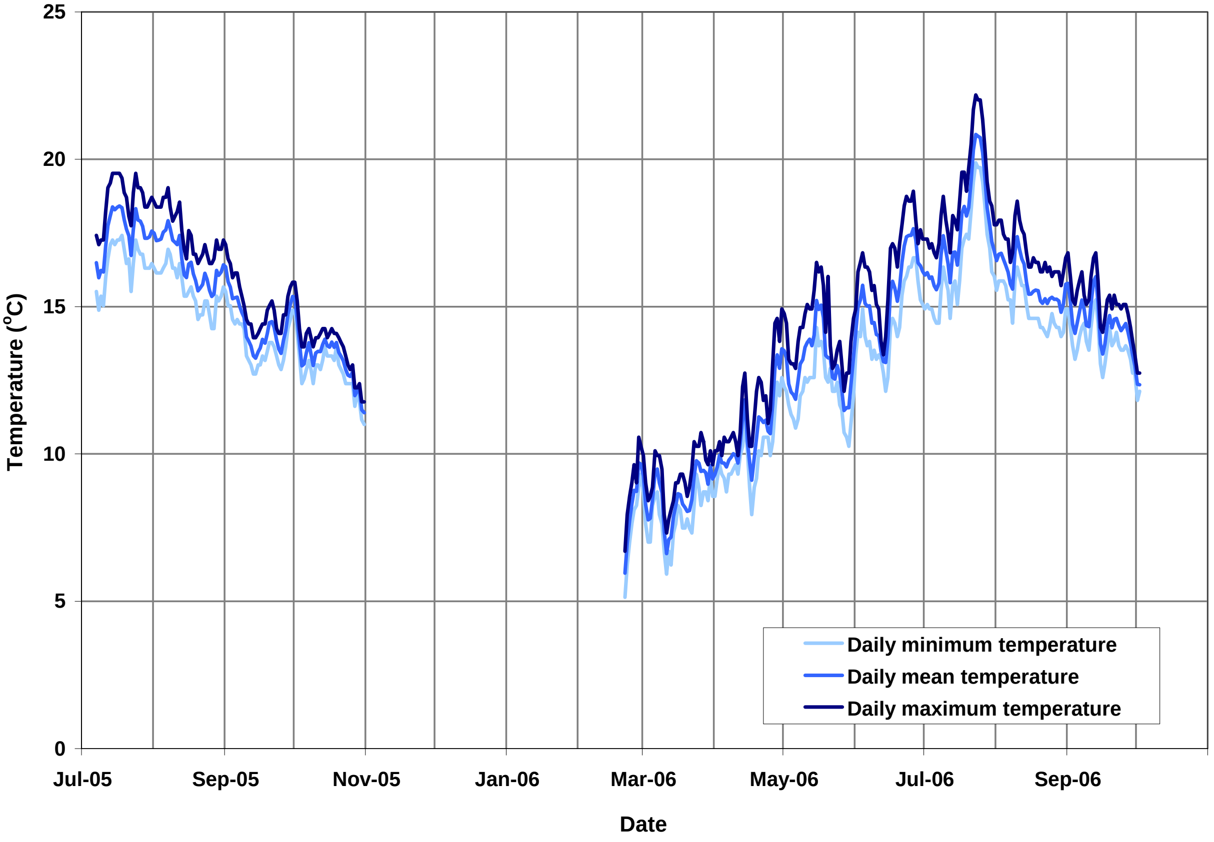

Figure F-8. Daily mean, minimum, and maximum water temperatures in the upper reach of Heath Canyon Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

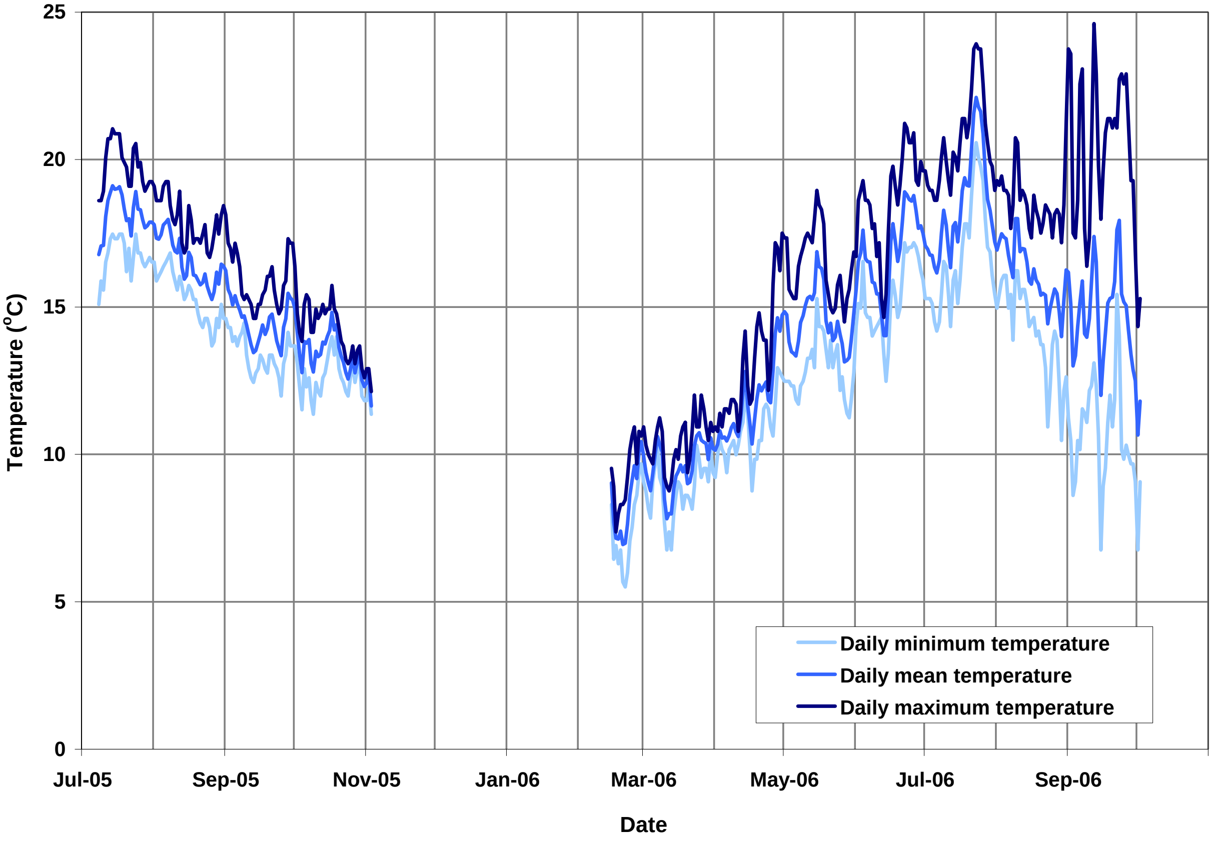

Figure F-9. Daily mean, minimum, and maximum water temperatures in the lower reach of Pickle Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

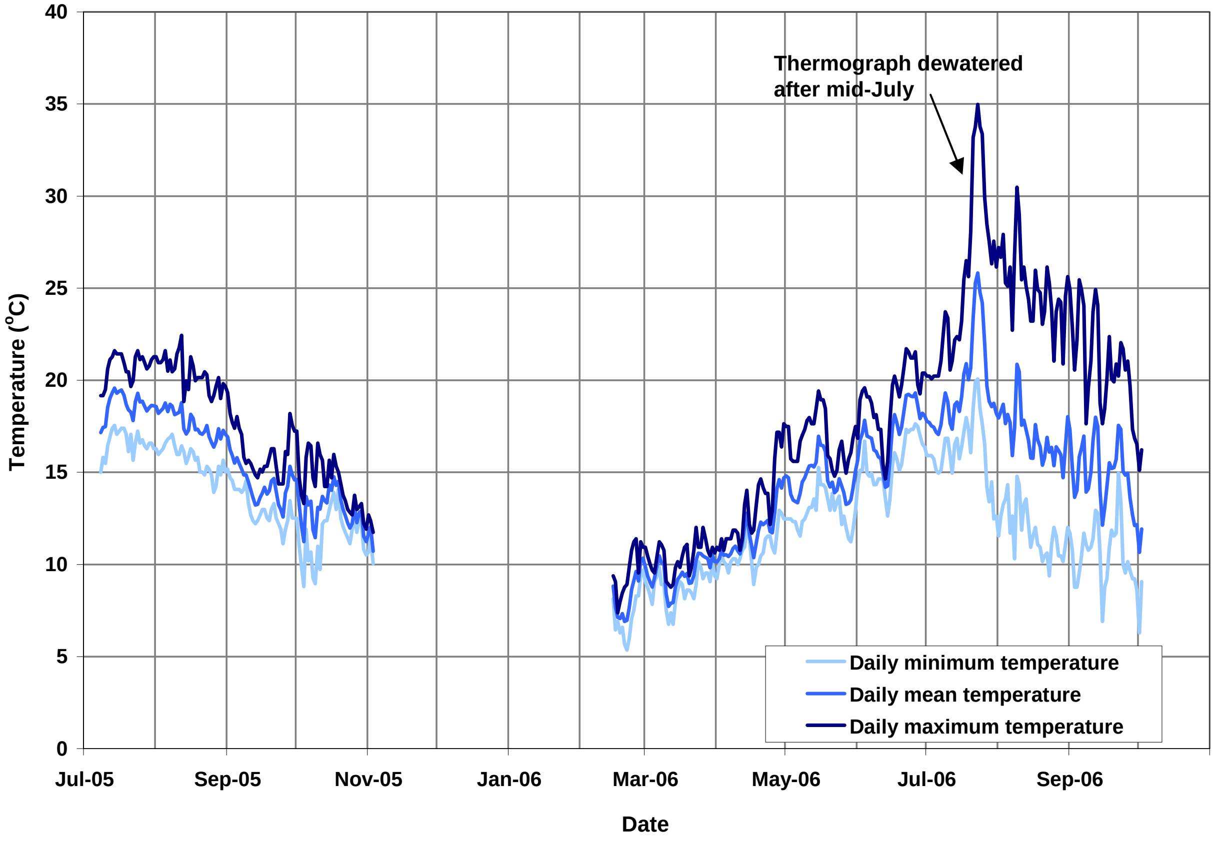

Figure F-10. Daily mean, minimum, and maximum water temperatures in the upper reach of Pickle Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

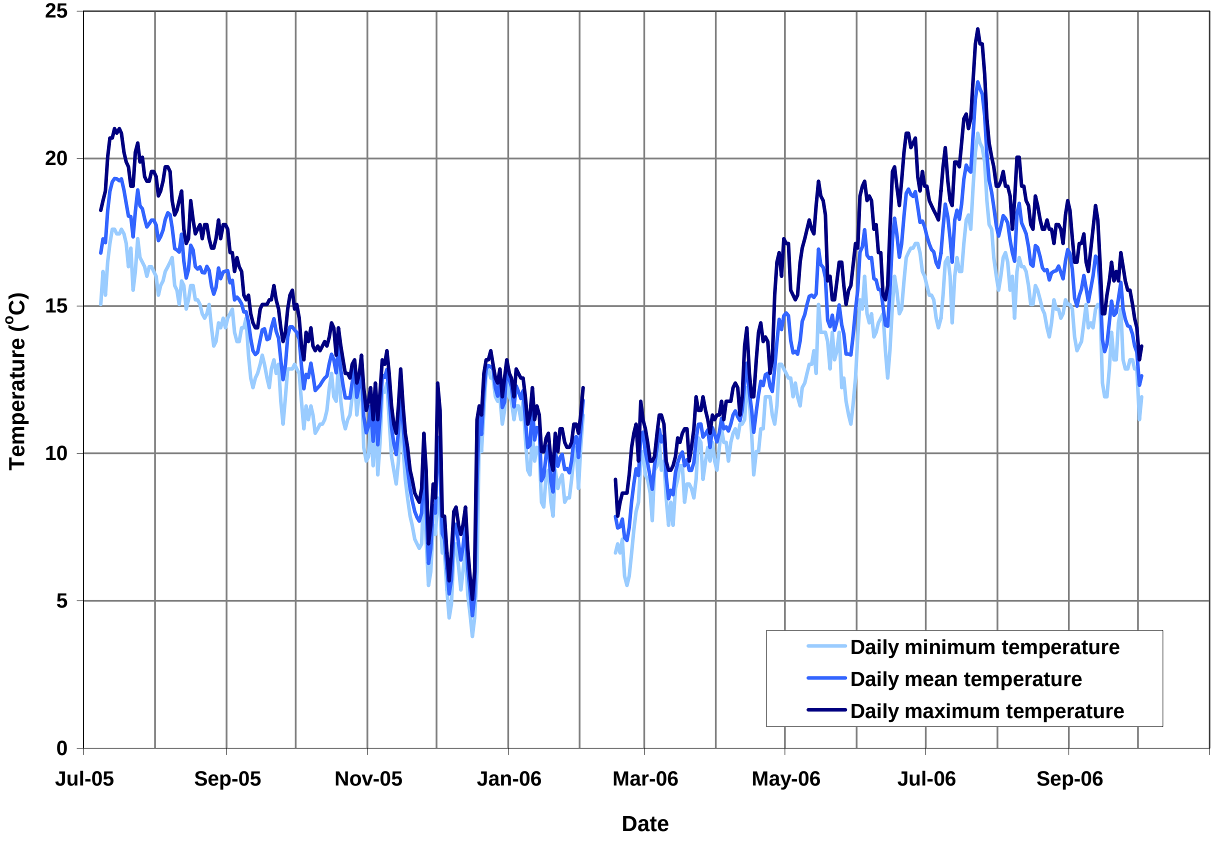

Figure F-11. Daily mean, minimum, and maximum water temperatures in the lower reach of Redwood Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

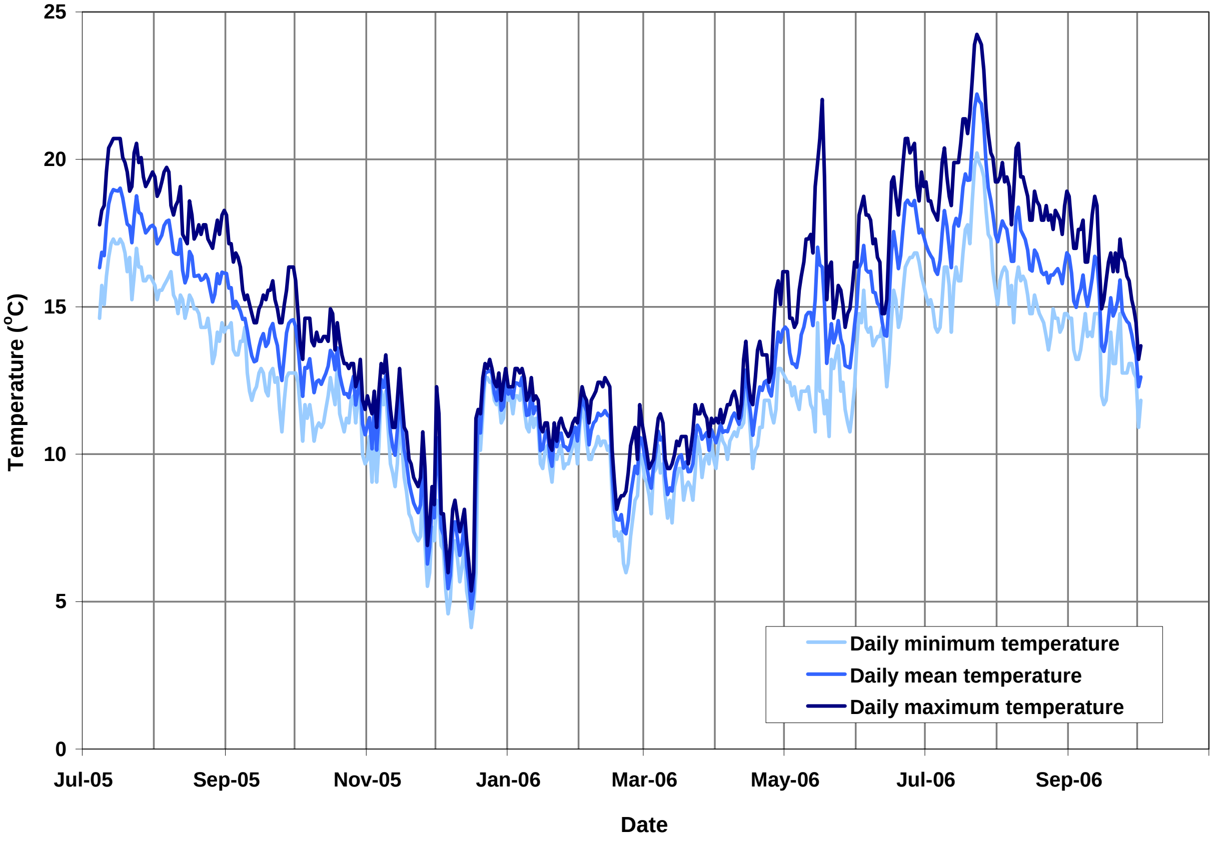

Figure F-12. Daily mean, minimum, and maximum water temperatures in the upper reach of Redwood Creek for the period 7 July 2005 to 2 October 2006.

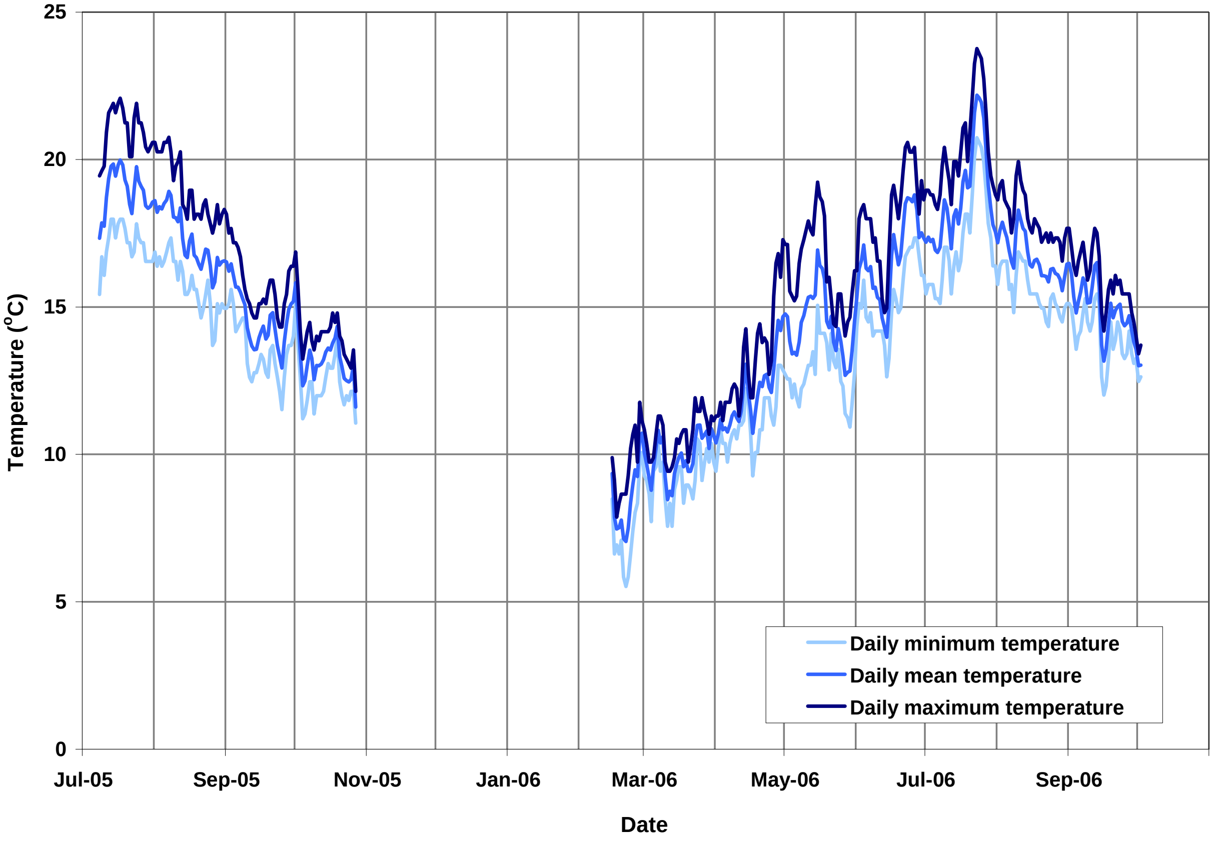

Figure F-13. Daily mean, minimum, and maximum water temperatures in the lower reach of Ritchey Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

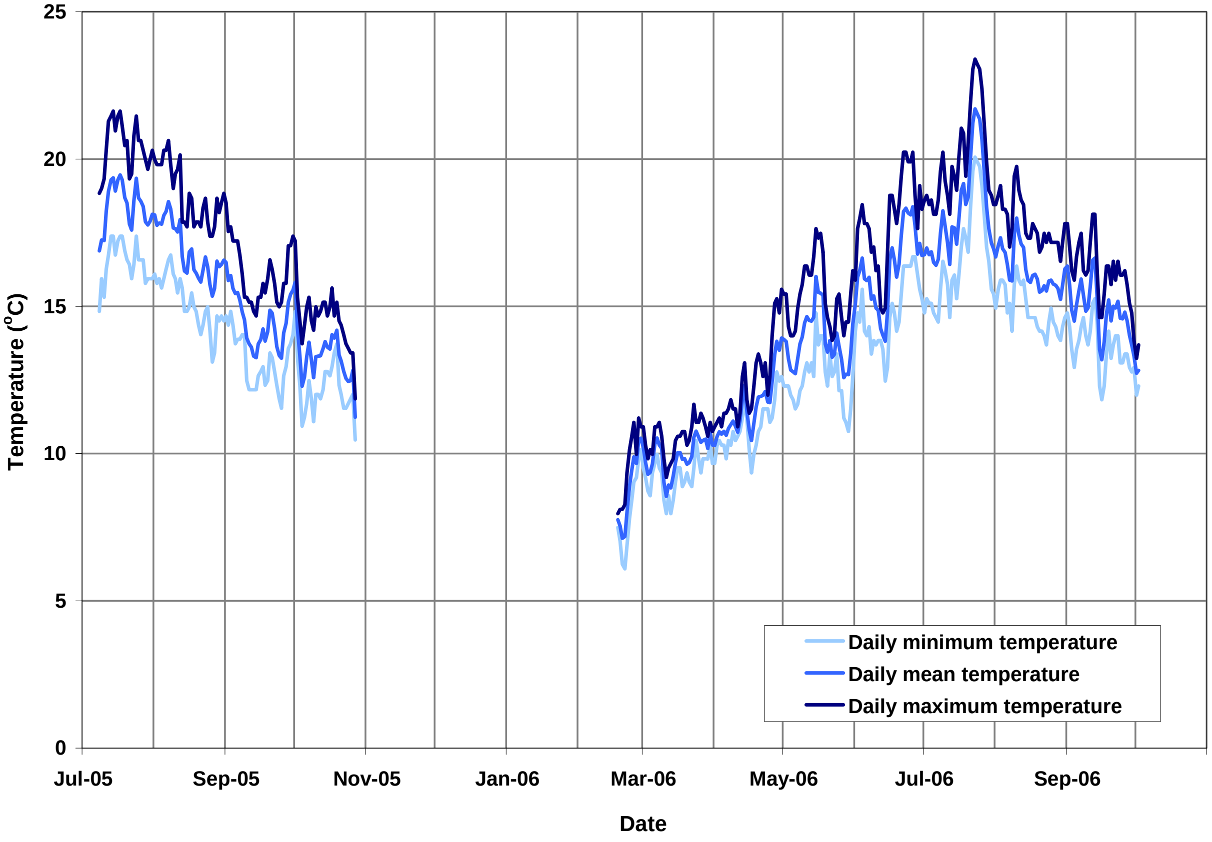

Figure F-14. Daily mean, minimum, and maximum water temperatures in the middle reach of Ritchey Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

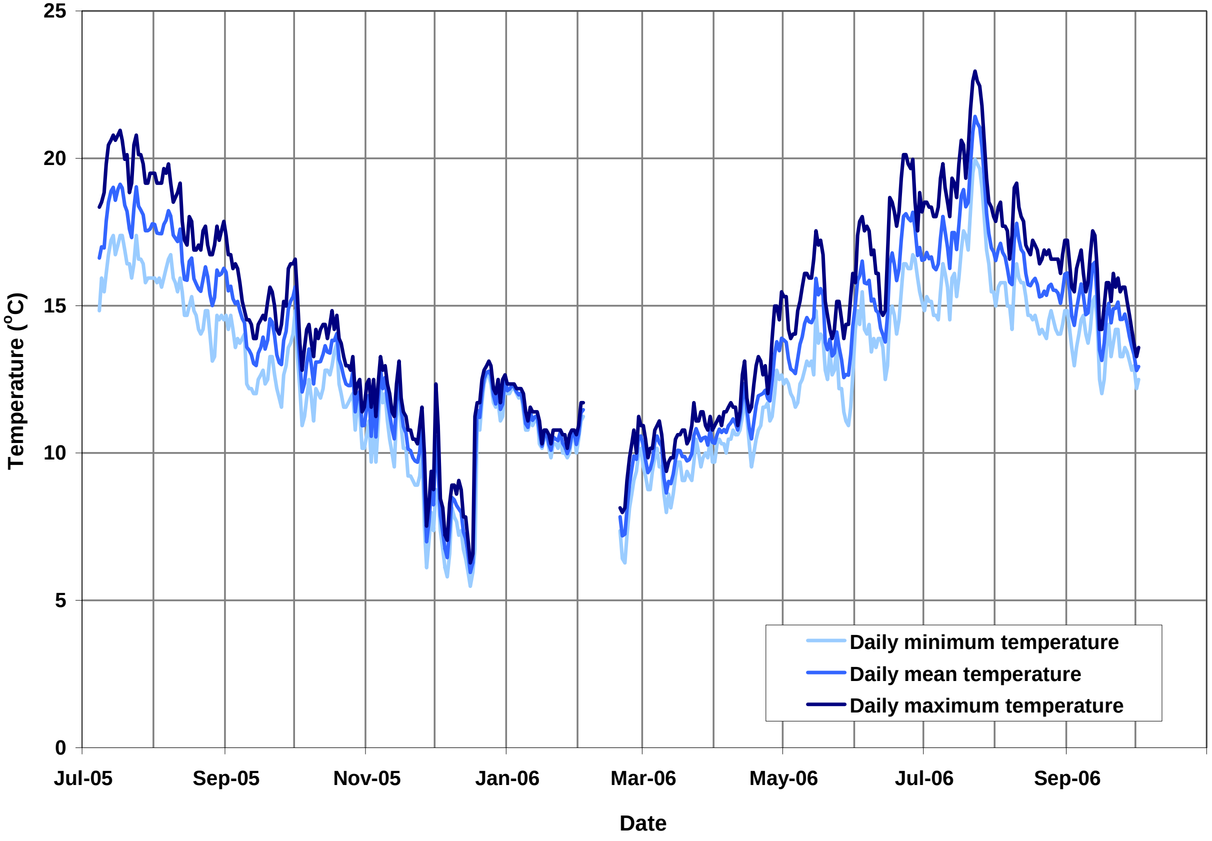

Figure F-15. Daily mean, minimum, and maximum water temperatures in the upper reach of Ritchey Creek for the period 7 July 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.

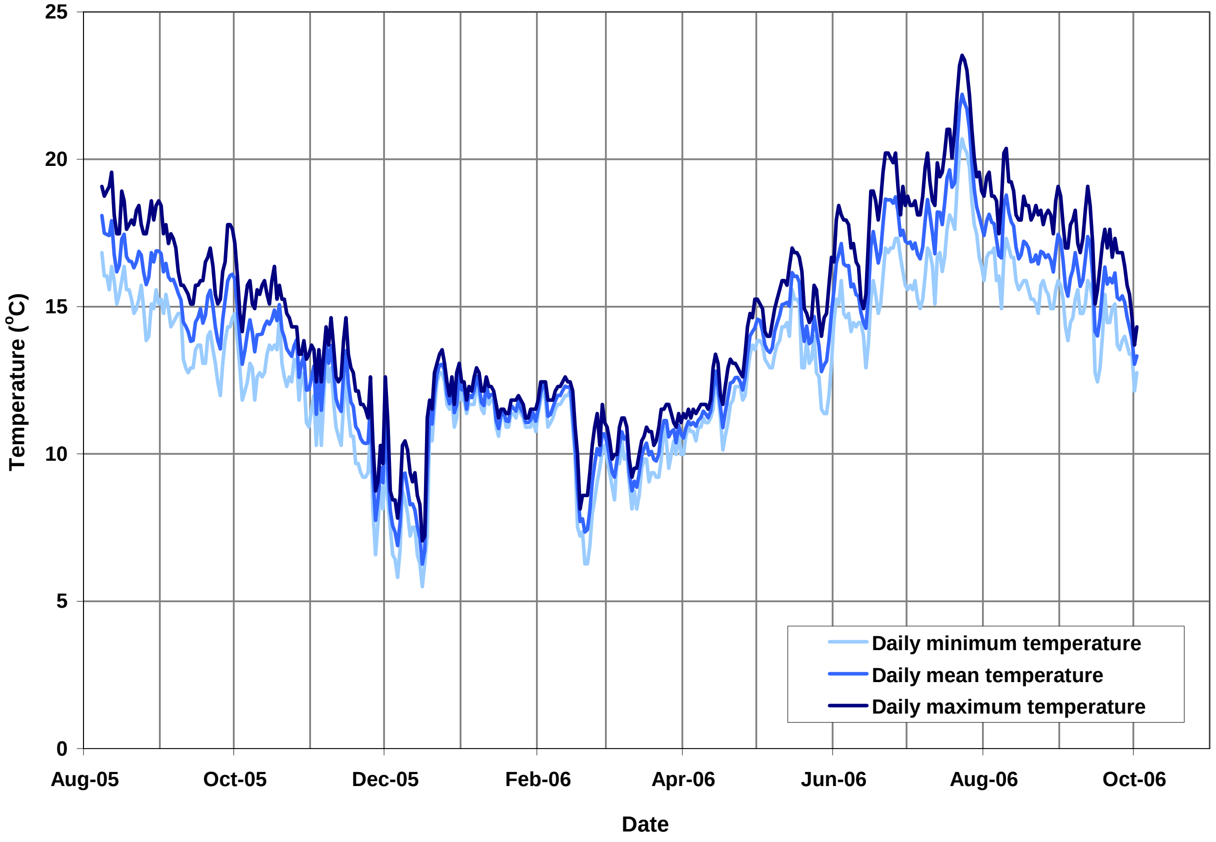

Figure F-16. Daily mean, minimum, and maximum water temperatures in the lower reach of York Creek for the period 8 August 2005 to 2 October 2006.

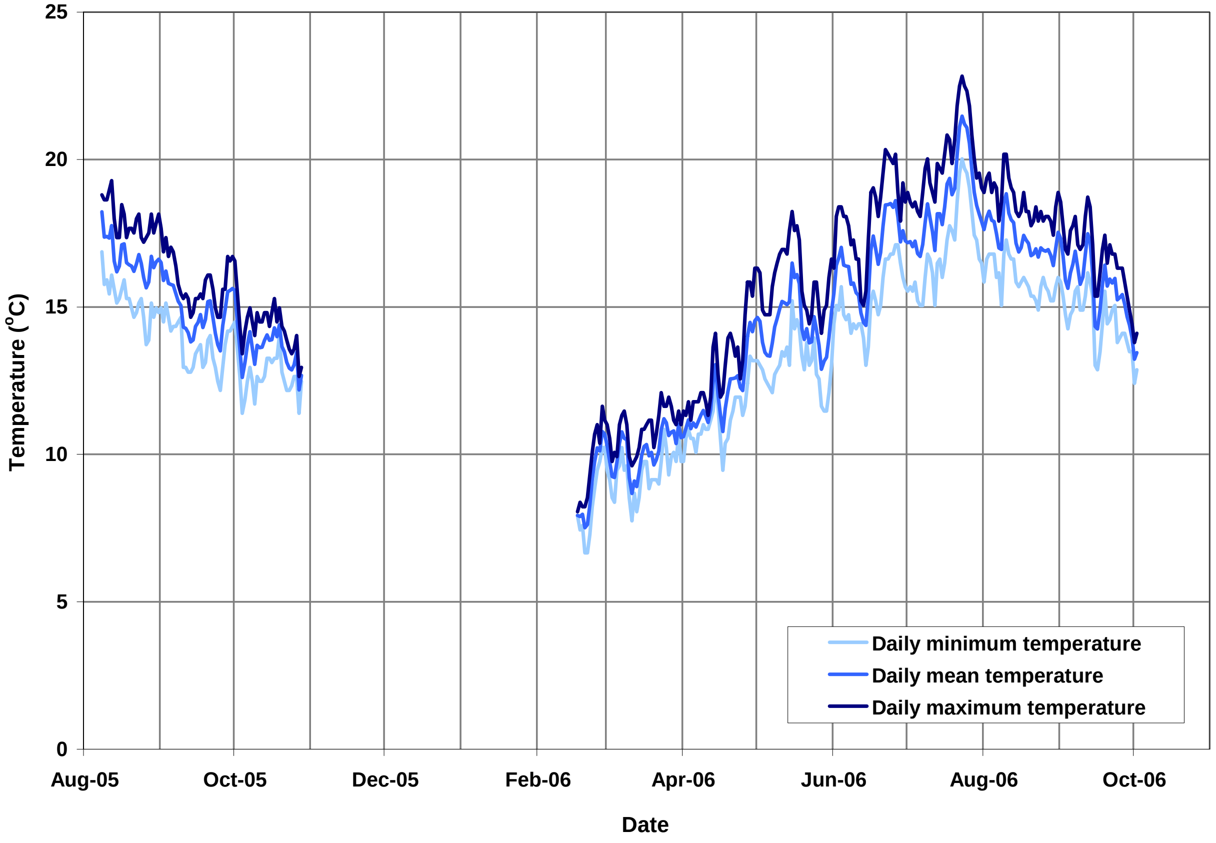

Figure F-17. Daily mean, minimum, and maximum water temperatures in the upper reach of York Creek for the period 8 August 2005 to 2 October 2006. Missing data are due to thermograph displacement from high flow event.