Juvenile bull trout and rainbow trout movements and growth in selected tributaries of the Chester Morse Lake basin, Cedar River Municipal Watershed, Washington

Final Report of Research

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Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 The Cedar River Municipal Watershed

The Cedar River Municipal Watershed (CRMW) supplies approximately two-thirds of the City of Seattle's water. The 91,638-acre CRMW is owned by the City of Seattle and located southeast of North Bend, Washington, immediately south of the I-90 corridor. Seattle Public Utilities (SPU) manages the CRMW reservoir system, which includes Chester Morse Lake (CML) and Masonry Pool (MSP), for multiple objectives, including high quality drinking water, in-stream flow management, hydroelectric power, and limited flood control. A natural falls downstream of Masonry Dam prohibits upstream movement of anadromous species and has isolated fish in the reservoir complex for potentially thousands of years. The fish community in CML is relatively simple and includes bull trout *Salvelinus confluentus*, rainbow trout *Oncorhynchus mykiss*, pygmy whitefish *Prosopium coulteri*, and shorthead sculpin *Cottus confusus*.

Masonry Dam was completed in 1914, increasing the elevation of the historic Cedar Lake from 1,532 feet to a maximum operating level of 1,563 feet. The SPU typically operates the reservoir at water levels between 1,544 to 1,563 feet annually. Lowest reservoir levels generally occur during late summer and fall. Late autumn rains and higher stream flows partially refill the reservoir, but snowmelt is critical to reaching complete reservoir volume in late spring. Under normal management scenarios, low reservoir levels (to approximately 1,538 feet) are not known to create physical or temperature barriers to fish movement through the deltas of the Cedar and Rex rivers, which are the two largest tributaries to CML. Smaller tributaries of CML, such as Rack Creek, can flow subsurface, disconnect from the lake, and create barriers to fish movement at the stream-lake confluence. Winter and spring frequently bring large amounts of rain, and rain-on-snow events that cause the reservoir level to rise quickly. During these seasonal events, reservoir elevations can vary substantially from week to week.

The SPU manages the CRMW under a 50-year Habitat Conservation Plan (CRW-HCP, City of Seattle 2000), which was completed in 2000. The plan is designed to provide certainty of drinking water and to protect and restore habitats of fish and wildlife affected by watershed management activities, including water supply management operations. One of the main commitments under the CRW-HCP is to provide funding for research and monitoring to provide information for achieving the conservation objectives of the CRW-HCP. Several projects described in the CRW-HCP address the ecology of bull trout relative to water use management.

The present study was developed to assess the seasonal movements, general distribution, habitat use, and growth of bull trout and rainbow trout in selected streams of the CRMW. Concurrent projects include monitoring temporal and spatial characteristics of bull trout spawning, monitoring movement and seasonal use of reservoir habitat by bull trout, rainbow trout and pygmy whitefish through acoustic telemetry, and studying the impacts of inundation on incubating bull trout eggs. Collectively, these studies will explore the effects of environmental factors such as temperature, flow, and lake level on metrics of interest and are important for a complete understanding of, and developing effective management strategies for, the adfluvial populations of fish in the CRMW. Results will increase our understanding of the effects of water operations on these fish and allow SPU managers to make more informed decisions about reservoir management in the future. Further, a better understanding of fish movements and distribution in selected streams of the upper CRMW will help SPU managers prioritize potential restoration sites and activities.

1.2 Bull trout status and life history

Bull trout in the western United States were listed as threatened under the Endangered Species Act in November 1999 (64 Federal Register 58909). Because of this, concerns about management of CML water level and its effects on bull trout passage at stream mouths and diversion structures have surfaced. Bull trout require specific habitat conditions, preferring cold-water temperatures, complex forms of cover for predator avoidance and energy conservation, and loose, clean gravel for spawning and rearing (Fraley and Shepard 1989; Rieman and McIntyre 1993). These fish show diverse life histories, including anadromous, adfluvial, fluvial, and resident (Brenkman and Corbett 2005; DuPont et al. 2007). Adfluvial fish spend the majority of their time in lakes or reservoirs and use larger tributaries for spawning and rearing. Fluvial fish spend their entire lives in large rivers and streams and, like their adfluvial brethren, can grow to large sizes. Resident fish are generally much smaller and spend their entire lives in headwater streams. Potentially, bull trout in the CRMW express all three freshwater life history strategies, but definitive evidence is lacking for strictly fluvial or resident life histories. The adfluvial life history has been documented for bull trout in the CRMW and indicates that many fish move to the lake at some point in their first few years of life (Wyman 1975; Connor et al. 2001). Our research was designed, in part, to substantiate these findings.

Past sampling in CML indicates that most bull trout are greater than 230 mm fork length (FL) when they are in the lake (Connor et al. 2001). In contrast, SPU surveys indicate that most individuals sampled from streams are less than 200 mm, suggesting that fish move to the lake before they reach this size. Also, bull trout are more common in the lower reaches of streams in the CRMW, particularly when compared to the headwaters. A frequency distribution of back-calculated lengths from scale samples for fish captured in CML was bimodal, suggesting that some bull trout spend two or more years in streams before moving to CML. This indicates slower growth rates for stream fish when compared to individuals that migrate immediately to the lake or spend only one year in streams (Connor et al. 2001). In September 1993, age-0 bull trout comprised 38% of fish captured in the Cedar and Rex rivers while age-1 fish comprised 62% of those captured. Two individuals greater than 200 mm, and expected to be age 2, were also captured (Connor et al. 2001). Size distribution of bull trout in streams of the CRMW suggests that most fish are adfluival, but more evidence confirming this notion would be helpful.

Bull trout in the CRMW commonly spawn in the lowest gradient portions of streams immediately upstream of the reservoir, typically within about 2.6 km (SPU unpublished data). Spawning typically begins the last week of September in the Cedar and Rex river systems and during mid-October in Rack Creek once surface connection with CML is re-established (SPU, unpublished data). Relatively few individuals spawn in the upper reaches of either the Cedar or Rex rivers, and it is unknown whether these fish are adfluvial individuals making long migrations or whether they are fluvial or resident forms. Due to the specific habitat requirements and movements of bull trout, water management at CML may influence their spawning and rearing success, particularly in the lower reaches where streams can become dry during certain times of the year or where inundation occurs during reservoir re-filling.

1.3 Rainbow trout status and life history

The rainbow trout in the CMRW occur sympatrically with bull trout in the lake and tributaries. The species is more widespread than bull trout in the upper CRMW, occurring from the reservoir complex to upper headwater streams. Though there is some evidence to suggest that rainbow trout were introduced above the outlet of CML (Marshall et al. 2004), it could be a native non-anadromous form of the coastal rainbow trout described by Behnke (1992). In general, the habitat requirements for stream dwelling juvenile rainbow trout differ somewhat from those for bull trout, lacking the bull trout's preference for very cold water temperatures (less than 10°C) and not being so closely associated with the stream substrate as juvenile bull trout (Meehan and Bjornn 1991).

Previous studies have aged adult rainbow trout from the CRMW using scales from fish collected throughout the reservoir complex. Wyman (1975) found that rainbow trout showed three patterns of early growth that suggested fish moved to the reservoir between 1 – 3 years of age. All rainbow trout showed a small increment of growth on the annulus for their first year of life, with some showing significant growth during their second year. Others showed a relatively minor second-year growth followed by significant growth in the third year, and still others showed three years of slow growth before rapid growth began. The analysis suggests that rainbow trout show varied strategies for moving to CML that may be influenced by rearing conditions in different streams. We hope that our research can help define the life history strategies of rainbow trout in the CRMW.

Connor et al. (2001) found that rainbow trout captured in gill nets within the reservoir complex ranged between 165 to 554 mm in total length. Within tributary habitat of the Cedar and Rex rivers, they found four distinct age classes ranging in size from 99 to 246 mm. The frequency distribution of back-calculated lengths showed that the majority of rainbow trout captured in the reservoir complex spent their first year rearing in tributaries before migrating to the reservoir. Approximately 15% of individuals sampled in the reservoir complex appeared to rear in stream habitat for two years prior to migrating to the lake (Connor et al. 2001). While the majority of fish captured during September 1993 electrofishing surveys were between 0 to 2 years of age, a few fish larger than 240 mm appeared to be age-3. Connor et al. (2001) suggest that the presence of these individuals in the stream indicates that the river systems likely support a resident rainbow trout population.

1.4. Study goal and objectives

The overall goal of this project was to increase our understanding of the ecology and biology of bull trout and rainbow trout in the CRMW. The objectives of this project were to: (1) describe some general characteristics of bull trout and rainbow trout populations in four main stream systems of the CRMW; (2) document the magnitude, direction, and timing of movements shown by these fish; (3) estimate rates of growth of juvenile bull trout and rainbow trout on an annual and seasonal basis; and (4) explore the possible influence of environmental factors such as flow, temperature, and reservoir elevation on fish movements.

2.0 Study area

2.1 General study area

The study area for this project included four tributaries of CML: Boulder Creek (a tributary of the Rex River), Cedar River, Rack Creek, and Rex River (Figure **1**). We classified streams into four general types for sampling: (1) larger, mainstem rivers (e.g., the Cedar and Rex rivers); (2) floodplain channels [FPC] associated with the lower Cedar River (i.e., FPC-3, FPC-4, and FPC-5); (3) wetland-fed systems that are tributary to mainstem rivers (e.g., Eagle Ridge, Cabin, and Morse creeks); and (4) higher gradient streams originating from north facing slopes (e.g., Boulder and Rack creeks). All references to lake elevation in this document are reported in feet (Seattle datum) rather than metric units, as this is the traditional reporting method used by water managers at SPU.

2.2 Boulder Creek

Boulder Creek is a relatively high gradient stream (4-8%) that flows into the Rex River about 315 m upstream of CML (all values stated herein are relative to a lake level of 1,560 feet elevation). The lowest reaches of Boulder Creek flow through an incised clay channel and have relatively deep pools with some cover (e.g., tree roots). About 800 m upstream from the confluence, the stream becomes wider and substrates become larger consisting of cobble with occasional pockets of gravel. Here, the channel steepens and larger boulders become more frequent, creating small pools throughout the reach. Because of low flows, a large alluvial deposit, very deep bedrock in the valley, and poorly sorted substrates, up to 1,000 m of lower Boulder Creek typically flows subsurface late in the summer and remains dry into early autumn. Previous SPU surveys show that bull trout spawn in low densities in Boulder Creek and that rainbow trout were numerically dominant.

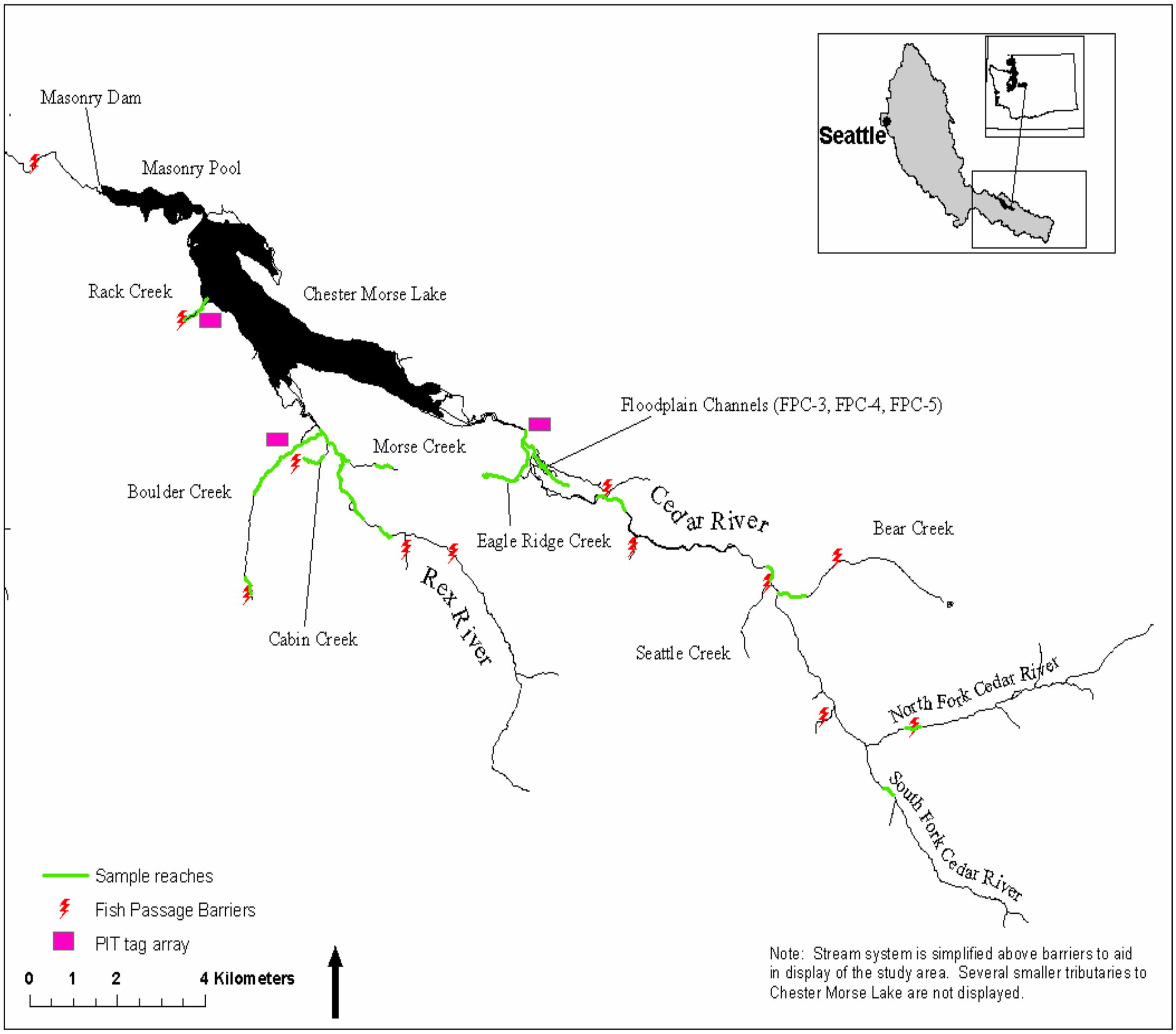

Figure 1.—Map of selected tributaries of the upper Cedar River Municipal Watershed. Reaches sampled during the study are highlighted in green

The November 2006 flood deposited a large alluvial wedge approximately 500 m upstream of the Rex River along Boulder Creek, and the stream braided into multiple smaller channels at this location. Due to the extensive flat floodplain along Boulder Creek, the stream likely will not process the material deposited during the 2006 floods in the near future, and we expect fish passage through this reach to be problematic for some time. Surveys on Boulder Creek at the 500-meter alluvial wedge indicate that fish passage is possible when the USGS gage at the Rex River (12115500) is between 60-80 cfs.

2.3 Cedar River

The Cedar River originates along the west side of the Cascade crest at the eastern extent of the watershed (i.e., Yakima and Meadow passes) and drains westward to CML. This is a relatively large stream with a wide channel, an extensive network of floodplain and slope-influenced channels in a broad channel migration zone, and several tributaries ranging from steep headwater streams near the Cascade crest to wetland-fed systems within our study area. The low gradient reach of river immediately upstream of the reservoir is a zone that experiences seasonal lake inundation, potentially impacting spawning and rearing habitat. Barriers to bull trout migration include gradient breaks at tributary mouths and a large falls on the North Fork Cedar River (Figure 1). Additionally, a portion of the Cedar River between 2,450 m and 2,800 m upstream of CML flows subsurface each summer. This 350 m reach presents a migration barrier to fish moving up or downstream during late summer. A potential for a short-term barrier at the lake/river interface could form on the Cedar and/or Rex rivers during extremely low reservoir levels, but this barrier would probably be short lived due to the river cutting through the delta and reforming the channel (SPU 2007).

Three floodplain channels (FPC-3, FPC-4, and FPC-5) enter the Cedar River at approximately 1,100 m to 1,300 m upstream of CML. These channels may be important rearing habitat for young fish because they provide refuge from high flows and predators in the Cedar River and have consistently cold annual temperatures with abundant cover in the form of wood and overhead vegetation that may reduce competition with conspecifics. In this area of the Cedar River, the river splits around a large island forming two distinct channels, called the New Main and the Old Main Cedar River. A large wetland and beaver dam-influenced stream, Eagle Ridge Creek, flows into the New Main channel.

The Cedar River supports the largest stream network and most diverse habitats of the tributaries of CML. It also has the greatest number of bull trout redds each year relative to all other streams in the system and the most diverse and abundant rearing habitat (SPU unpublished data). Thus, the Cedar River is regarded as one of the most critical habitat areas for bull trout in the CRMW. Juvenile bull trout and rainbow trout are common in the Cedar River, but bull trout densities become quite low upstream of Seattle Creek.

2.4 Rack Creek

Rack Creek is a small, high gradient tributary with about 1,000 m of habitat accessible to fish downstream of a natural gradient barrier. The streambed consists of large cobble and boulder substrate with abundant interstitial spaces between rocks. Local areas of gravel provide spawning opportunities for bull trout and spawning surveys indicate that this stream accounts for 1-5% of all bull trout redds annually (SPU unpublished data). Rack Creek enters CML approximately 8.3 km west of the mouth of the Cedar River and 3.1 km west of the mouth of the Rex River (Figure 1). During late summer, portions of the stream flow subsurface. The stream loses its connectivity with CML as reservoir levels drop below approximately 1,550 feet in elevation for much of the summer and early fall, reconnecting only during intermittent high flow events or ultimately with reservoir refill.

2.5 Rex River

The Rex River is a major tributary of CML originating from a north-facing slope at the southern boundary of the watershed, separating the Cedar and Green river drainages (Figure 1). The Rex River is a relatively complex system with an upper high gradient section, a lower mainstem section heavily influenced by lake levels, and several tributaries with associated wetlands (e.g., Cabin and Morse creeks). It lacks the extensive network of floodplain channels in the Cedar River system. The high gradient portion of this stream begins approximately 1,300 m upstream of CML and has a low frequency of pools. The mainstem portion of the river, from the confluence with the reservoir upstream to 1,300 m, has many deep pools and considerable amounts of large woody debris. Due to the low gradient of the river near CML, an inundation zone at high lake levels can extend several km upstream to the confluences of Boulder and Cabin creeks. A natural falls barrier located 4,600 m upstream of CML blocks the upstream migration of fish into the headwater portions of the Rex River.

2.6 Wetland fed systems—Cabin, Morse, and Eagle Ridge creeks

Cabin and Morse creeks are tributaries of the Rex River, entering the mainstem channel 590 m and 1,075 m upstream of CML. Eagle Ridge Creek is tributary to the Cedar River (1,385 m upstream of CML) and supports an extensive and unique wet meadow system fed by depressional wetlands. These creeks are wetland-fed systems characterized by dense vegetation and marshy, wetland scrub-shrub and sedge habitats. Eagle Ridge and Morse creeks have large, complex, open marsh areas that expose them to direct sunlight, which may warm surface temperatures considerably during the summer. In contrast, Cabin Creek originates from a higher elevation depressional wetland that flows downslope through a dense forest before reaching the heavily forested floodplain of the Rex River.

3.0 Methods

3.1 Fish capture and marking

We captured bull trout and rainbow trout with either minnow traps or backpack electrofishing, or a combination of the two methods. Gee-type minnow traps were baited with canned salmon in film canisters and placed in the stream about 10-m apart, yielding about 10 traps for each 100-m interval. The traps were constructed of 6.4 mm (1/4") square galvanized wire mesh and were 42 cm (16") long, and 23 cm (9") wide with a 22 mm (7/8") diameter entrance. Traps were fished from one to three consecutive nights and bait was replaced after three sets. We used minnow traps primarily during the early season (i.e., May – June) during the latter end of bull trout emergence and when electrofishing was ineffective due to cold temperatures and high flows. The traps were also used in habitats that were less amenable to electrofishing (e.g., deep pools). Electrofishing was conducted with a backpack electrofisher (model LR-24 or 15-D, Smith-Root, Inc., Vancouver, WA) set to deliver pulsed DC at 90-Hz and 1-ms duty cycle (determined from previous experience) with voltage ranging from 300 to 500 V (determined automatically by the LR-24 electrofisher). Electrofishing consisted of a two or three person crew performing upstream, single-pass efforts without block nets through the 100-m sample sections. All fish were netted and placed into 5-gallon buckets with fresh water and vegetation for cover. Very small rainbow trout were not often netted as they were locally very abundant, time consuming to measure, and were too small to tag.

All captured salmonids were anesthetized with 50 mg/L tricaine methanesulfonate (MS-222) buffered with an equal amount of sodium bicarbonate, measured for fork length (mm) and weighed (nearest 0.01g). Fish greater than 70 mm received a single, full duplex Passive Integrated Transponder (PIT) tag (12 x 2-mm, 0.09 g in air, 134.2 kHz; Biomark, Boise, ID) placed ventrally into the body cavity at the posterior end of the pectoral fin and 1-2 mm from the mid-ventral line. We did not tag fish if the weight of the PIT tag was greater than 2% of a fish's weight. Tags were injected into fish with a modified syringe and 12-gauge hypodermic needle with a sharp beveled edge. Larger, 23-mm PIT tags were used for fish greater than 120-mm because of body size considerations (Bateman and Gresswell 2006). All PIT tagging followed the procedures outlined by the Columbia Basin Fish and Wildlife Authority (1999). After tagging, fish were allowed to recover in buckets of fresh water and released near their capture site. We also weighed, measured, and released fish that were too small for tagging.

We plotted length frequency distributions for all fish captured by stream, month, and year. We used these distributions to assign fish ages and lengths to any distinct modes and estimated annual growth of fish from age-0 to age-1. Annual growth rates derived from analysis of the length frequency distributions were validated by recaptures of PIT-tagged fish (see below).

3.1.1. Sampling in 2005

Sampling in 2005, the first project year, went from August to the end of October. We established sampling reaches along streams by flagging every 100 m beginning at the stream mouth or at a bridge crossing with easy access and targeted streams with a known presence of bull trout, including Boulder Creek (seven days) and Rack Creek (four days). We also sampled Cabin Creek, Bear Creek, and the Cedar and Rex rivers for one day each. Because PIT tag detection systems were going to be installed in Boulder and Rack creeks, we spent most of the initial sampling effort in those streams.

3.1.2. Sampling in 2006

In 2006, we sampled fish from all the streams previously mentioned and from Eagle Ridge and Morse creeks, the South Fork of the Cedar River, and three channels in the Cedar River floodplain. Sampling occurred from June through October, except from about September 1 – 12 when extreme fire conditions prohibited activity within the CRMW. Otherwise, the core areas of Rack Creek, Boulder Creek, and the Rex and Cedar rivers were sampled monthly.

3.1.3. Sampling in 2007

Sampling in 2007 comprised our most substantial effort of the study and went from June through October. All the streams sampled in 2006 were sampled again in 2007, except for FPC-3 and Bear Creek.

3.2 PIT tag interrogation systems

To document the movements of bull trout and rainbow trout, we installed in-stream PIT tag interrogation systems in three tributaries of the watershed: Rack Creek, Boulder Creek, and the Cedar River. The systems continually monitored for PIT-tagged fish and provided information on the daily, seasonal, and annual movements of fish in and through that area.

Our PIT tag interrogation systems were comprised of a full-duplex, multiplexing transceiver (FS1001M Biomark, Boise, ID) stationed near the stream and connected to a personal data assistant (PDA; Dell Axim X50 or X51), power supply, and antennas. Up to six custom-built antennas of varying sizes were placed in the stream to span the wetted width (see details below). The transceiver sent power to the antennas, which in turn generated an electrical field. When a PIT-tagged fish passed within the read range of the antenna, the transceiver recorded the unique tag code, date, time, and antenna number. The transceivers were downloaded automatically twice a day to the PDA. Direct current (DC) electricity was provided to each system by a propane-powered thermoelectric generator (Model 5060, Global Thermoelectric, Inc.) and backed up by two 12 volt, 110 amp-hour batteries. Major, bed mobilizing floods on 6 and 7 November 2006 destroyed most antennas and shut down all three PIT tag interrogation systems for up to four weeks. We re-installed some antennas at each site during the first week of December to provide monitoring in the thalweg (see details below).

3.2.1. Boulder Creek PIT tag system

The Boulder Creek PIT tag system was installed in October 2005, about 1,120 m upstream of CML. As described by Connolly et al. (2005), the use of at least two antenna arrays positioned within a few meters of each other in an upstream-downstream configuration allows determination of the direction of fish movement. Increasing the number of arrays increases the detection efficiency of a system. At Boulder Creek, we used four antennas to form three arrays (A, B, and C), with the most upstream array designated "A", the middle array designated "B", and the most downstream array designated "C". Antennas for PIT tag interrogation systems were classified as either "pass-by", "hybrid", or "pass-through" configurations. Pass-by antennas were placed flat against the substrate so that fish passed above them. This orientation has been found to be most resistant to being moved or damaged by high flows (Connolly et al. 2008). Hybrid antennas were anchored on the upstream side only, which allowed the downstream end to float and adjust to water height. Finally, pass-through antennas were placed perpendicular to flow—with the top usually out of the water—to present a rectangular opening for fish to swim through. They potentially provided the best detection ability, but were prone to being moved or damaged by high flows or debris. In Boulder Creek, array A was comprised of two pass-by antennas that spanned the stream width, array B was one hybrid antenna, and array C was one pass-by antenna (Figure 2; Appendix 1).

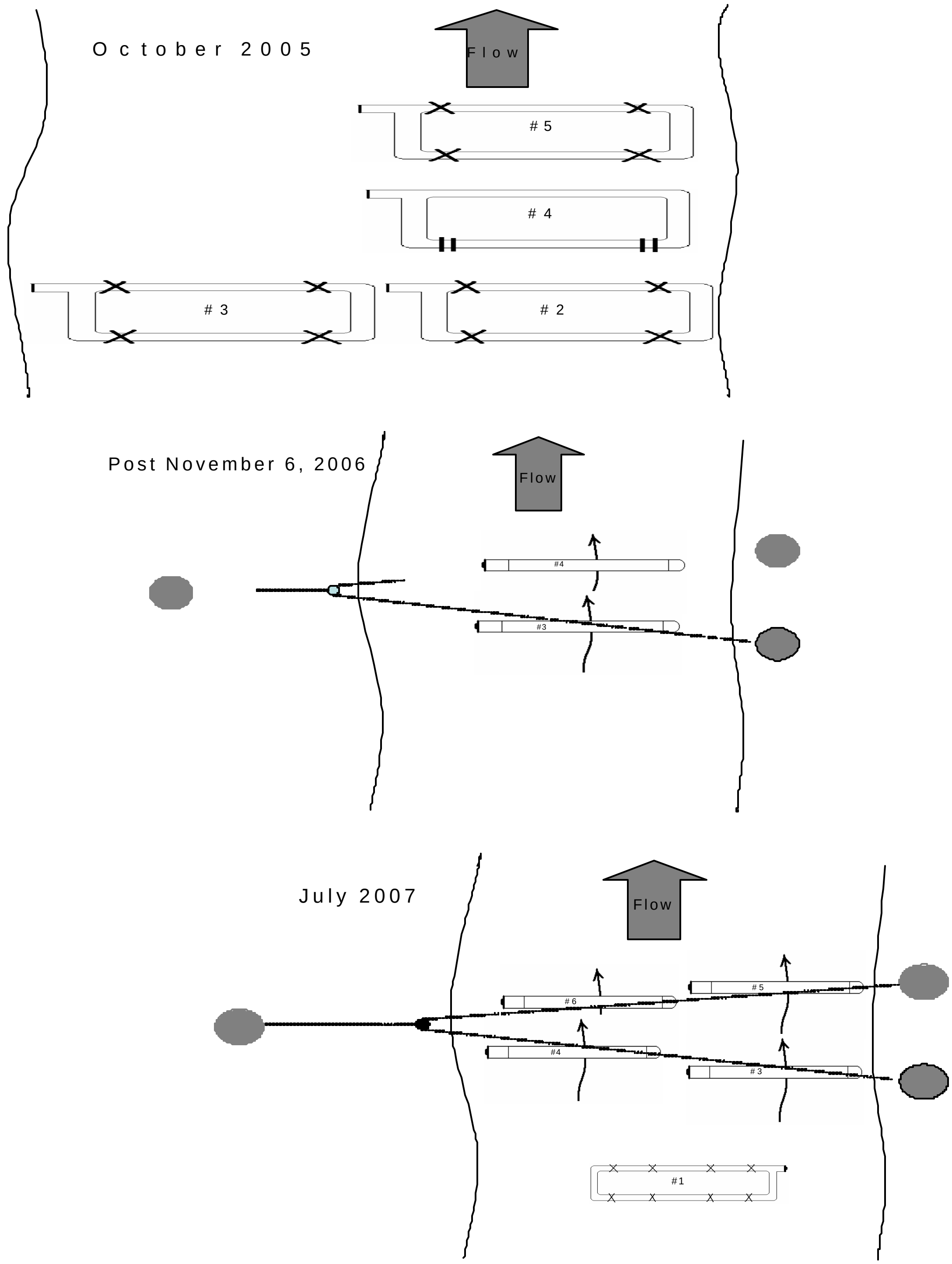

Figure 2.—Diagram of PIT tag antenna placement in Boulder Creek before (upper panel) and after (middle and lower panels) a flood in November 2006. Large circles represent trees for anchoring suspended steel cable.

3.2.2. Cedar River PIT tag system

The Cedar River PIT tag system was installed in August 2006, about 70 m downstream of the Camp 18 bridge and 640 m upstream of CML. This system was comprised of six 6.1-m-long, 0.61-m-wide antennas forming three arrays. The most upstream array (A) had three pass-by antennas, the middle array (B) had one hybrid antenna, and the most downstream array (C) had two antennas that were suspended beside each other from a steel cable and tied to anchor points in the river bed. Because the river was so wide in this area, some of our arrays did not span the entire width. However, all of the arrays were designed to cover the thalweg, with each positioned close to the north shore of the river (Figure 3).

3.2.3. Rack Creek PIT tag system

The system on Rack Creek was installed in October 2005, about 330 m upstream from where the creek enters CML. The antennas spanned the width of the stream and were comprised of two pass-through antennas (arrays A and B), and two pass-by antennas, forming array C (Figure 4).

3.3 Fish movements

The products of the methods described above were essentially two-fold: (1) the installation of several fixed, in-stream PIT tag interrogation systems with the potential for year-round operation; and (2) the establishment of large populations of PIT-tagged bull trout and rainbow trout in several streams of the upper CRMW. The PIT-tagged fish, interrogation systems, and recapture events provided the data needed to describe the distance, direction, and timing of fish movements throughout the study area.

There were two ways to determine the movements of individual marked fish: (1) detection of a PIT-tagged fish at an interrogation system; or (2) recapturing a marked fish, either by trap or by electrofishing, at a location other than where it was tagged. Using data from the PIT tag interrogation systems, we recorded a detection event if a PIT-tagged fish was detected on one or more antennas. The distance moved by each fish was determined by calculating the difference (m) between the location of tagging and subsequent recapture or interrogation events. Every fish was given an initial capture location based on mean river meter (e.g., a fish caught between 100 and 200-m was assigned a capture location of river meter 150), which allowed for a spatial resolution of fish movement of 100-m.

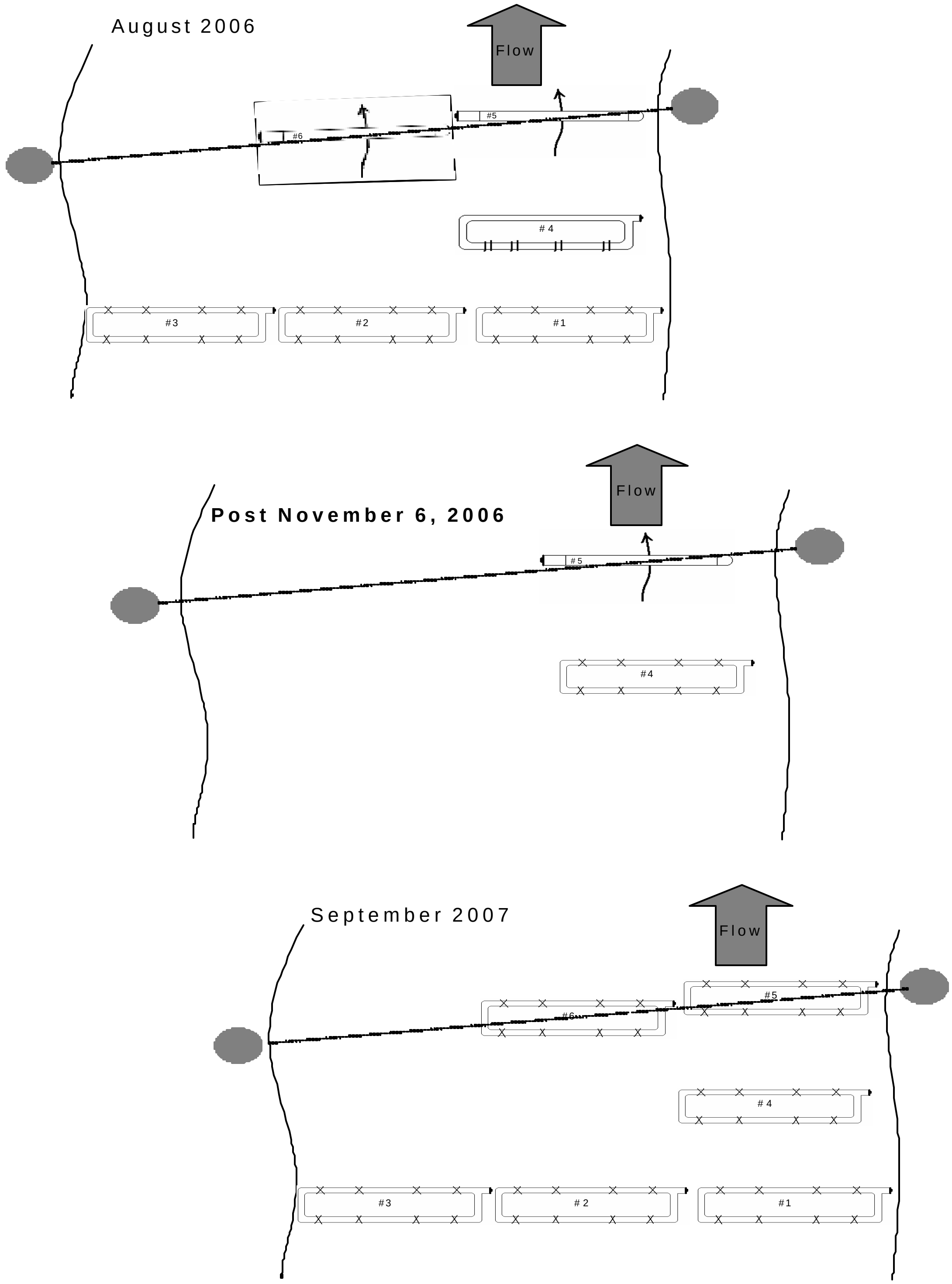

Figure 3.—Diagram of PIT tag antenna placement in the Cedar River before (upper panel) and after (middle and lower panels) a flood in November 2006. Large circles represent trees for anchoring suspended steel cable.

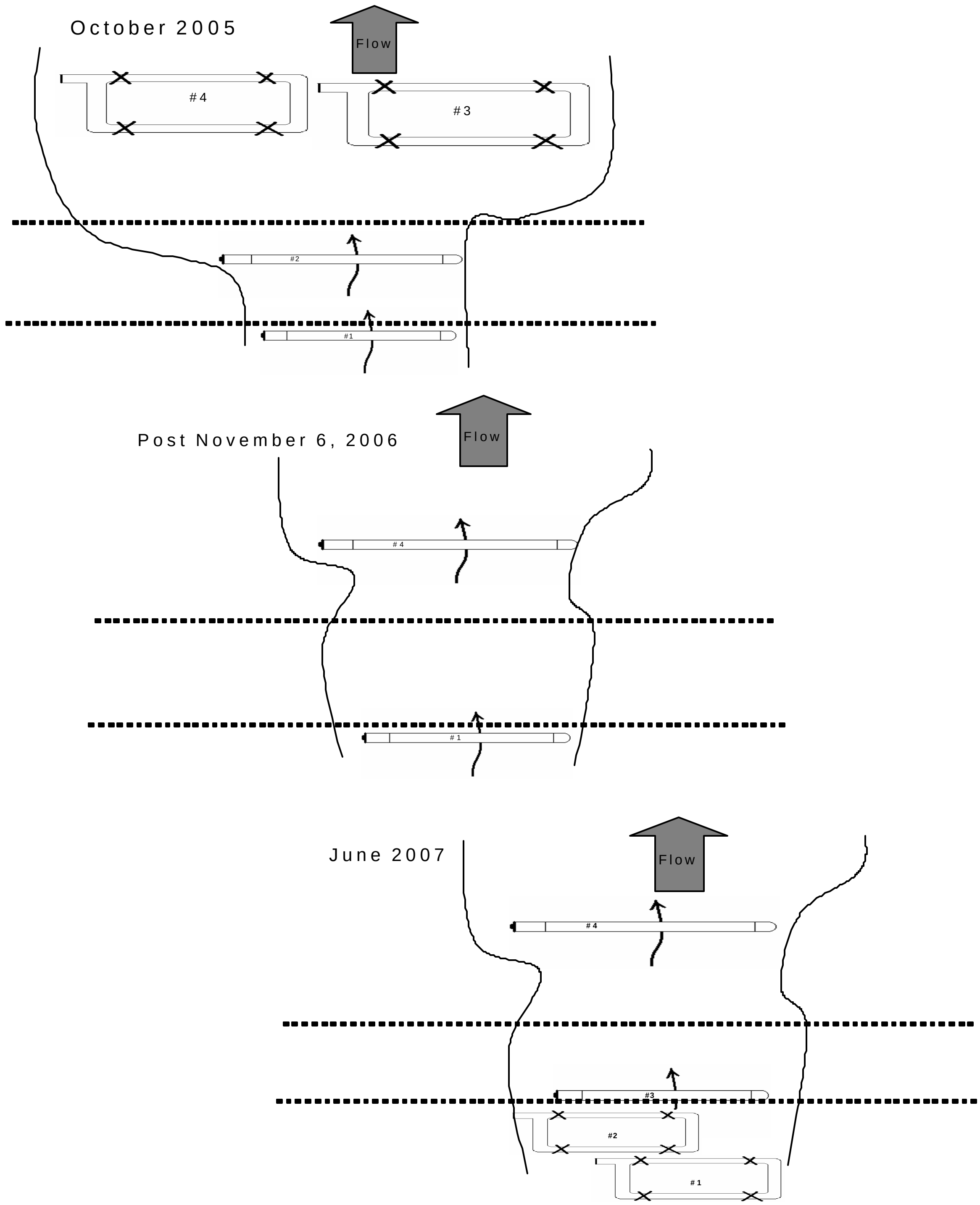

Figure 4.—Diagram of PIT tag antenna placement in Rack Creek before (upper panel) and after (middle and lower panels) a flood in November 2006. Dashed lines represent a road going over the creek.

The direction of fish movement (i.e., upstream or downstream) was determined by more detailed analysis of data from the PIT tag interrogation systems. For this, we classified fish into three categories: (1) definitive up or downstream movement; (2) reasonable assumption of up or downstream movement; or (3) do not know or insufficient data. For a fish to be placed in the first category, it must have been detected sequentially (either up or downstream) at two arrays within a short time (e.g., within hours). For a fish to be placed in the second category it must have been detected on at least one array and we assumed direction of movement based on location of tagging. The final category was for fish with data insufficient to determine direction. We plotted detection or passage events for fish in each stream over time against key environmental variables (e.g., water temperature, flow, reservoir elevation) to document any seasonal trends in movement and factors that may influence it. We also plotted the percent of fish that emigrated and their lengths against location of capture to assess any longitudinal gradients in these metrics.

For fish that we recaptured, we determined the distance and direction they moved by calculating the difference between their recapture and tagging locations. We plotted these values against each other for fish in each stream to determine the magnitude of distances moved and the influence of time between capture events.

3.4 Fish growth

We estimated annual rates of growth for fish in each stream by analysis of length frequency distributions for age-0 and age-1 fish. Recapture of PIT-tagged fish also allowed for direct measurement of annual and seasonal growth. For each recaptured fish, we derived growth trajectories by plotting length and weight over time from consecutive capture events. To estimate annual absolute growth rates of individuals, we simply subtracted their length at tagging from that at recapture for fish that had at least a year between capture events. We derived instantaneous growth rates for these fish by dividing the absolute growth rate by the number of days between capture events:

$$\frac{\sum_{i=1}^{n} \frac{L_{i+1} - L_i}{d_{i+1} - d_i}}{n} = g$$

where n is the number of recapture events in the sample, L is fork length (mm), d is the day of capture, and g is the sample specific growth rate. Because such a long time elapsed between capture events, our annual estimates of fish growth may not represent that which occurred only within the stream they were captured. In other words, because fish in the CRMW were quite mobile (see results section), their growth over a single year could have occurred anywhere, not just within the stream in which they were captured. Because of this, we did no statistical analysis of our annual growth estimates, but instead used them to validate growth derived from our length frequency distributions and for relative comparisons to fish from other areas.

We estimated seasonal growth rates of recaptured fish in each stream using combined data from our 2006 and 2007 catches only. For this analysis, we used only fish that were tagged and recaptured between June and September and where at least 30 days had elapsed between capture events. We used the formula presented above to derive an instantaneous growth rate for each fish and calculated a mean rate for the sample of fish from each stream. We compared the means using a one-way ANOVA followed by Tukey's HSD test when the F-test was significant ($P < 0.05$).

3.5 Environmental variables—water temperature, habitat fragmentation, stream flow, lake elevation

Water temperature data loggers (Hobo Water Temp Pro Data Logger, Onset® Computer Corporation, Bourne, MA) were deployed in Rack and Boulder creeks in 2005 and in the Rex River, FPC-5, and Cabin and Eagle Ridge creeks in 2006. Loggers were placed inside a PVC pipe drilled with several holes to allow water flow and sealed with a threaded end cap. The PVC pipe was secured to a steel stake that was pounded into the streambed. Water temperature (±0.2°C) was recorded every 90 minutes and data were downloaded in the fall and spring.

We obtained discharge of the Cedar River and Boulder Creek (in cfs) from U. S. Geological Survey stream gages located in these streams (USGS stream gages 12115000 and 12115700). For each day, we calculated a daily median value from instantaneous values (recorded every 15 min) posted on the USGS website. Because a gage was not present on Rack Creek, we used flow from the Boulder Creek site as a surrogate for Rack Creek. Water elevation changes in CML can lead to dewatering at the mouths of some smaller tributary streams during summer low flow conditions. Also, changes in lake level can affect the deltas of both the Cedar and Rex rivers, either inundating these areas or drying them out and exposing large areas of vegetation, although hydrologic connection of these river systems is always maintained. We obtained lake elevation data from the USGS gage and weather station (USGS site 12115900) located at the Overflow Dike between Chester Morse Lake and Masonry Pool, 5 km southeast of Cedar Falls. Together, water temperatures, Cedar River discharge, and lake elevation were plotted against fish movement data to determine potential correlations. On these graphs, we also plotted the range of dates when streams flowed subsurface due to low water conditions and warm ambient temperatures.

4.0 Results—bull trout

4.1 Capture, marking, and length frequencies of bull trout

4.1.1. 2005

A summary of our sampling effort in 2005 is shown in Table 1. We captured, weighed, and measured 290 bull trout in four streams of the CRMW (Table 2). Of these, 190 fish were PIT-tagged (Figure 5). Most (63%) of the fish were captured in Rack Creek, with Boulder Creek accounting for 23% of the catch, the Rex River system (exclusive of Boulder Creek) 8%, and the Cedar River system 6%. These results represent the total catch for 2005 and do not account for the variable level of effort between streams. Results should not be interpreted as differences in fish densities between these streams. Length frequency distributions of fish captured in each stream by month revealed two distinct size classes (Figure 6; Appendix 2). Although our sampling was limited in 2005, bull trout showed modal size-classes centered around fish of about 75 mm and 125 mm, which were presumably age-0 and age-1 fish (Appendix 2). No bull trout died during our minnow trapping efforts and only one died (0.3% of the total captured) when we sampled using electrofishing methods.

4.1.2. 2006

In 2006, we sampled considerably more stream area (Table 1) and captured, weighed, and measured 1,400 bull trout (Table 2). Of these, we PIT-tagged 693 fish (Figure 5) that had a mean (± SD) length and weight of 110 ± 29 mm and 16.2 ± 19 g. This time, the Cedar River drainage accounted for most (51%) of the bull trout captured, followed by the Rex River drainage (23%), Rack Creek (17%), and Boulder Creek (7%). Length frequency distributions of fish captured in each stream by month again revealed the presence of two distinct size classes corresponding to age-0 and age-1 fish (Figure 6; Appendix 2).

Table 1.—Distance sampled by stream (August to October 2005, June to October 2006, and June to October 2007) in the Cedar River Municipal Watershed.

	2005	**2006**	**2007**
Stream		**Distance sampled (meters)**	
Boulder Creek	1,000	2,200	2,700
Cedar River			
Mainstem habitat	100	3,350	3,100
FPC-3		200	
FPC-4		400	400
FPC-5		800	800
Bear Creek	100	400	
Eagle Ridge Creek		200	1,200
Rack Creek	1,000	1,000	1,000
Rex River			
Mainstem habitat	100	2,200	2,900
Cabin Creek	200	600	600
Morse Creek		400	600
Total (Year)	2,500	11,750	13,300

Table 2.—The number of bull trout handled and PIT-tagged in the Cedar River Municipal Watershed, 2005 - 2007.

		Stream system				
Year	Category	Boulder Creek	Cedar River	Rack Creek	Rex River	Total
2005	Handled	67	17	184	22	290
	Tagged	61	13	107	9	190
2006	Handled	81	582	417	320	1,400
	Tagged	60	351	117	165	693
2007	Handled	152	854	364	182	1552
	Tagged	59	482	122	117	780
Total	Handled	301	1453	965	524	**3243**
	Tagged	177	845	344	288	**1654**

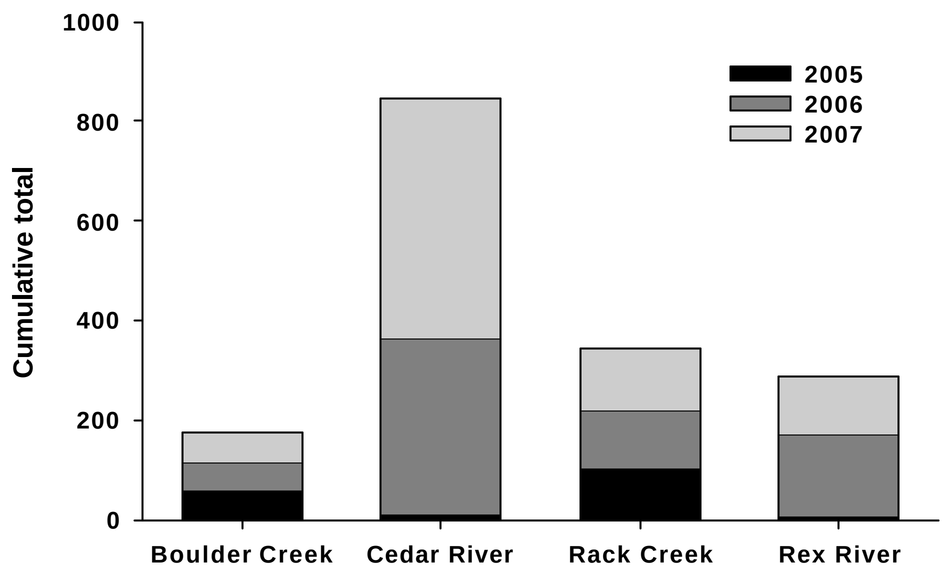

Figure 5.—Cumulative number of bull trout that were PIT-tagged in four drainages of the Cedar River Municipal Watershed, 2005 – 2007.

We also captured a few fish less than 50 mm during June through August in Rack Creek and the Rex River, indicating late emergence or slow growth. The number of age-1 fish tended to decrease from summer to autumn due presumably to emigration of this age group (see below). There was no relation between length of fish and capture location for any of the streams we sampled (Figure 7). Nine bull trout died during our minnow trapping efforts and three during electrofishing, for a total mortality rate of 0.9%.

4.1.3. 2007

In 2007, we sampled extensive lengths of streams (Table 1) and captured, weighed, and measured 1,552 bull trout (Table 2). Of these, we PIT-tagged 780 fish (Figure 5) with a mean (± SD) length and weight of 107 ± 27 mm and 15.0 ± 18 g. The Cedar River drainage accounted for most (55%) of the bull trout we caught, followed by Rack Creek (23%), the Rex River (12%), and Boulder Creek (10%). Length frequency distributions once again revealed the presence of two dominant size classes of fish that were age-0 and age-1 (Figure 6; Appendix 2). Catches were greatest in July, August, and September with numbers of age-1 fish generally decreasing over time. We also captured a few, very small fish in June and July in Boulder Creek, the Cedar River, and Rack Creek, again indicating late emergence or slow growth. We found no relation between length of fish and capture location for any of the streams we sampled (Figure 7). Four bull trout died during our minnow trapping efforts and two during electrofishing, for a total mortality rate of 0.4%.

4.2 Interrogations of PIT-tagged bull trout

4.2.1. Boulder Creek

We installed the PIT tag interrogation system at Boulder Creek on 5 October 2005 and it remained operational for most of 2005 – 2007, except for random days when equipment malfunctioned and during the flood in November 2006. In Boulder Creek, after the flood, we re-installed pass through antennas in December by suspending cable from trees across the stream (Figure 2). We found this technique especially valuable for anchoring antennas in the highly mobile streambed. The Boulder Creek system was operational for 780 out of 818 possible days. During this time, this system detected 45 unique tags, or about 25% of the total number of fish tagged in this creek. Most of these detections (99%) were from fish tagged in Boulder Creek.

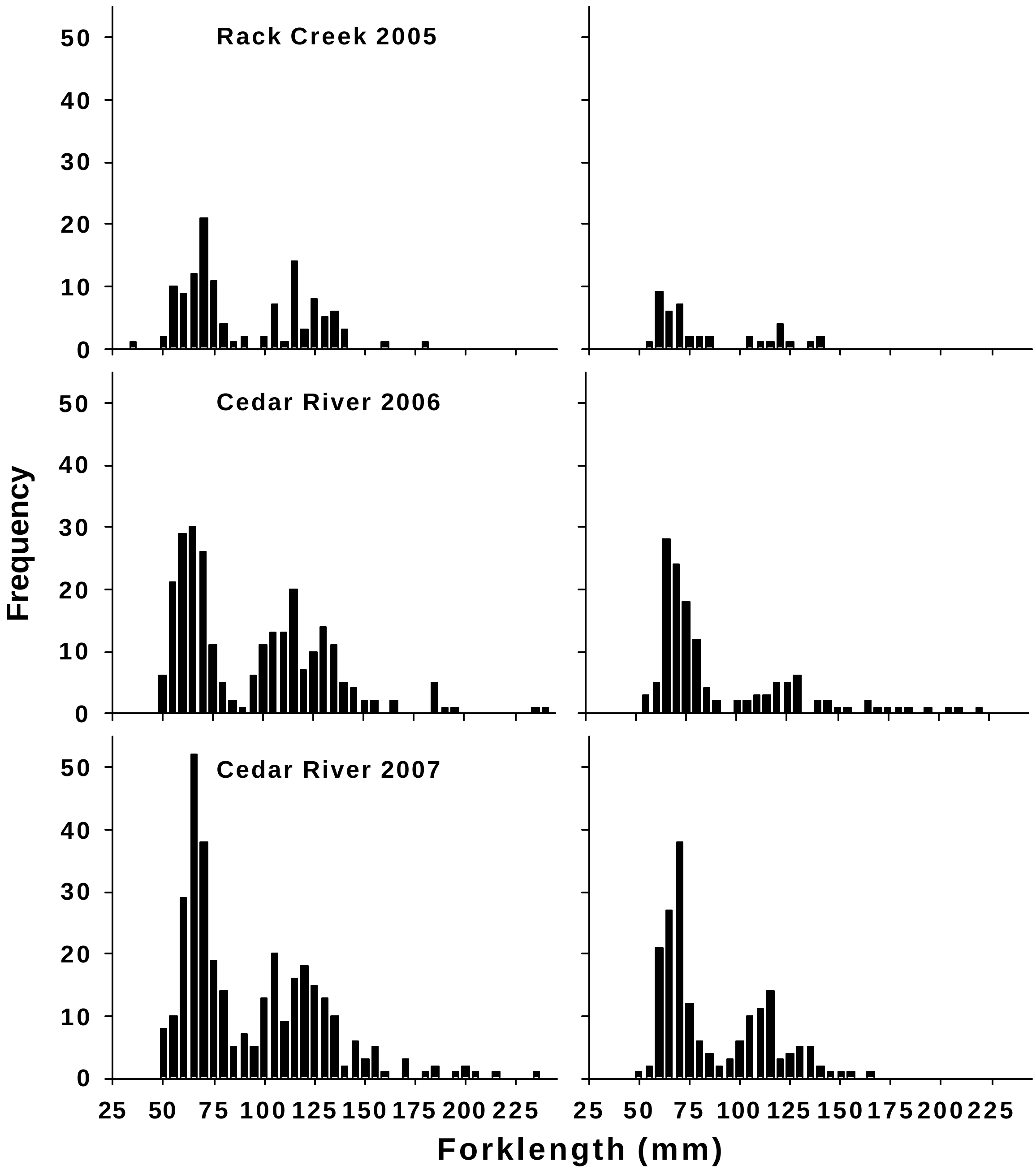

Figure 6.—Examples of length frequency distributions of bull trout captured in August (left panels) and September (right panels) in two tributaries of the Cedar River Municipal Watershed. Complete length frequencies by stream, month, and year are in Appendix 2.

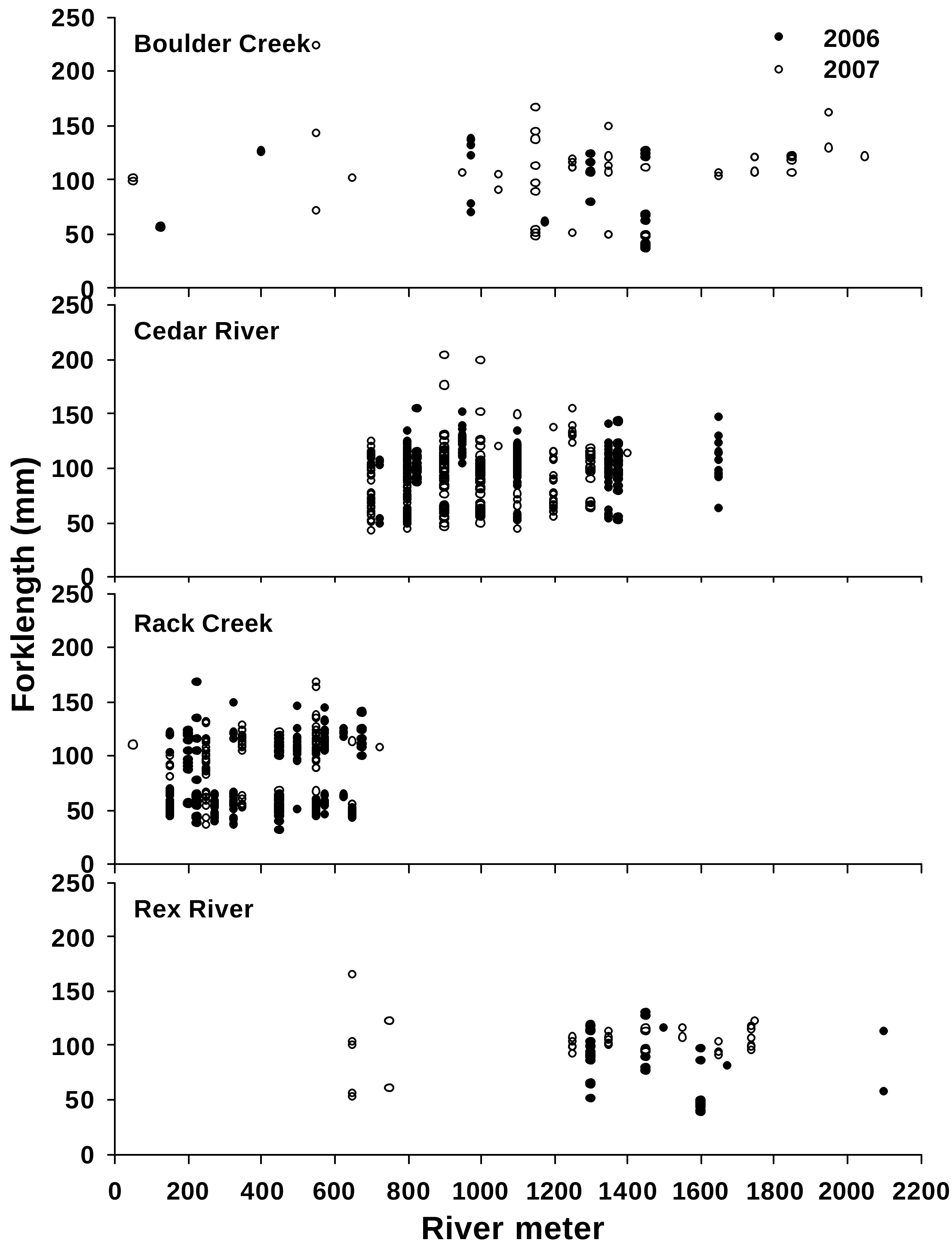

Figure 7.—Length of bull trout relative to their location of capture in four streams of the Cedar River Municipal Watershed, 2006 and 2007.

4.2.2. Cedar River

We installed the Cedar River PIT tag interrogation system on 11 August 2006 and it remained operational until the November 2006 flood. We re-installed one pass-by and one hanging antenna in the thalweg after the flood (Figure 3). During this time, the system detected 54 unique bull trout, or about 15% of the total tagged in this river prior to November 2006. These fish originated primarily from the mainstem Cedar River and FPC-5, but several fish came from other areas, including FPC-3, FPC-4, and Eagle Ridge Creek. We completed a full reinstall of the PIT tag array in September 2007 when streamflows dropped low enough for us to work on anchor points. From 11 August 2006 through 31 December 2007, the Cedar River system detected an additional 177 bull trout, which was about 21% of the total number of fish tagged in this creek. We also detected four bull trout moving upstream in the Cedar River from other tributaries of CML (see section 4.5) and numerous adults moving upstream originally tagged in the lake (SPU unpublished data).

4.2.3. Rack Creek

We installed the Rack Creek interrogation system on 6 October 2005 and it remained operational for most of 2005 – 2007. There were random days, however, when the system was not functioning due to equipment failure and the system was inoperable for a time following the large flood of November 2006. The re-installed antennas at Rack Creek were all pass-through and began functioning during the first week of December 2006 (Figure 4). In total, this system was operational for 704 out of 817 possible days. From 6 October 2005 through 31 December 2007, the Rack Creek system detected 93 individual bull trout, or 27% of the total number of fish tagged in this creek. Most (97%) of the fish detected were from Rack Creek.

4.3 Movements of bull trout via PIT tag interrogations

4.3.1. Boulder Creek

We recorded 60 movements from 45 individual fish detected at this site. Most of the movements were in a downstream direction—only six fish were detected moving upstream. In 2005, although we PIT-tagged 43 fish in this creek, only six fish moved downstream in late October and November (Figure 8). In 2006, most fish moved downstream from about mid-July to November, but the total number of fish moving was relatively small (Figure 8). In 2007, a few fish moved downstream from January to July, but the largest number emigrated in early October through November, following a two-month period of subsurface flow at the mouth and intermittently along the stream (Figure 8). Most of the fish that moved downstream were greater than 80 mm and ranged up to 200 mm, indicating they were mostly age-1 fish or older (Figure 9). Emigrating fish measured within three months prior to detection had a mean (SD) length of 130.4 (38.7; N = 19) mm. There was no relation between the percent of fish that emigrated and their capture location (Figure 10).

4.3.2. The Cedar River system

Of the 177 PIT-tagged bull trout detected in this stream, we recorded 12 upstream and 150 downstream movements—all in 2006 and 2007 (Figure 11). Movements were detected soon after the interrogator was installed in August 2006 and lasted until mid-November. The number of fish moving downstream peaked during the last week of September. In 2007, a few fish moved downstream prior to July, but the bulk of emigration occurred from August to November (Figure 11). Again, most of the fish that emigrated were greater than 80 mm and as large as 240 mm (Figure 9). Downstream moving fish had a mean (SD) length of 131.8 (47.3; N = 40) mm. There was no relation between the propensity to emigrate and capture location despite differences in accessible habitat sampled (Figure 10) and, in fact, the percentage of fish that emigrated from different sections of the river was consistent, ranging from 15 to a little over 20% regardless of capture location.

4.3.3. Rack Creek

Of the 93 PIT-tagged bull trout detected by the interrogation system, we recorded 31 upstream and 69 downstream movements (Figure 12). In 2006, downstream movement of juvenile fish started in May, peaked in July, and continued into early August. All of these movements occurred prior to the creek going dry near and downstream of the interrogator. A few fish moved downstream after autumn rains restored surface flow and re-connected Rack Creek to the lake. In 2007, a few fish moved downstream prior to mid-July before the creek went subsurface (Figure 12). After autumn rain re-established surface flows, sometime in late

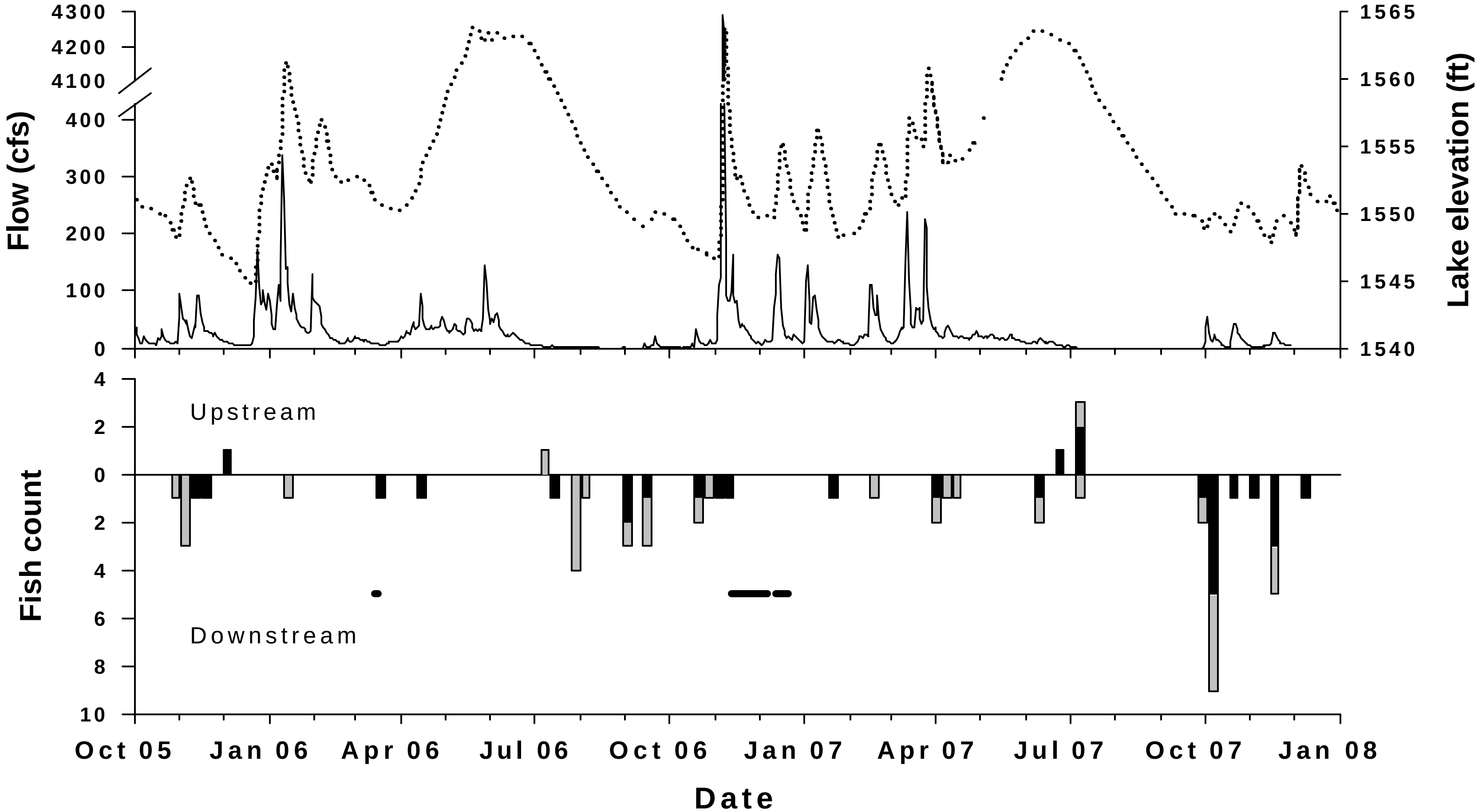

Figure 8.—Number of bull trout that moved up or downstream in Boulder Creek (lower panel), stream flow in Boulder Creek (solid line, upper panel), and elevation of Chester Morse Lake (dashed line, upper panel) in the Cedar River Municipal Watershed, 2005 – 2007. Thick, horizontal black lines denote periods when the PIT tag interrogation system was not operating. Bins are one week.

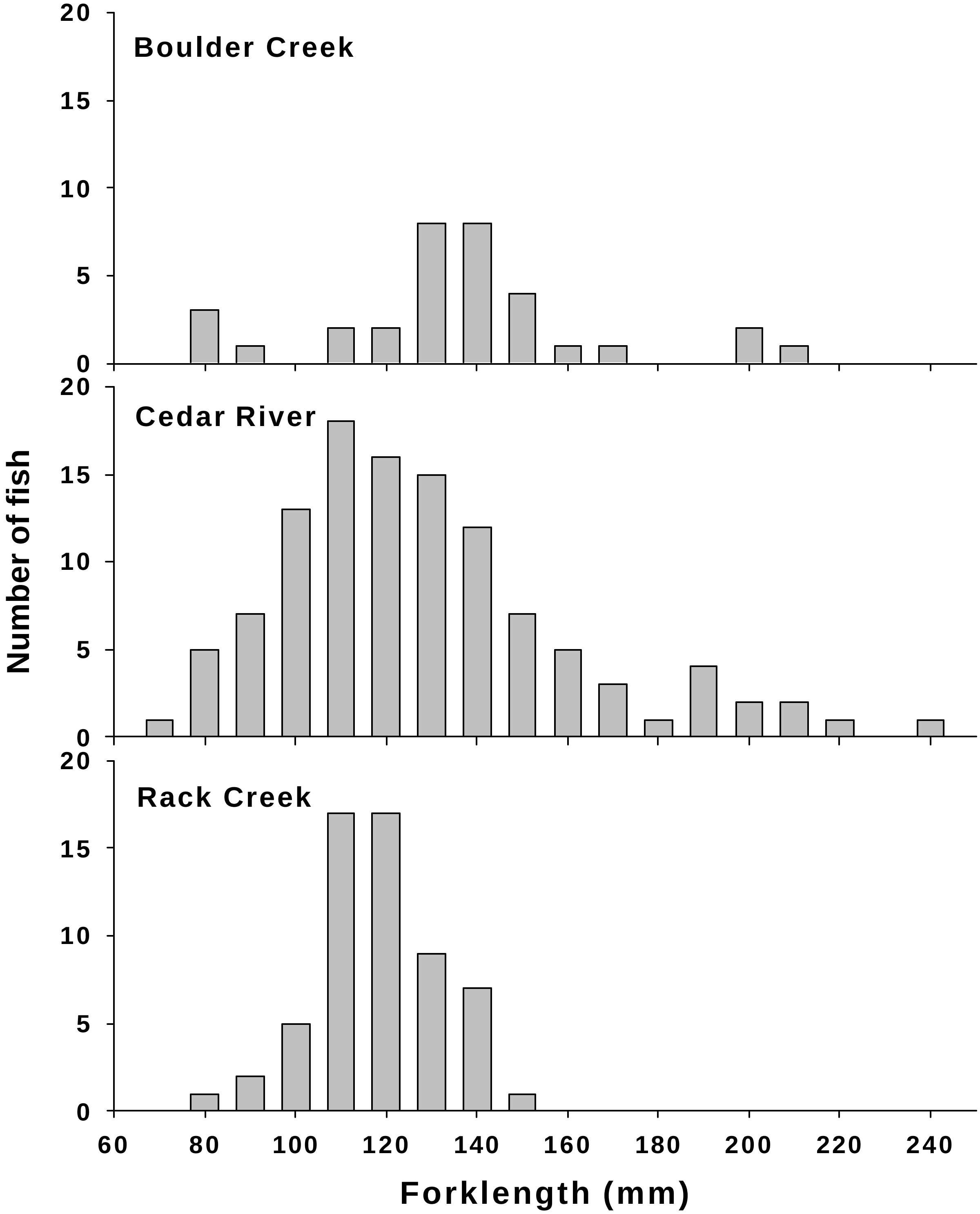

Figure 9.—Number of bull trout that emigrated from three streams in the Cedar River Municipal Watershed relative to their length at tagging, 2005 – 2007.

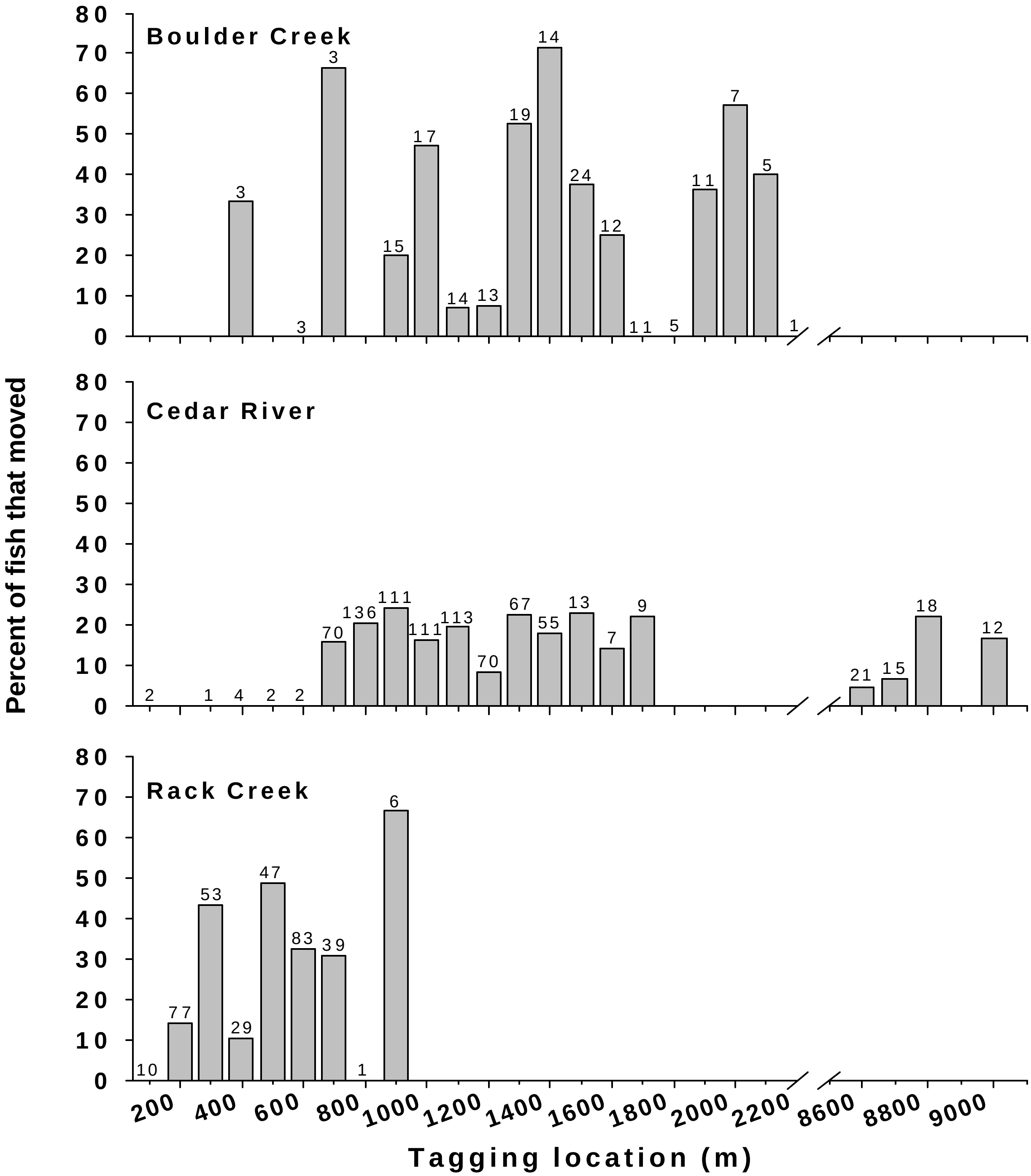

Figure 10.—Percent of bull trout that emigrated relative to their tagging location in three streams of the Cedar River Municipal Watershed, 2005 – 2007. Numbers above each bar are the total number of fish tagged in that section. Because of a fish barrier, Rack Creek was only sampled to the 1000 m point.

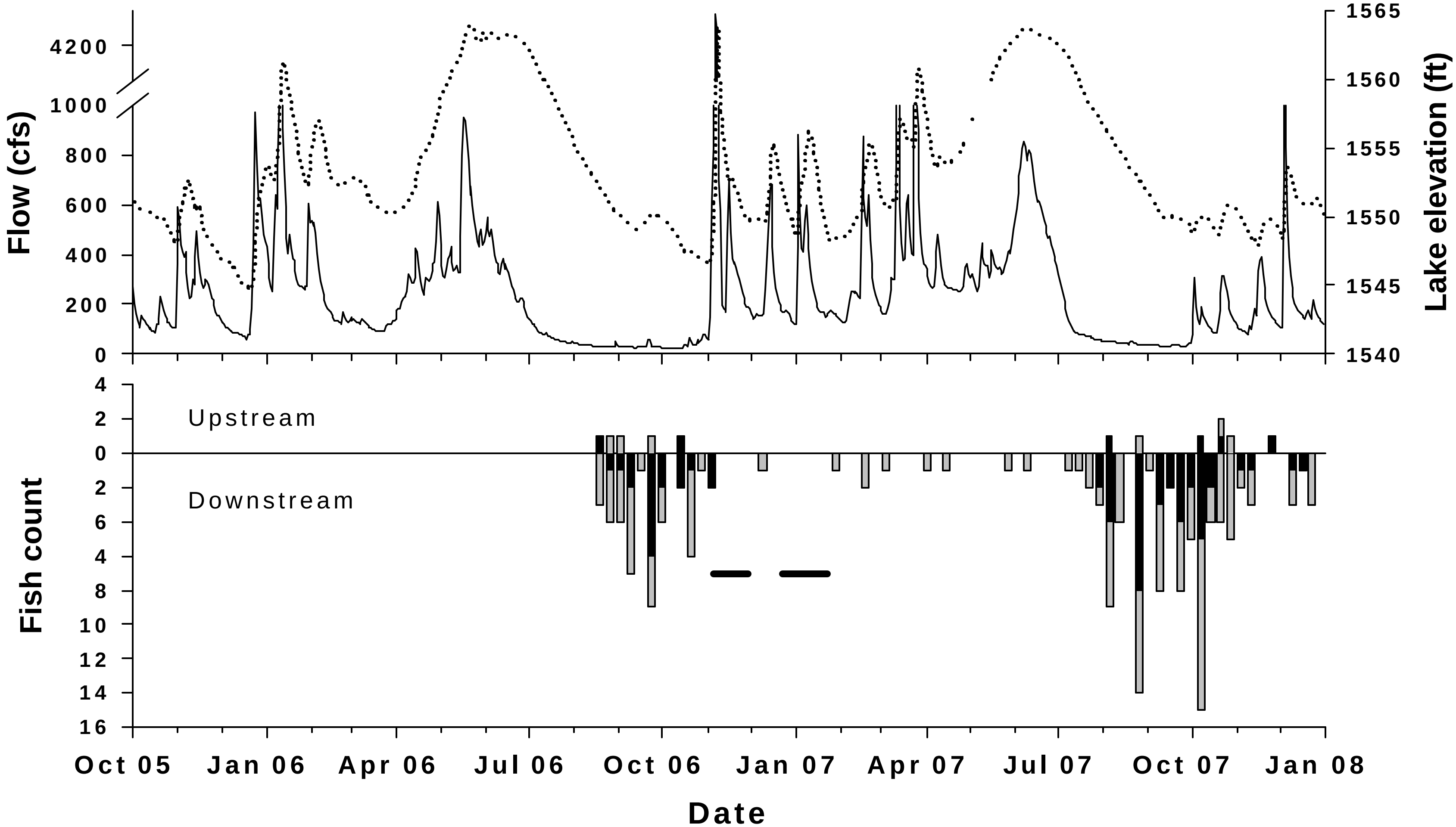

Figure 11.—Number of bull trout that moved up or downstream in the Cedar River (lower panel), stream flow in the Cedar River (solid line, upper panel), and elevation of Chester Morse Lake (dashed line, upper panel) in the Cedar River Municipal Watershed, 2005 – 2007. Thick, horizontal black lines denote periods when the PIT tag interrogation system was not operating. Bins are one week.

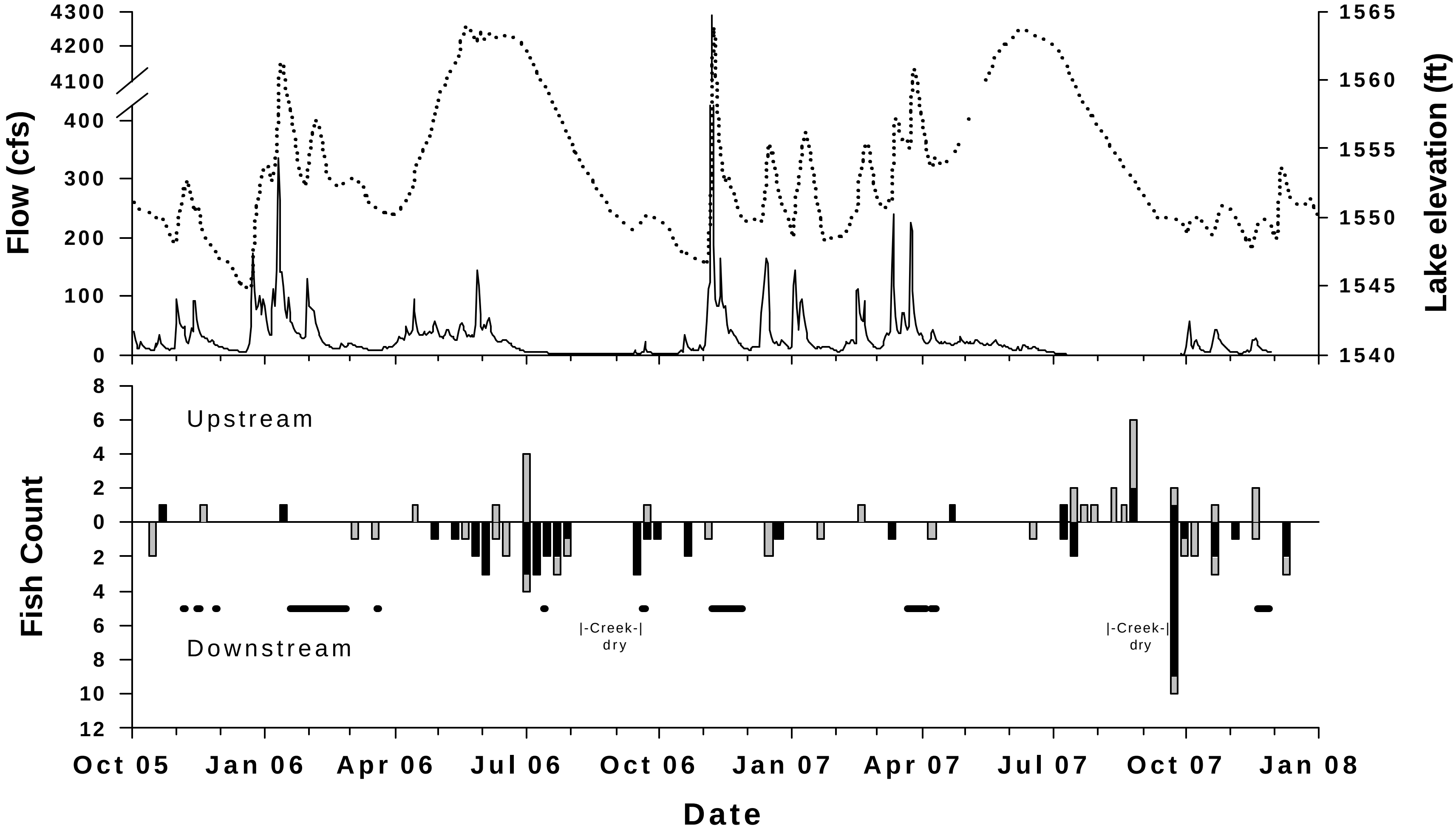

Figure 12.—Number of bull trout that moved up or downstream in Rack Creek (lower panel), stream flow in Boulder Creek (used as a surrogate for Rack Creek, solid line, upper panel), and elevation of Chester Morse Lake (dashed line, upper panel) in the Cedar River Municipal Watershed, 2005 – 2007. Thick, horizontal black lines denote periods when the PIT tag interrogation system was not operating. Bins are one week.

September, a large pulse of fish emigrated downstream. Migrants in Rack Creek ranged from about 80 to 150 mm, indicating that they were mostly age-0 and age-1 fish (Figure 9). Fish that moved downstream had a mean (SD) length of 120 (25.7; N = 6) mm. Again, there was no relation between percent of fish emigrating and capture location (Figure 10).

4.4 Movements of bull trout via recaptures of PIT-tagged fish

In total, we recaptured 256 bull trout that were PIT-tagged in 2005-2007. One hundred fish were recaptured in Rack Creek, 96 in the Cedar River, 36 in Boulder Creek, and 24 in the Rex River. No bull trout were recaptured outside the stream that they were initially tagged in, but numerous movements between tributaries and mainstem habitats were noted, particularly in the Cedar and Rex rivers. For example, of twelve fish tagged in the mainstem Cedar River, three were recaptured in FPC-4 and nine in the Cedar River. Of 30 fish tagged in FPC-4, four were recaptured in the Cedar River, and the rest in FPC-4. Finally, of 52 fish that were tagged in FPC-5, three were recaptured in the Cedar River, and the rest in FPC-5. In the Rex River, three fish were tagged in the mainstem and all were recaptured there. Twenty-one fish were tagged in Cabin Creek, with three recaptured in the Rex River and the rest in Cabin Creek.

Recaptured bull trout in Boulder and Rack creeks showed substantial intra-stream movements, both up and downstream (Figure 13). While 45% of recaptures in Boulder Creek showed maximum movements greater than 200 m, only 16% of fish in Rack Creek showed this magnitude of movement. Of the recaptures in Boulder Creek that moved more than 200 m and stayed in the system, 100 % (8 of 8) of those originally tagged below the reach at rkm 1.2 moved upstream, while 88 % (7 of 8) of those tagged above rkm 1.2 moved downstream. In Rack Creek, the amount of up and downstream movements shown by fish was more balanced throughout the length of the stream.

Recaptures indicated that there was considerable movement of fish between the mainstem Cedar River and the floodplain channels, FPC-4 and FPC-5 (Figure 14). Seven bull trout tagged in these two channels were recaptured downstream in the Cedar River, and three fish tagged in Cedar River were recaptured upstream in FPC-4.

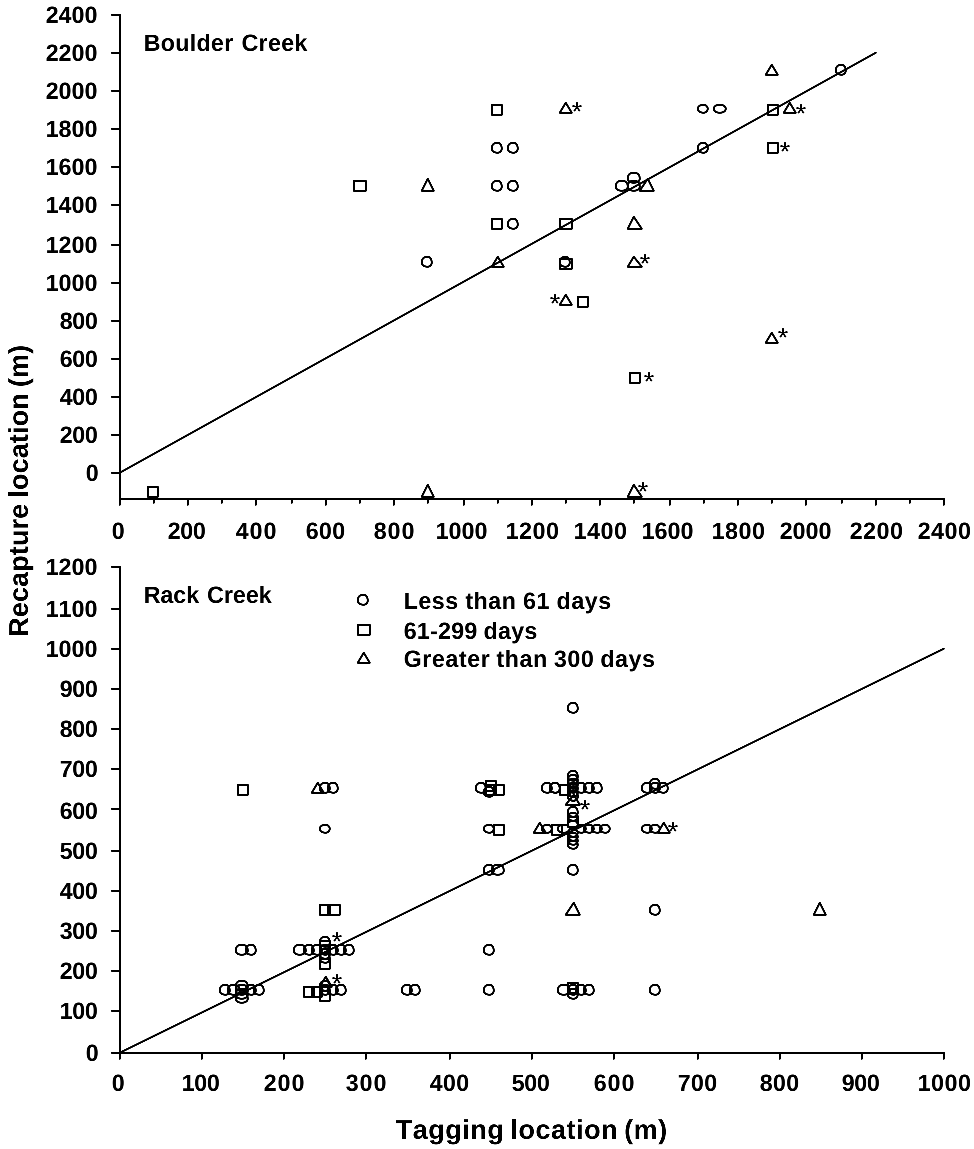

Figure 13.—Maximum distance moved (± 50 m) by recaptured bull trout that were originally PIT-tagged in (A) Boulder Creek and (B) Rack Creek, 2005-2007. Symbols represent the number of days between tagging and recapture events. Fish that were at least 150 mm at recapture are indicated with an asterisk. Symbols above the diagonal line indicate upstream movement, while those below indicate downstream movement. The three symbols on the X-axis in the upper graph represent three bull trout that were recaptured in the Rex River. Overlapping symbols at some locations were moved along the axes to facilitate interpretation.

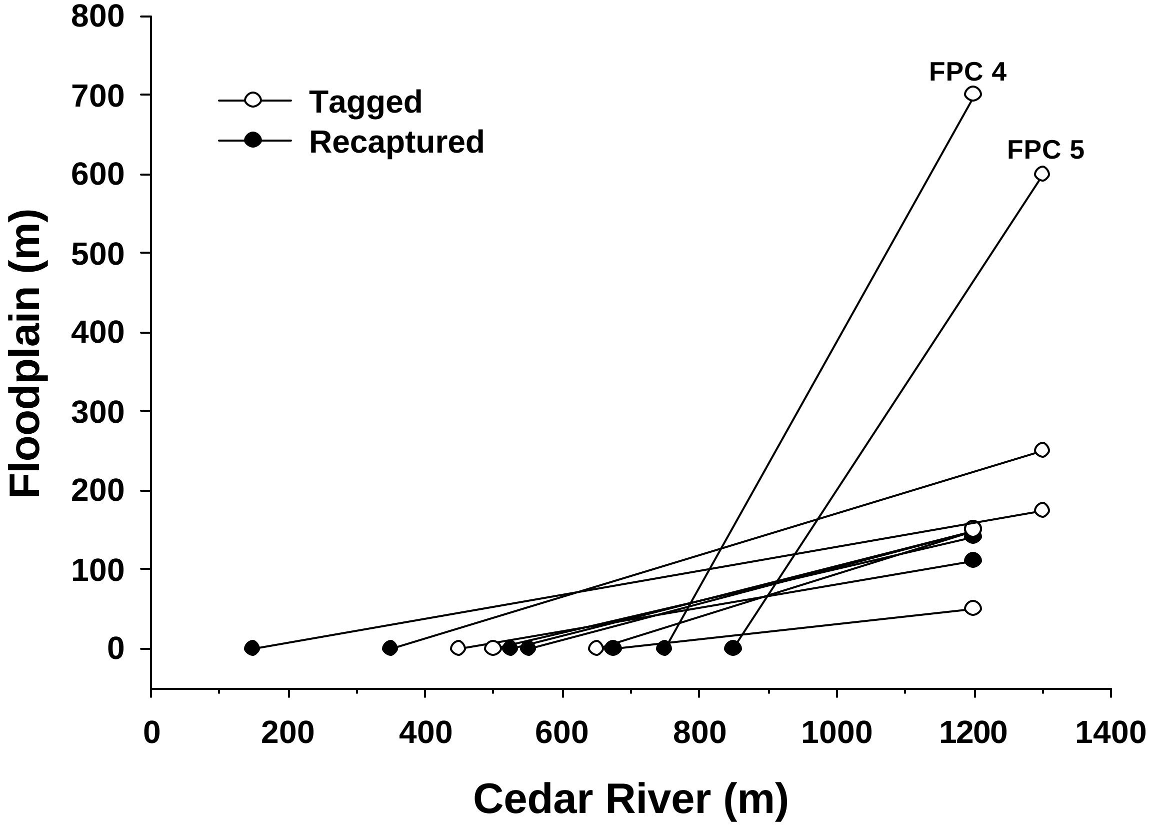

Figure 14.—Movement of recaptured, PIT-tagged bull trout between the mainstem Cedar River, FPC-4, and FPC-5. Fish tagged and recaptured within the mainstem Cedar River or within an individual FPC are not shown. Open circles indicate location where a fish was tagged, closed circles indicate where it was recaptured. The zero point on the y-axis represents locations in the Cedar River.

4.5 Movements of bull trout in the reservoir

There were six bull trout that moved downstream from tributaries, into CML, through the lake, and then upstream into different streams (Table 3). Three of these fish were originally tagged in Rack Creek, one was tagged in Cabin Creek, and two were tagged in the Rex River. Five of these fish eventually moved into the Cedar River and one moved upstream into Rack Creek. At the time of tagging, these fish ranged in size from 70 – 148 mm. One of the most extensive histories we recorded came from a bull trout (110 mm FL) tagged on 30 June 2006 in Rack Creek at river

Table 3.—Location, date, and size at tagging and subsequent recapture or interrogation location of bull trout that traversed Chester Morse Lake in the Cedar River Municipal Watershed, 2005-07.

Tagging location	Dated tagged	Fork length (mm)	Date recaptured	Location recaptured	Date interrogated	Location interrogated
Rack Creek	8.18.05	135			9.20.06	Cedar River
Cabin Creek	9.1.05	70	5.24.06	Cabin Cr.		
					8.27.06	Cedar River
Rack Creek	6.30.06	145			6.30.06	Rack Creek
					8.20.06	Cedar River
Rack Creek	6.30.06	110	7.28.06	Rack Creek		
					9.14.06	Rack Creek
			9.18.06	Rack Creek		
					10.11.06	Cedar River
Rex River	8.22.06	148			4.16.07	Rack Creek
Rex River	9.22.06	144			10.19.07	Cedar River

meter 500. We recaptured this fish one month later near the tagging site and it had grown to 114 mm. On 14 September 2006, it moved downstream past the Rack Creek PIT tag interrogation system. This passage event was confirmed when the fish was recaptured four days later at river meter 150, where it had grown to 116 mm. Finally, on 11 October 2006, we detected this fish moving upstream past the Cedar River interrogation system, an estimated linear distance of 8.3 km.

A few fish moved downstream from tributaries, possibly entered CML, and returned to the same stream (Table 4). Although we cannot say unequivocally that these fish actually entered the reservoir (they could have simply resided below the detector), those with a long time between interrogation events were most likely to show this behavior.

Table 4.—Location, date, and size at tagging and subsequent recapture or interrogation date of bull trout that potentially entered Chester Morse Lake in the Cedar River Municipal Watershed, 2005-07.

Tagging location	Dated tagged	Fork length (mm)	Date downstream movement	Date upstream movement	Elapsed time (d)
Boulder Creek	6.16.06	87	5.21.07	8.23.07	94
Rack Creek	6.30.06	102	7.25.06	11.13.07	476
Rack Creek	7.7.06	140	12.19.06	11.16.07	332
Boulder Creek	7.26.06	123	7.31.06	8.16.06	16
Boulder Creek	8.16.06	136	7.6.07	8.16.07	41
Boulder Creek	8.31.06	224	6.19.07	7.5.07	16
Boulder Creek	9.15.06	115	1.16.07	7.5.07	170
Rack Creek	5.23.07	92	7.11.07	7.31.07	20
Cedar River	7.23.07	183	9.9.07	10.2.07	23

4.6 Growth of bull trout

4.6.1. Annual growth of bull trout in Boulder Creek

Although we did not catch many bull trout in Boulder Creek, the length frequency distributions indicated that fish grew about 50 – 60 mm from age-0 to age-1 (see Appendix 2). In total, we recaptured 36 PIT-tagged bull trout from Boulder Creek—3 in 2005, 10 in 2006 and 40 in 2007. The growth trajectories of these fish are shown in Appendix 2. Several of our fish were age-0 when they were tagged and had about a year elapse between mark and recapture events. The growth rates of these fish validated the growth we observed in the length frequency distributions. These fish grew an average (± SD) of 0.13 (±0.02) mm per day and increased in mass by 0.07 (±0.05) g per day, which resulted in adding about 48 (± 6) mm and 24 (± 20) g per year. We also recaptured two individuals after about a year that were about 190 mm when they were tagged (Appendix 2). These fish, probably age-1 or older, grew about 30 mm in a year.

4.6.2. Annual growth of bull trout in the Cedar River system

Length frequency distributions from July, August, and September of 2006 and 2007 indicated that fish grew 40 – 50 mm from age-0 to age-1 (see Appendix 2). In total, we recaptured 97 PIT-tagged bull trout from the Cedar River—none in 2005, 40 in 2006, and 64 in 2007 (some fish were recaptured more than once; Appendix 2). Only five fish were recaptured about a year after tagging, with four of them coming from FPC-5 and one from the mainstem Cedar River. The growth rates of these fish ranged from about 30 – 40 mm per year, which was lower than rates derived from our length frequency analysis.

4.6.3. Annual growth of bull trout in Rack Creek

Analysis of the length frequency distributions from fish in Rack Creek indicated that bull trout grew about 40 – 50 mm from age-0 to age-1 (Appendix 2). We recaptured 100 PIT-tagged bull trout from Rack Creek—16 in 2005, 44 in 2006 and 65 in 2007. Growth trajectories of these fish are shown in Appendix 2. Although we captured only a few fish that had about a year elapse between marking and recapture, their growth rates validated those from our length frequency distributions. On average, fish recaptured a year after tagging grew about 40 mm and added about 22 g of mass.

4.6.4. Annual growth of bull trout in the Rex River

Based on analysis of length frequencies, annual growth of age-0 bull trout in the Rex River was similar to fish in other streams (Appendix 2). From age-0 to age-1, bull trout grew about 40 – 50 mm. Although we recaptured 24 PIT-tagged bull trout from Rex River or Cabin Creek (12 in 2006 and 14 in 2007; Appendix 2), only three fish were recaptured a year after tagging and provided estimates of annual growth. All of these fish were from Cabin Creek and grew from 20 – 40 mm per year, which is lower than values derived from an analysis of length frequencies.

4.6.5. Seasonal growth of bull trout in the CRMW

In 2006 and 2007, the growth rates of bull trout from June through September ranged from 0.06 to 0.16 mm per day and differed significantly between fish in different streams (F = 10.7, P < 0.001; Figure 15). Post-hoc tests, however, revealed that this difference was due to the growth rates of fish in Rack Creek being significantly lower than those for fish in the Cedar River.

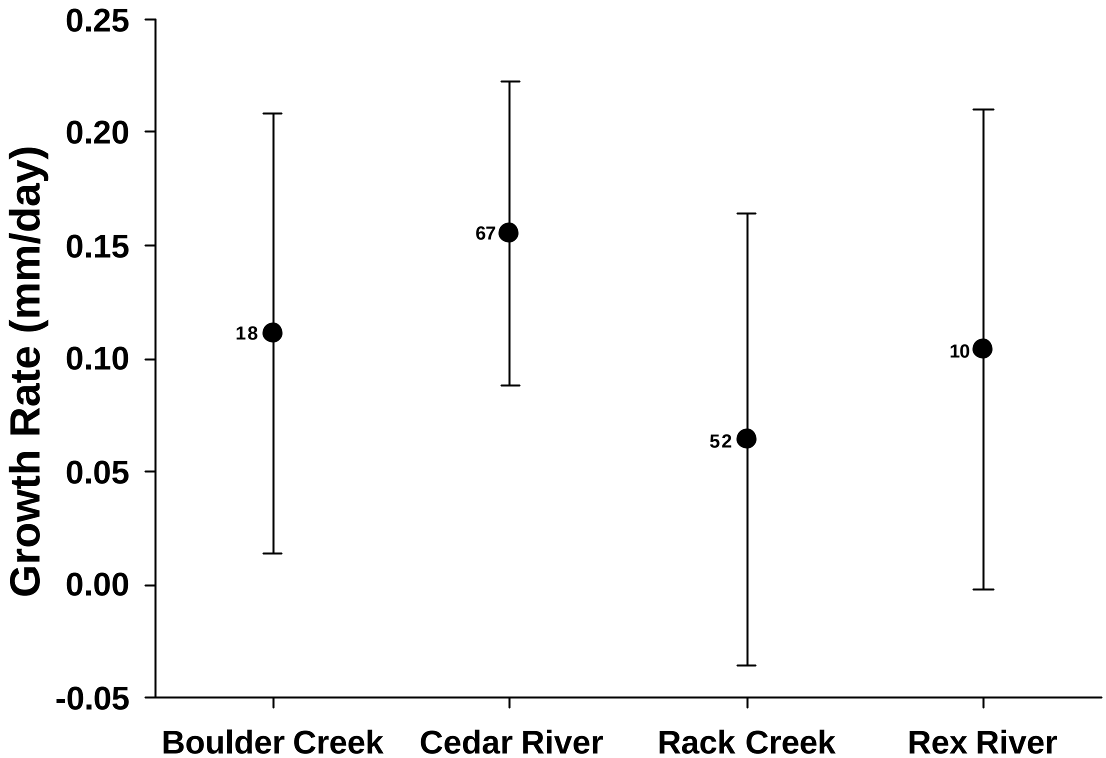

Figure 15.—Mean (and SD) instantaneous growth rates of bull trout in four streams of the Cedar River Municipal Watershed, 2006 and 2007. Data were derived from PIT-tagged fish that were marked and recaptured between 1 June and 30 September each year.

4.7 Environmental variables—water temperature, stream flow, and lake elevation

Water temperatures in Boulder and Rack creeks ranged from about 0°C to a maximum of 15°C (Figure 16). Temperatures were coldest from December through February and warmest during July and August. Summer temperatures in Rack Creek were slightly cooler than those in Boulder Creek. Large portions of the fish-bearing area on these high gradient creeks commonly went dry in the late summer, leaving sections impassable to fish. Water temperatures in Cabin

Creek, a wetland fed system and a tributary of the Rex River, ranged from about 0°C in February to 14°C in July. Temperatures in Eagle Ridge Creek, also a wetland fed stream and a tributary of the Cedar River, were somewhat warmer and ranged from 3.8°C in May to 18.7°C in July (Figure 16). Water temperatures in the Cedar River never exceeded 12°C and were even cooler in one of its floodplain tributaries, FPC-5 (Figure 16).

In 2005, flows in the Cedar River ranged from about 150 – 200 cfs in May and declined to summer baseflow about 30 – 40 cfs during August and September (see Figure 17). From October through December, stream flows were highly variable, ranging from about 60 to almost 1,000 cfs. In 2006, flows ranged from about 300 to almost 2,000 cfs in January and gradually declined to a low of about 90 cfs in April. The spring freshet increased flows up to 1,000 cfs in mid-June before declining to a minimum flow in early October of about 20 cfs. The November floods brought peak flows of nearly 4,300 cfs to the Cedar River. During 2006, there were 10 days in which flows were greater than 1,000 cfs.

Flows in Boulder Creek were less variable than those in the Cedar River (Figure 17). In general, flows were highest in winter and early spring, peaking around 400 cfs in January of 2005 and in late March in 2006. Flows in Boulder Creek were lowest in the summer, sometimes going subsurface (e.g., the summer of 2007). The highest flows recorded during our study were in November 2006 when flood waters increased flows to over 4,000 cfs.

The elevation of CML in 2005 was between 1,560 and 1,563 feet from early May to July (see Figure 18). From early July through September lake elevation showed a steady decline, reaching a low of about 1,550 feet in early October. Thereafter, lake elevation was variable, but continued to decline to about 1,545 feet in mid-December. In 2006, lake elevation at CML ranged from about 1,560 feet in January to 1,550 feet in early April. Spring rains and runoff increased the lake elevation to about 1,564 feet during May and June. Thereafter, lake elevation declined to a low of about 1,547 feet in early November. The heavy rains and flooding in November 2006 raised the lake elevation to almost 1,565 feet. In 2007, lake elevation was between 1,549 to 1,560 feet from January to early May. Like 2006, spring rains and runoff increased the lake elevation to about 1,564 feet during May and June. Thereafter, lake elevation declined to a low of 1,548 feet in mid-November.

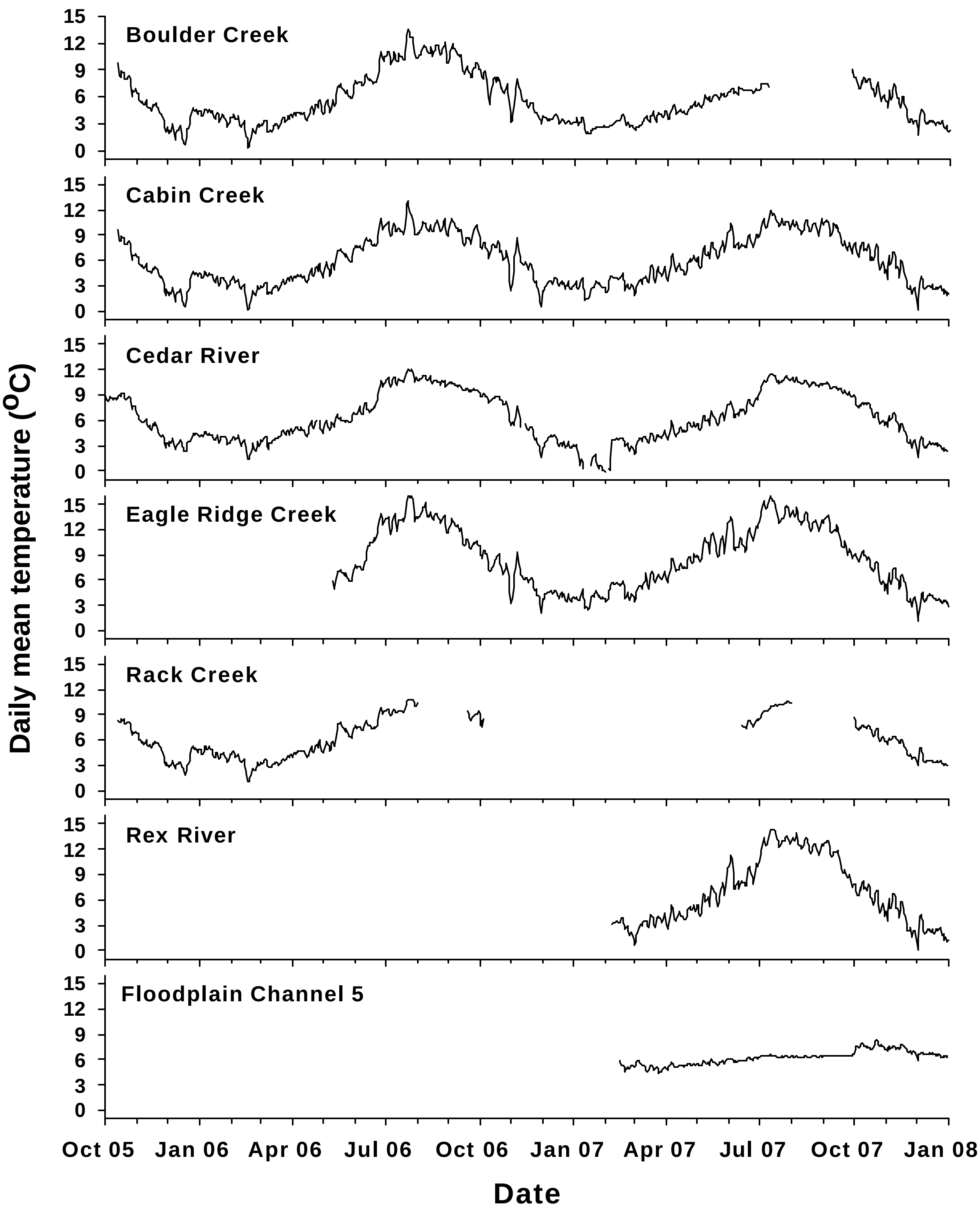

Figure 16.—Water temperature profiles of seven streams in the Cedar River Municipal Watershed, 2005–2007. Missing data indicates when the creeks were partially dry or temperature loggers were lost or not yet in place.

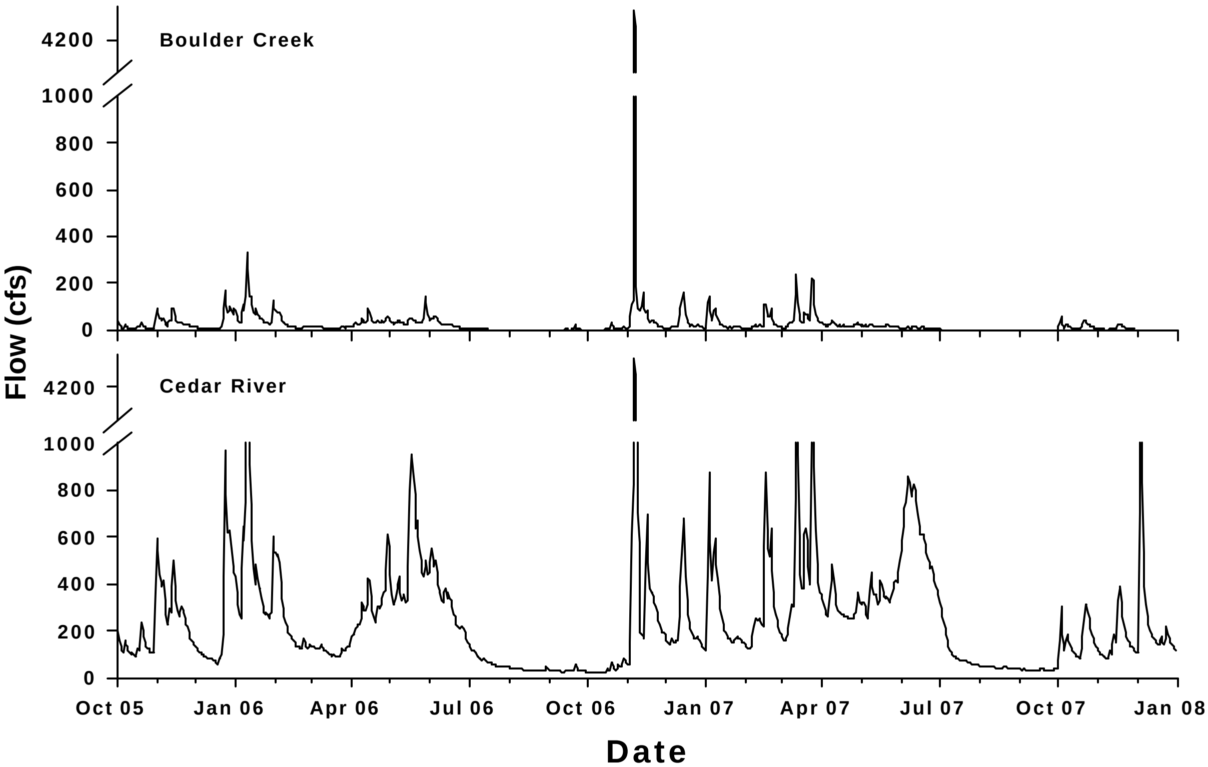

Figure 17.—Stream flow in Boulder Creek (used as a surrogate for Rack Creek) and the Cedar River, Cedar River Municipal Watershed, 2005 – 2007.

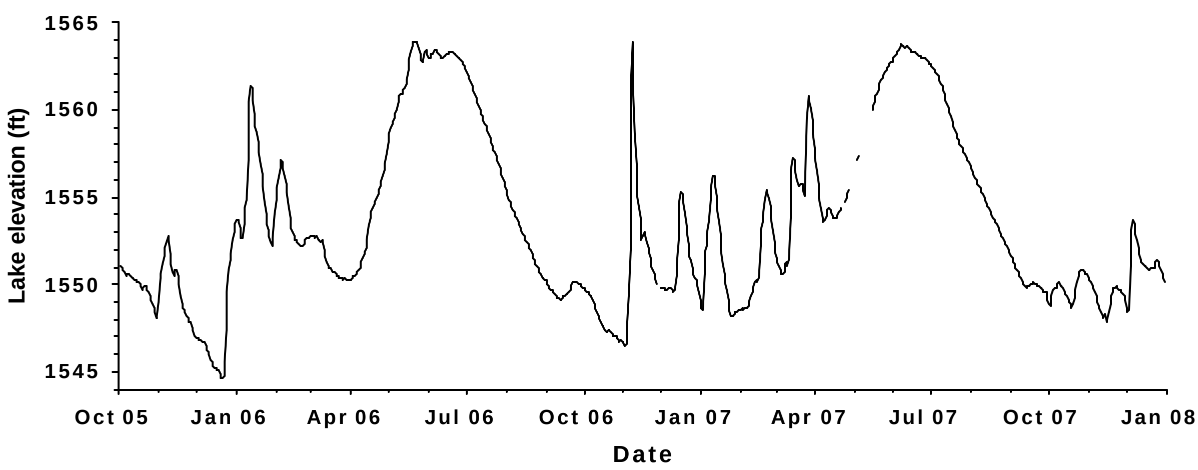

Figure 18.—Elevation of Chester Morse Lake, Cedar River Municipal Watershed, 2005 – 2007.

5.0 Results—rainbow trout

5.1 Capture, marking, and length frequencies of rainbow trout

5.1.1. 2005

In 2005, although sampling was limited (Table 1), we captured, weighed, and measured 497 rainbow bull trout (Table 5). Of these, 198 fish were PIT-tagged (Figure 19). Most (64%)

Table 5.—Number of rainbow trout handled and PIT-tagged in the Cedar River Municipal Watershed, 2005 – 2007.

		Stream system				
Year	Category	Boulder Creek	Cedar River	Rack Creek	Rex River	Total
2005	Handled	320	55	92	30	497
	Tagged	141	19	32	6	198
2006	Handled	468	386	70	470	1394
	Tagged	392	260	36	253	941
2007	Handled	763	571	119	614	2067
	Tagged	378	318	17	335	1048
Total	Handled	1550	1012	281	1114	**3957**
	Tagged	899	597	83	594	**2173**

of the fish were captured in Boulder Creek, with Rack Creek accounting for 19% of the catch, the Cedar River 11%, and the Rex River 6%. These results represent the total catch for 2005 and do not account for the variable level of effort between streams. Results should not be interpreted as differences in fish densities between these streams. Length frequency distributions of fish captured in each stream by month revealed two size classes that were centered around fish of about 60 mm and 110 mm in August (Figure 20; Appendix 3). These fish were presumably age-

0 and age-1. Only two fish died during our minnow trapping efforts (0.4% of the total captured) and no fish died when we sampled with electrofishing.

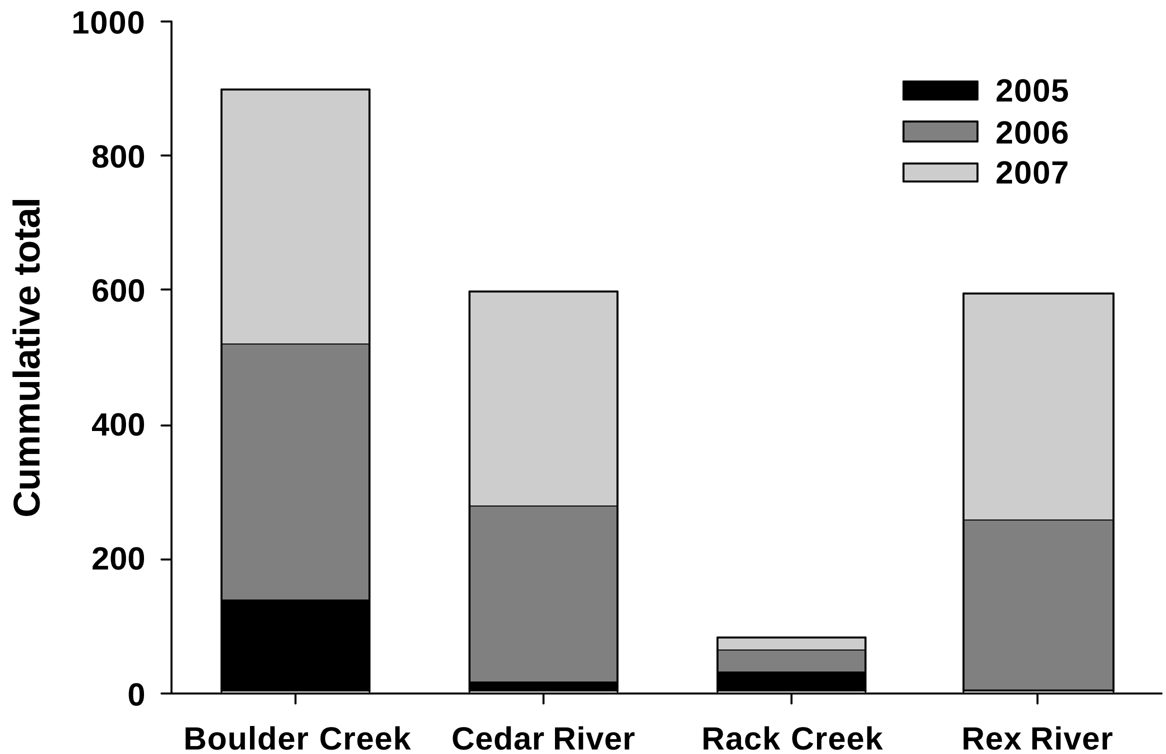

Figure 19.—Cumulative number of rainbow trout that were PIT-tagged in four drainages of the Cedar River Municipal Watershed, 2005 – 2007.

5.1.2. 2006

In 2006, we sampled more stream area (Table 1) and captured, weighed, and measured 1,394 rainbow trout (Table 5). Of these, we PIT-tagged 941 fish (Figure 19) that had a mean (± SD) length and weight of 114 ± 32 mm and 21.7 ± 24 g. This time, the Rex River and Boulder Creek each accounted for about 34% of the fish we caught, followed by the Cedar River (28%) and Rack Creek (5%). Length frequency distributions of fish captured in each stream by month again revealed the presence of two distinct age classes corresponding to age-0 and age-1 fish (Figure 20; Appendix 3).

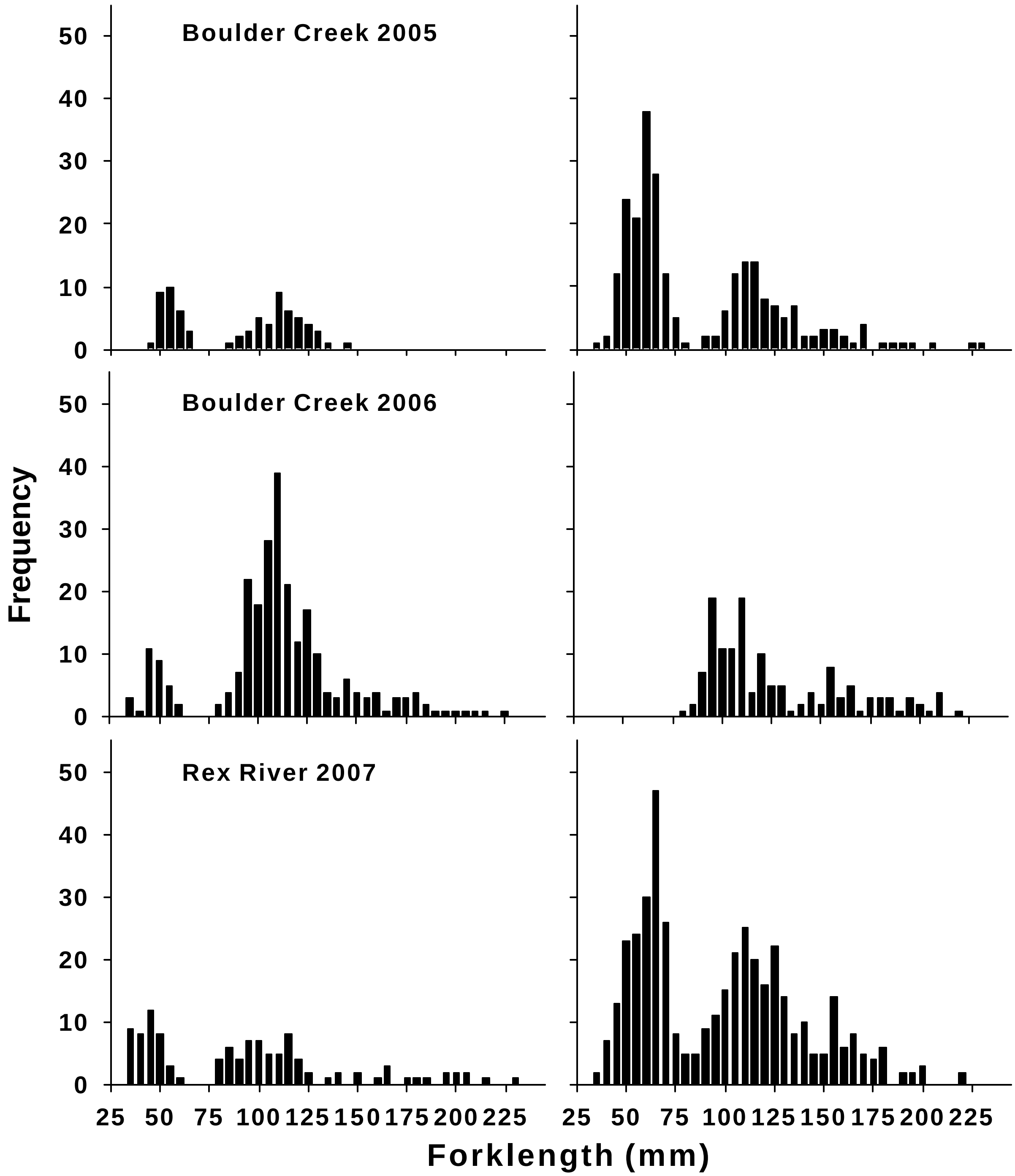

Figure 20.—Examples of length frequency distributions of rainbow trout captured in August (left panels) and September (right panels) in two streams of the Cedar River Municipal Watershed. Complete length frequencies by stream, month, and year are in Appendix 3.

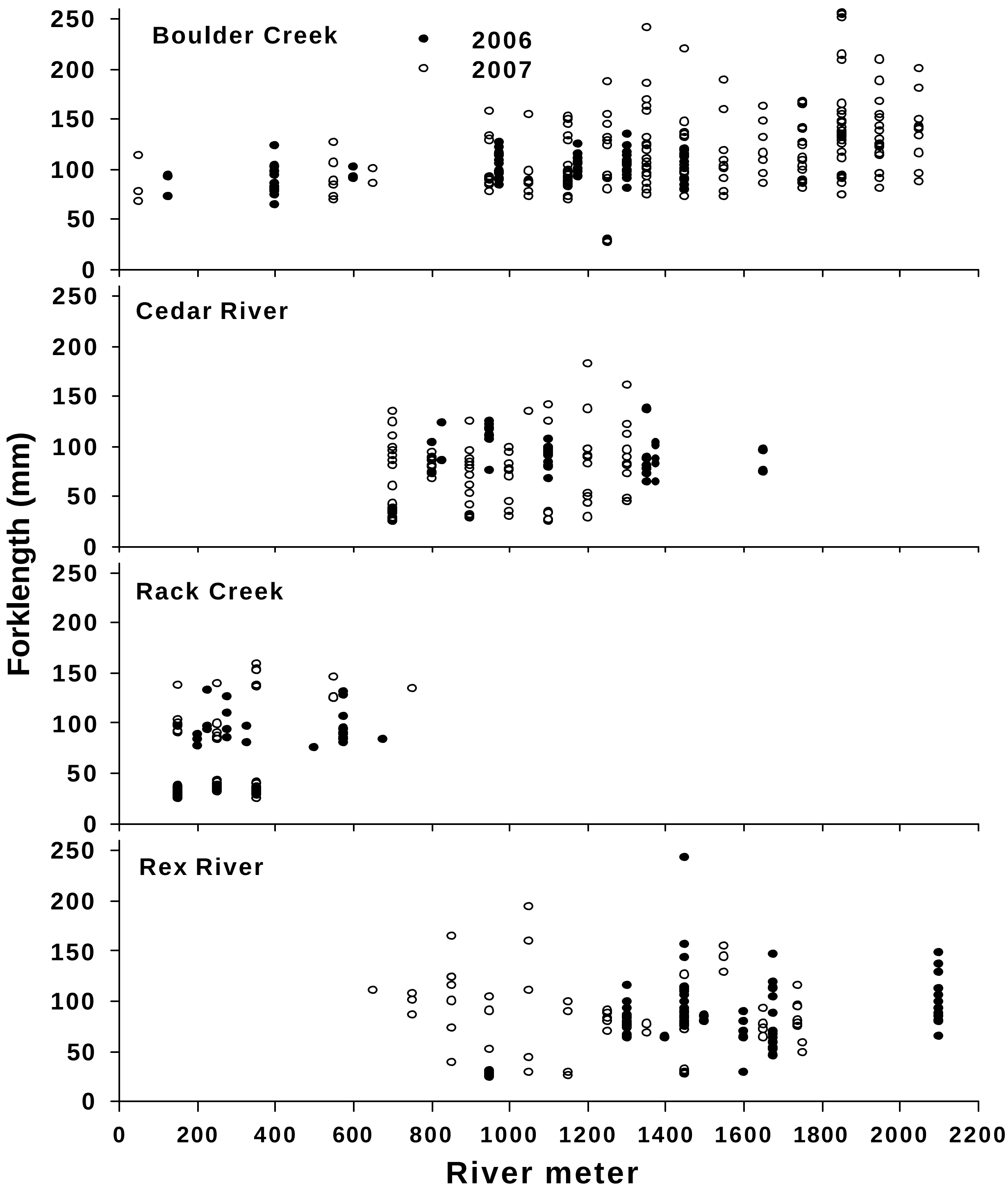

Figure 21.—Length of rainbow trout relative to their location of capture in four streams of the Cedar River Municipal Watershed, 2006 and 2007.

We also captured several fish less than 50 mm and greater than 150 mm, particularly in August and September. There was no relation between length of fish and capture location for the Cedar River, Rack Creek, and the Rex River, but rainbow trout tended to increase in size in an upstream direction in Boulder Creek (Figure 21). Five rainbow trout each died during our minnow trapping and electrofishing efforts, for a total mortality rate of 0.7%.

5.1.3. 2007

In 2007, we sampled more stream area (Table 1) than in 2006 and captured, weighed, and measured 2,067 rainbow trout (Table 5). Of these, we PIT-tagged 1,048 fish (Figure 19) that had a mean (± SD) length and weight of 120 ± 35 mm and 25.7 ± 24 g. Boulder Creek accounted for 37% of the fish we caught, followed by Rex River (30%), Cedar River (28%) and Rack Creek (6%). Length frequency distributions of fish captured in each stream by month revealed the presence of three size classes that corresponded to age-0, age-1, and age-2 fish (Figure 20; Appendix 3). In August, the modal size classes were centered around fish of about 40 mm, 120 mm, and 160 mm (Figure 20). Again, only fish in Boulder Creek tended to increase in size in an upstream direction (Figure 21). No rainbow trout died during our minnow trapping and 12 fish died during electrofishing efforts, for a total mortality rate of 0.6%.

5.2 Interrogations of PIT-tagged rainbow trout

5.2.1. Boulder Creek

From October 2005, through 31 December 2007, the Boulder Creek system detected 224 unique rainbow trout, or about 25% of the total number of fish tagged in this creek. Over 99% of these detections were from fish tagged in Boulder Creek.

5.2.2. Cedar River

From August 2006, through 31 December 2007, this system detected 33 unique rainbow trout, or about 6% of the total tagged in this river. Most of these fish were tagged in the Cedar River, but a few were also detected moving upstream that came from other tributaries (see section 5.5).

5.2.3. Rack Creek

During the same period mentioned for Boulder Creek, the Rack Creek system detected 16 individual rainbow trout, all of which were tagged in Rack Creek. This represented about 19% of the total number of rainbow trout tagged in this creek.

5.3 Movements of rainbow trout via PIT-tag interrogations

5.3.1. Boulder Creek

Of the 224 rainbow trout detected at the interrogation site, we recorded 35 upstream and 217 downstream movements. Some individuals had more than one movement event recorded. In 2006, fish showed consistent downstream movements from about April through mid-September (Figure 22). A pulse of downstream movement occurred during October and early November, 2006, prior to the flood. Over 35% of the fish that moved downstream did so during this time. In 2007, a few fish moved downstream consistently from January to early July, when the creek went dry in the lower section (Figure 22). After the creek had surface flows restored, sometime in late September, a large pulse of fish emigrated downstream (Figure 22). Most of the fish that emigrated were greater than 80 mm and ranged up 220 mm, indicating that they were primarily age-1 and age-2 fish (Figure 23). The mean (SD) length of fish that moved downstream within three months prior to detection was 117.4 (29.9; N = 72) mm. The percentage of fish that emigrated was strongly related to their tagging location (Figure 24), indicating that the further upstream a fish was tagged, the less likely it was to emigrate.

5.3.2. The Cedar River system

Of the 33 PIT-tagged rainbow trout detected in the Cedar River, 21 were moving downstream and seven upstream. Most of these movements occurred in 2007 (Figure 25). Because so few fish were detected at the Cedar River site, definitive trends in movement were not evident. Most fish moved downstream after August and again were usually greater than 80 mm (Figure 23). Two fish that moved upstream were tagged in Boulder Creek and Morse Creek (see next section). There was no relation between the propensity to emigrate and initial capture location (Figure 24). Although some fish tagged as far as 8,200 m upstream from CML were detected moving downstream, others that were tagged at least 13,000 m from CML were never detected.

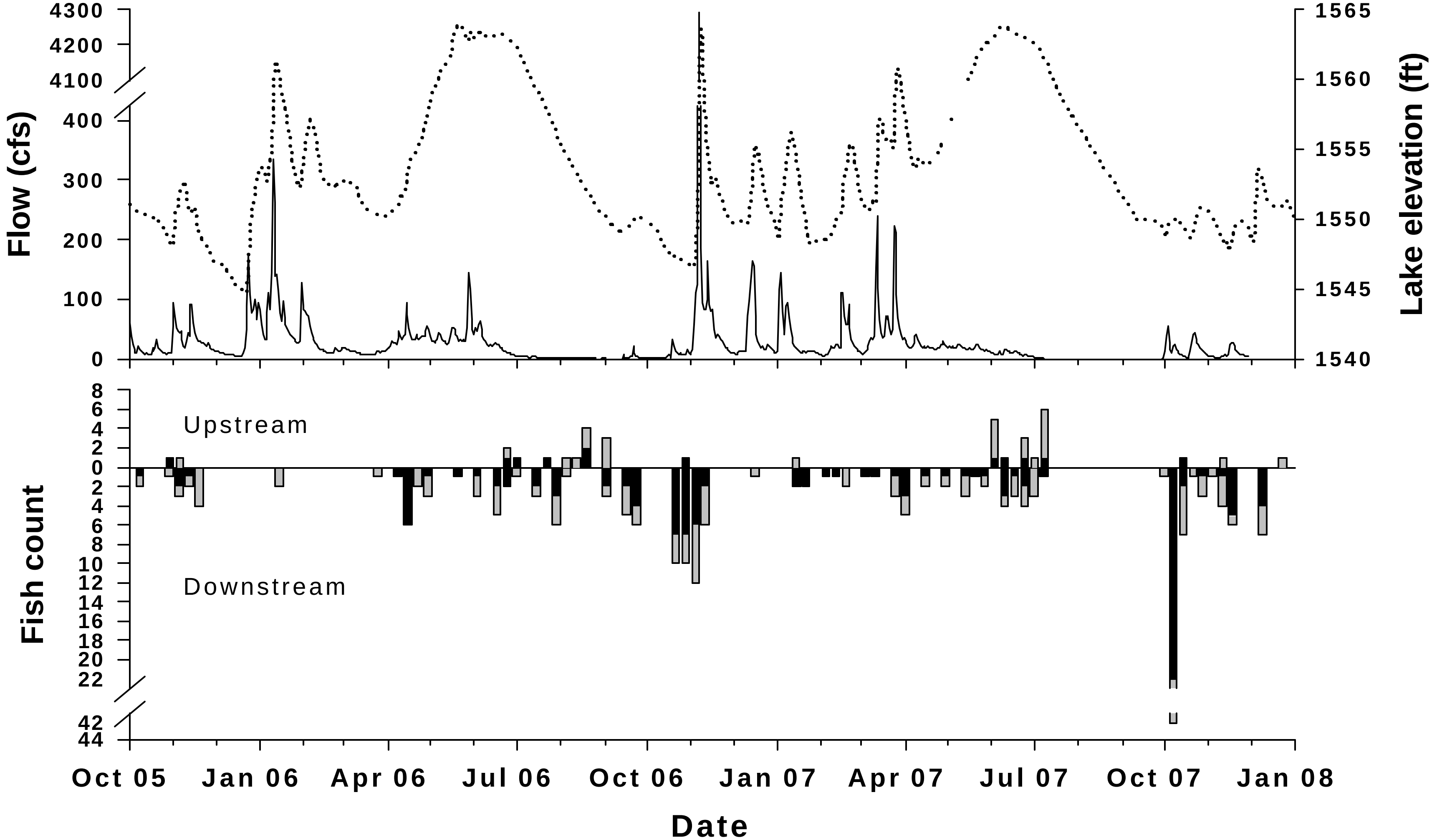

Figure 22.—Number of rainbow trout that moved up or downstream in Boulder Creek (lower panel), stream flow in Boulder Creek (solid line, upper panel), and elevation of Chester Morse Lake (dashed line, upper panel) in the Cedar River Municipal Watershed, 2005 – 2007. Thick, horizontal black lines denote periods when the PIT tag interrogation system was not operating. Bins are one week.

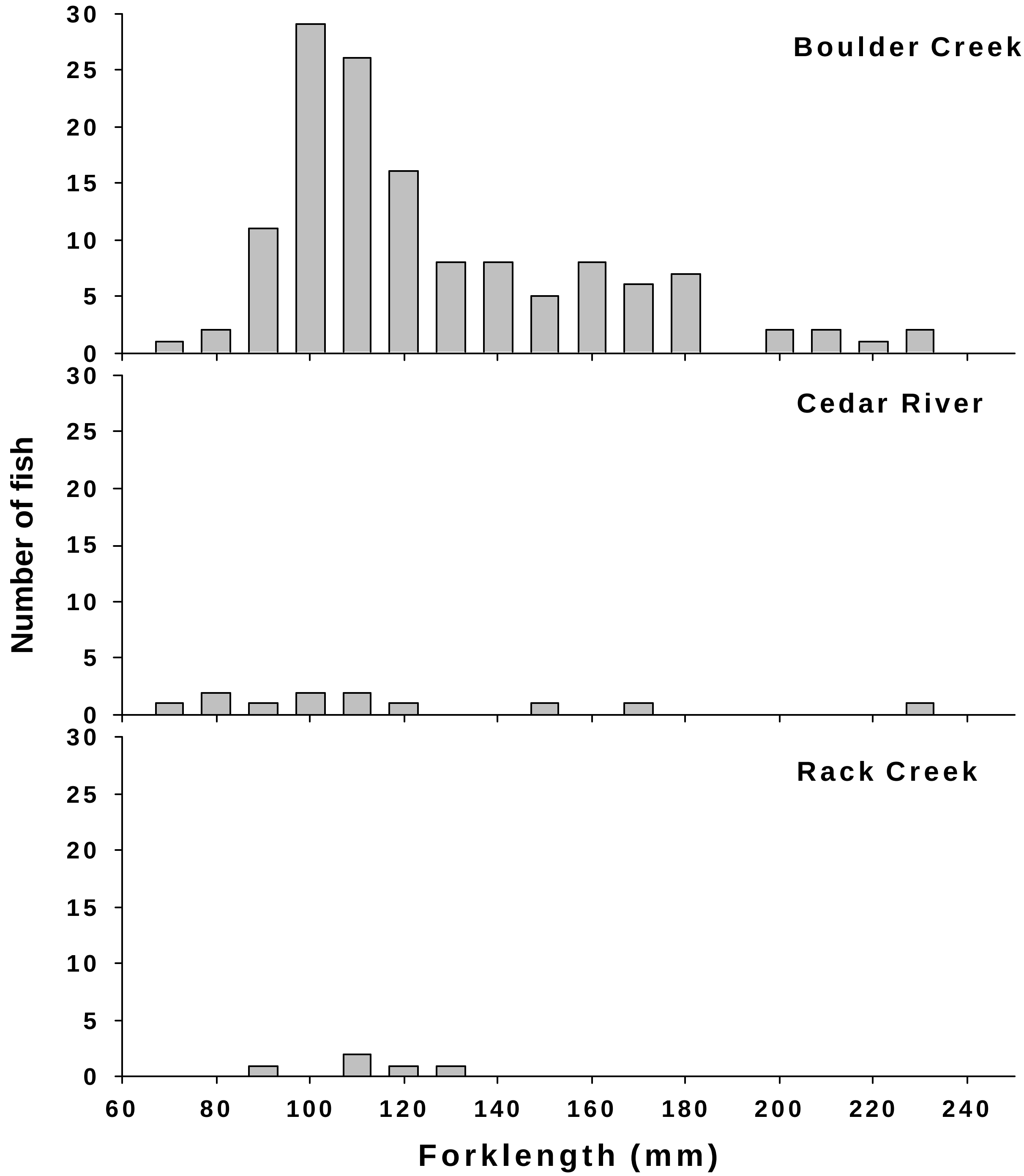

Figure 23.—Number of rainbow trout that emigrated from three streams in the Cedar River Municipal Watershed relative to their length at tagging, 2005 – 2007.

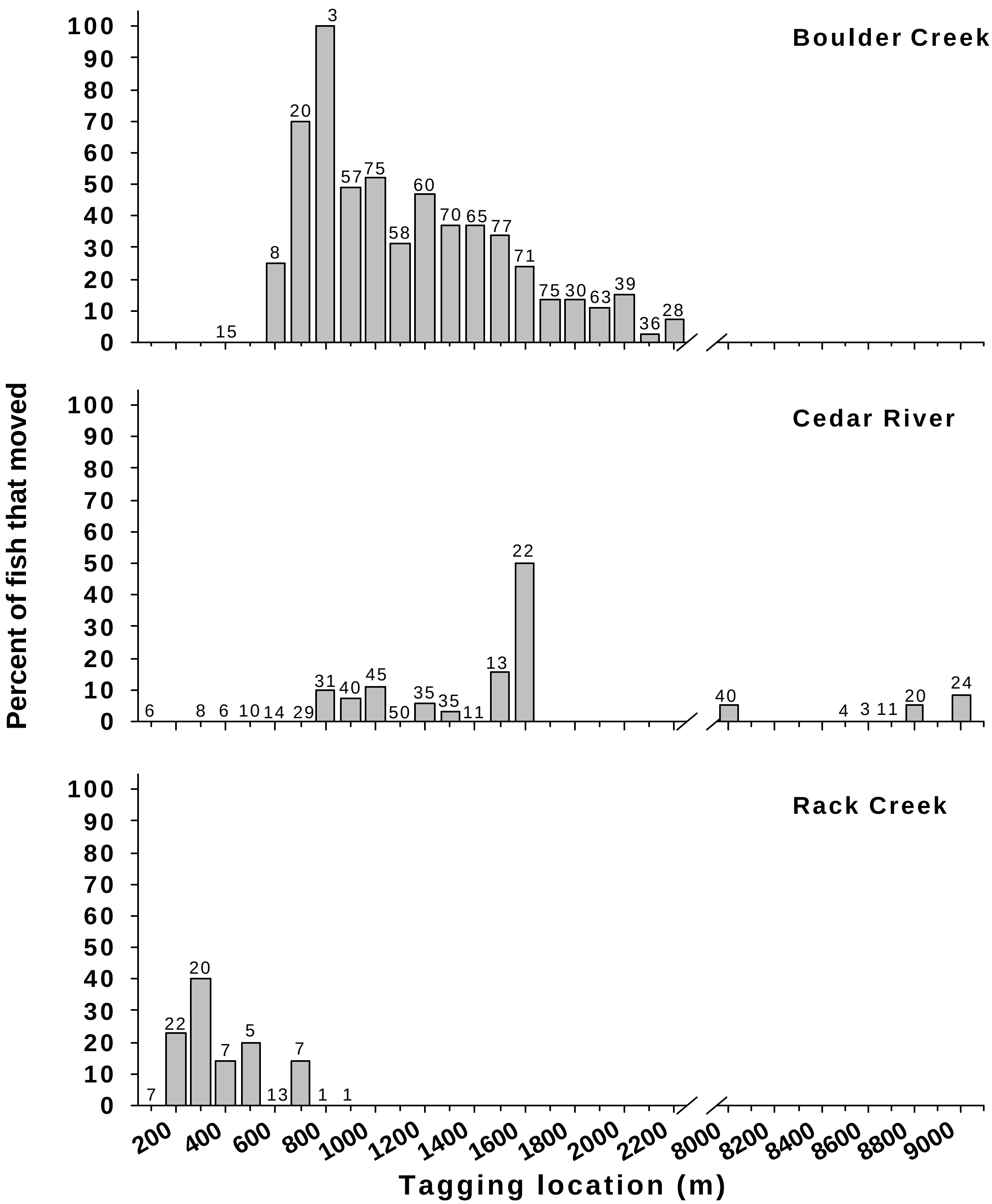

Figure 24.—Percent of rainbow trout that emigrated relative to their tagging location in three streams of the Cedar River Municipal Watershed, 2005 – 2007. Numbers above each bar are the total number of fish tagged in that section. No fish were sampled above 1000 m in Rack Creek because of a fish barrier.

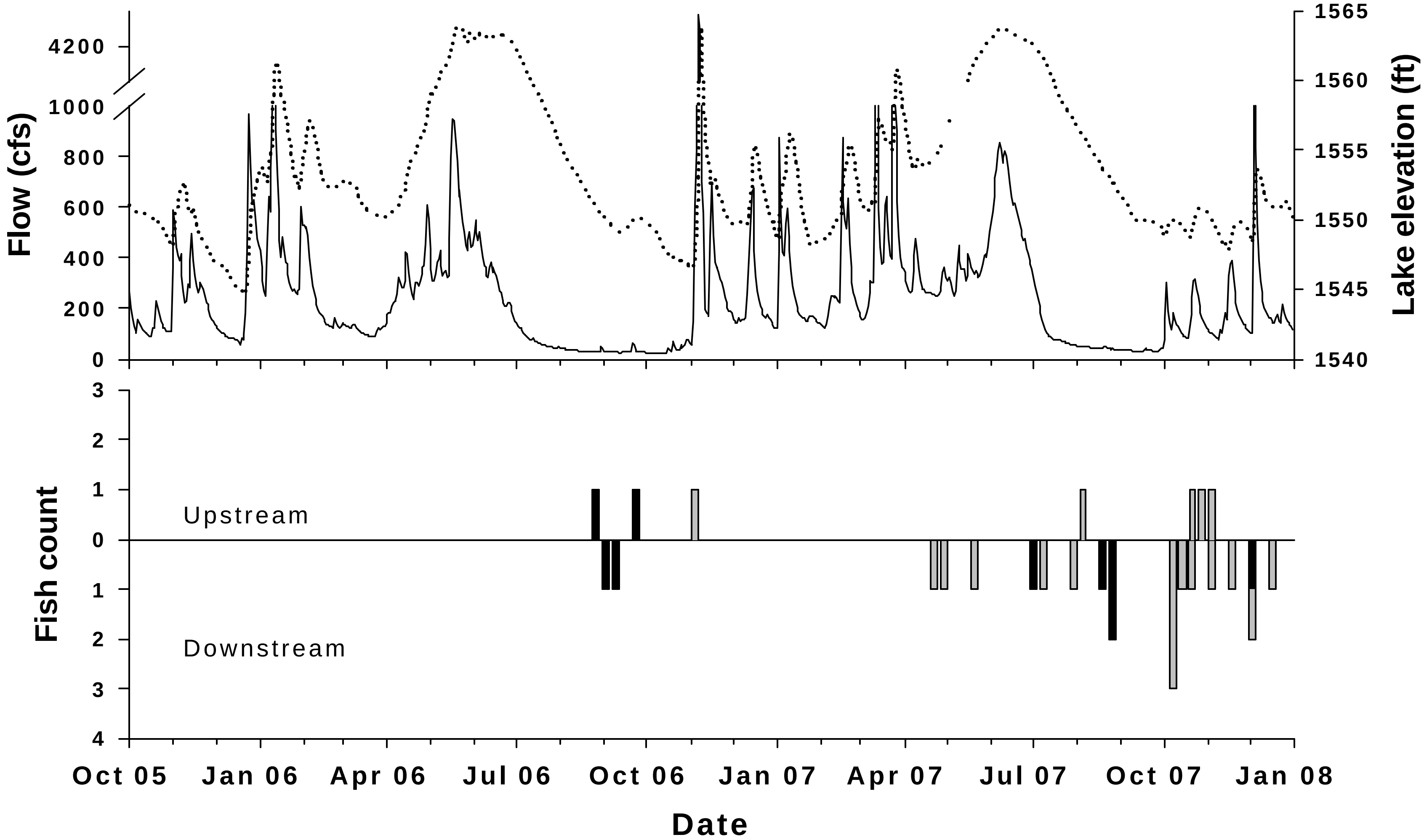

Figure 25.—Number of rainbow trout that moved up or downstream in the Cedar River (lower panel), stream flow in the Cedar River (solid line, upper panel), and elevation of Chester Morse Lake (dashed line, upper panel) in the Cedar River Municipal Watershed, 2005 – 2007. Thick, horizontal black lines denote periods when the PIT tag interrogation system was not operating. Bins are one week.

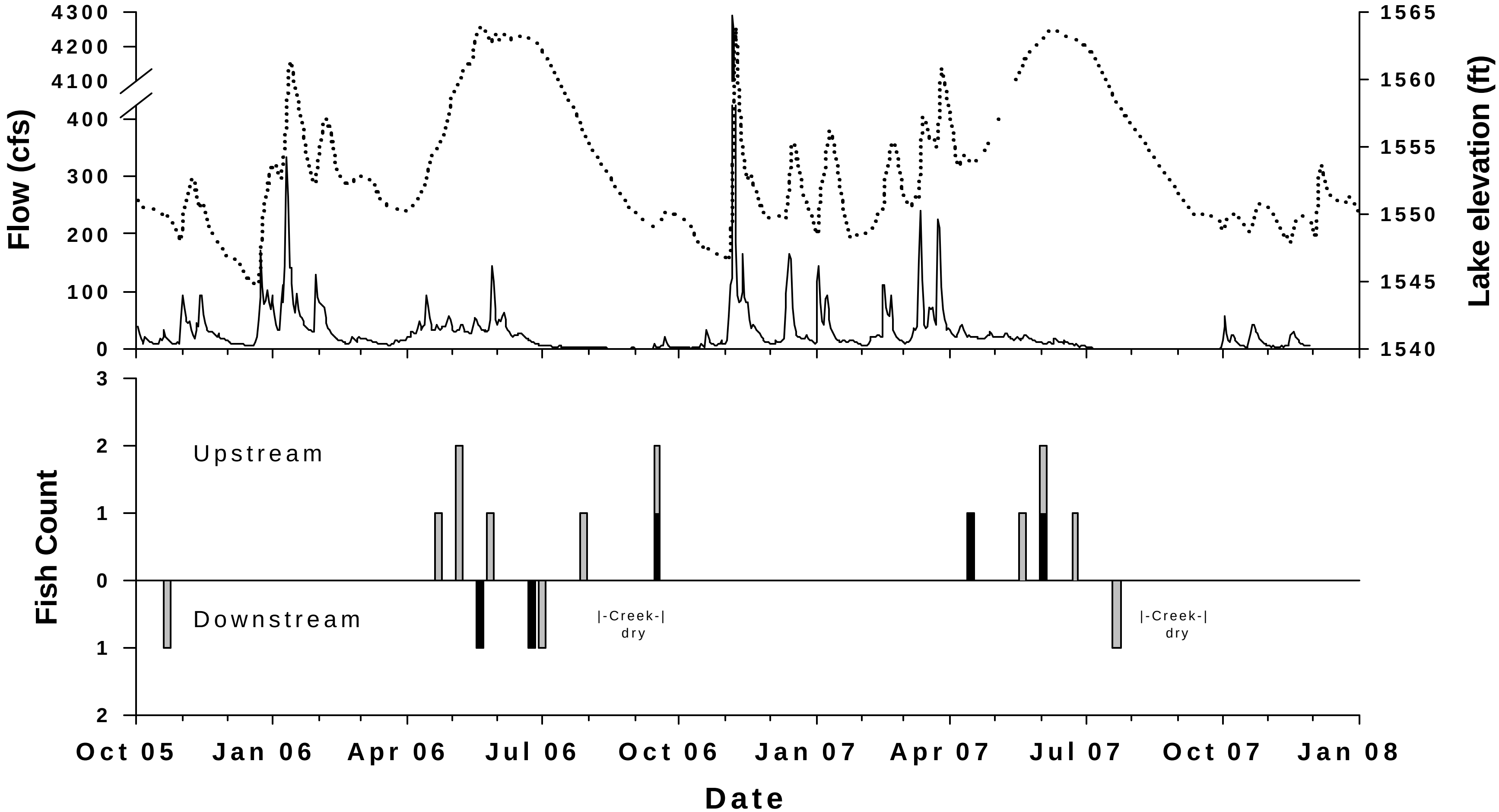

Figure 26.—Number of rainbow trout that moved up or downstream in Rack Creek (lower panel), stream flow in Boulder Creek (used as a surrogate for Rack Creek, solid line, upper panel), and elevation of Chester Morse Lake (dashed line, upper panel) in the Cedar River Municipal Watershed, 2005 – 2007. Thick, horizontal black lines denote periods when the PIT tag interrogation system was not operating. Bins are one week

5.3.3. Rack Creek

Of the 16 PIT-tagged rainbow trout detected by the interrogation system, 12 were moving upstream and five were moving downstream (Figure 26). Because so few fish were detected, no discernable trends in fish movement were apparent. All movements occurred from the spring to early autumn. Again, fish that moved were greater than 80 mm (Figure 23) and there was no relation between propensity to move and initial tagging location (Figure 24).

5.4 Movements of rainbow trout via recaptures of PIT-tagged fish

From all streams, we recaptured 320 rainbow trout that were PIT-tagged in 2005-2007. Twenty three fish were recaptured in Rack Creek, 25 in the Cedar River, 223 in Boulder Creek, and 49 in the Rex River. Only one rainbow trout was recaptured outside the stream in which it was initially tagged, this being a fish that was tagged in Cabin Creek and recaptured in Rack Creek. Most fish showed local, intra-stream movements of less than 200 m. In the Cedar River system, the only tributary to mainstem movements we observed were from three fish that were tagged in FPC-5 and recaptured in the Cedar River.

5.5 Movements of rainbow trout in the reservoir

There were five rainbow trout that moved downstream from tributaries, into CML, through the lake, and then upstream to the Cedar River PIT tag interrogation system (Table 6). Four of these fish came from the Rex River system and had from six months to more than a year elapse between their tagging and interrogation dates. One rainbow trout from Boulder Creek was tagged on 29 August 2006 and was detected on the Cedar River system about a month later. It had traveled an estimated linear distance of about 9 km during this time.

Like bull trout, some rainbow trout moved downstream from tributaries, possibly entered CML, and returned to the same stream (Table 7). Most of these fish originated from Boulder Creek. Again, we cannot say unequivocally that these fish actually entered the reservoir because they could have simply resided below the detector for a time, but those fish with a long time between interrogation events were most likely to enter CML.

Table 6.—Location, date, and size at tagging and subsequent interrogation of rainbow trout that traversed Chester Morse Lake in the Cedar River Municipal Watershed, 2005-07.

Tagging location	Date tagged	Fork length (mm)	Date interrogated	Location interrogated
Morse Creek	5.15.06	89	11.1.06	Cedar River
Rex River	7.20.06	156	7.18.07	Cedar River
Boulder Creek	8.29.06	224	9.16.06	Boulder Cr.
			9.23.06	Cedar River
Rex River	9.27.06	98	10.24.07	Cedar River
Rex River	9.28.06	174	7.30.07	Cedar River

5.6 Growth of rainbow trout

5.6.1. Annual growth of rainbow trout in Boulder Creek

Based on our analysis of length frequency distributions, rainbow trout in Boulder Creek grew about 50 – 60 mm from age-0 to age-1 (Appendix 3). In total, we recaptured 226 PIT-tagged rainbow trout from Boulder Creek—9 in 2005, 52 in 2006 and 240 in 2007. The growth trajectories of these fish are shown in Appendix 3. Several fish were age-0 when they were tagged and had about a year elapse between mark and recapture. The growth rates of these fish generally validated the growth we estimated from the length frequency distributions. Recaptured PIT-tagged fish grew about 48 ± 14 mm and 33 ± 15 g per year.

5.6.2. Growth of rainbow trout in the Cedar River

Like fish from Boulder Creek, length frequency distributions from August and September 2006 and 2007, indicated that fish from the Cedar River grew about 50 – 60 mm from age-0 to age-1 (see Appendix 3). We recaptured 25 PIT-tagged rainbow trout from the Cedar River—none in 2005, 9 in 2006 and 18 in 2007 (Appendix 3). Six of these fish were recaptured about a year after tagging and three of them were of a size at tagging indicative of age-0 fish. The growth rates of these fish ranged from about 30 – 40 mm per year, which was lower than rates derived from our analysis of length frequencies.

Table 7.—Location, date, and size at tagging and subsequent recapture or interrogation date of rainbow trout that potentially entered Chester Morse Lake in the Cedar River Municipal Watershed, 2005-07.

Tagging location	Dated tagged	Fork length (mm)	Date downstream movement	Date upstream movement	Elapsed time (d)
Boulder Creek	8.25.05	120	4.29.06	6.24.06	56
Boulder Creek	8.25.05	102	11.2.05	6.23.06	233
Rack Creek	8.30.05	132	7.25.06	4.13.07	262
Boulder Creek	9.21.05	136	8.7.06	8.27.06	20
Boulder Creek	9.26.05	135	4.9.06	8.31.06	144
Boulder Creek	9.28.05	120	6.29.06	9.14.06	77
Boulder Creek	7.24.06	90	10.19.06	6.21.07	245
Boulder Creek	8.29.06	93	1.13.07	5.31.07	138
Boulder Creek	8.29.06	125	11.4.06	1.14.07	71
Boulder Creek	8.31.06	104	2.17.07	7.6.07	139
Boulder Creek	8.31.06	96	1.17.07	6.3.07	137
Boulder Creek	8.14.07	158	10.2.07	11.9.07	38
Boulder Creek	9.19.07	170	11.10.07	12.20.07	40

5.6.3. Growth of rainbow trout in Rack Creek

Although we captured few rainbow trout in Rack Creek, an analysis of length frequencies indicated that fish grew about 55 mm from age-0 to age-1 (Appendix 3). We recaptured 23 PIT-tagged rainbow trout from Rack Creek. There were 8 recapture events in 2005, 11 in 2006 and 10 in 2007 (Appendix 4). A few age-0 fish were recaptured about a year after tagging and their growth rates were somewhat lower than those estimated from the length frequency distributions.

5.6.4. Growth of rainbow trout in the Rex River

Based on analysis of length frequencies, growth of age-0 rainbow trout in the Rex River was similar to fish in other streams (Appendix 3), averaging about 50 mm per year. We recaptured 49 fish from Cabin Creek and the mainstem Rex River—13 in 2006 and 41 in 2007 (some fish were recaptured more than once; Appendix 3). Although only a few fish were recaptured about a year after tagging, their growth rates were similar to those estimated from the length frequencies (data not shown).

5.6.5. Seasonal growth of rainbow trout in the CRMW

In 2006 and 2007, the growth rates of rainbow trout from June through September ranged from 0.07 to 0.18 mm per day and differed significantly between fish in different streams (F = 4.8, $P < 0.003$; Figure 27). Post-hoc tests revealed that growth of fish in Boulder Creek was significantly lower than that of fish in the Cedar and Rex rivers.

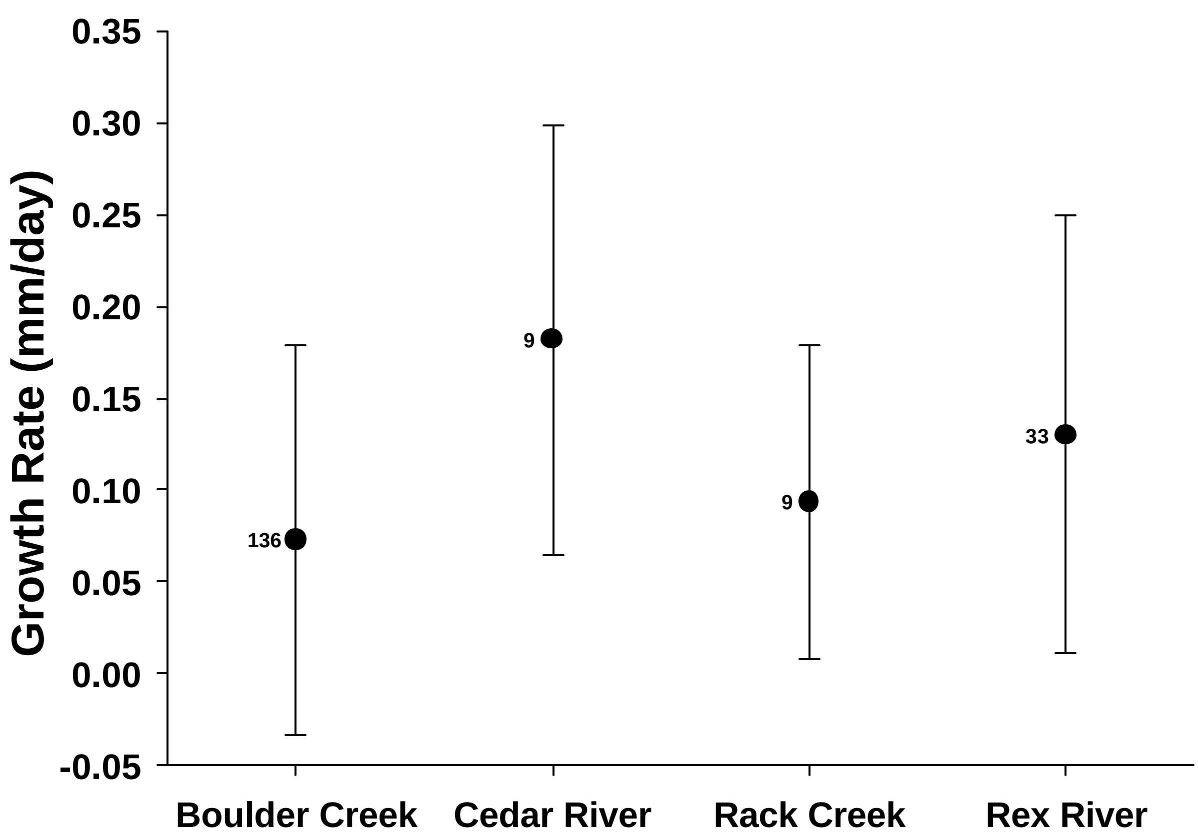

Figure 27.—Mean (and SD) instantaneous growth rates of rainbow trout in four streams of the Cedar River Municipal Watershed, 2006 and 2007. Data were derived from PIT-tagged fish that were marked and recaptured between 1 June and 30 September each year.

5.7 Summary comparison of juvenile bull trout and rainbow trout sample, growth, and behavioral characteristics

During the study, we tagged slightly more rainbow trout than bull trout in the CRMW, and the proportion of tagged fish by species differed greatly in each stream system (Table 8). Boulder Creek provided over 40% of the total rainbow trout tagged in the study, while less than 4% of rainbow trout tagged were from Rack Creek. Intermediate levels (27%) of rainbow trout were tagged in the Cedar and Rex rivers. In contrast, the majority of bull trout (51%) were tagged in the Cedar River, followed by 21% of the total tagged in Rack Creek (Table 8). The Rex River and Boulder Creek, where higher numbers of rainbow trout were captured, had the lowest numbers of bull trout tagged, comprising 17% and 11% of the total (Table 8).

The proportion of tagged fish that were recaptured or interrogated varied by stream and species (Table 8). In Boulder Creek, the proportion of tagged fish that were recaptured or interrogated was similar between species, ranging from 20 – 25%. In the Cedar River, the proportion of bull trout that were recaptured or interrogated was almost 3 – 4 times higher than values for rainbow trout. Bull trout and rainbow trout in Rack Creek, like those in Boulder Creek, were recaptured or interrogated at similar rates, which ranged from 19 – 29%. Finally, because we had no PIT tag interrogation system on the Rex River, no fish were interrogated. However, we did recapture equal proportions of each species in the Rex River.

The highest relative density of bull trout in both 2006 and 2007 was in Rack Creek while the highest density of rainbow trout occurred in Boulder Creek (Table 8). Bull trout had higher relative densities in the Cedar River when compared to rainbow trout, while in the Rex River, rainbow trout were found in higher relative densities than bull trout. Both species showed low annual variation in relative density within any stream (Table 8). The Cedar and Rex river systems have much wider mainstem channels, deeper pools, and more challenging habitat to sample than either Rack or Boulder creeks so comparisons of relative density between fish in these streams is unwarranted.

Data from our PIT tag interrogation sites indicated that downstream movements by bull trout in all streams occurred from May to November, with the majority occurring during autumn (Table 8). The only significant movement data we obtained for rainbow trout came from Boulder Creek. In this stream, most rainbow trout moved downstream from September to December, which is similar to the autumn movements of bull trout. There was insufficient data from PIT tag interrogation sites at the Cedar River or Rack Creek to describe the movements of rainbow trout definitively.

Bull trout making downstream movements ranged from 120 – 132 mm in length (Table 8). The smallest came from Rack Creek, while the largest were from the Cedar River and associated floodplain channels. Fish in this size range were probably age-1 fish that were moving downstream at the end of their second year of stream residence. In Boulder Creek, the mean fork length of rainbow trout moving downstream was about 117 mm, which was slightly smaller than the sizes of emigrating bull trout but also indicative of age-1 fish.

Finally, the annual growth rates of bull trout and rainbow trout were generally similar and varied little by stream (Table 8). Although the annual rate of growth for bull trout in all streams ranged from 20 – 60 mm, most fish grew from 40 – 60 mm per year. Rainbow trout showed less variation in annual growth and ranged from 50 – 60 mm. Growth rates of bull trout were lowest for fish in the Rex River system, including Cabin and Morse creeks.

Table 8.—Summary of various sampling, movement, and growth metrics for bull trout and rainbow trout in the four streams of the Cedar River Municipal Watershed, 2006 – 2007. For the metrics, *recaptured* = the percentage of PIT-tagged fish that were recaptured to hand; *interrogated* = the percentage of PIT-tagged fish that were logged on a detection system; *density* = relative density based on CPUE and stream area sampled (fish/100m^2); *downstream movement* = the range of months when fish were detected on interrogation systems; *length* = the mean fork length (mm) of fish during the time of downstream migration; and *annual growth rate* is the range of change in length over one year (mm). Two values in a row represent separate estimates from 2006 and 2007.

Stream and Metric	Bull trout	Rainbow trout
Boulder Creek		
No. PIT-tagged	177	899
Recaptured (%)	20	25
Interrogated (%)	25	25
Density	0.70, 0.57	3.46, 2.68
Downstream movement	July – Nov, Oct – Nov	Oct – Nov, Sep – Dec
Length	130.4	117.4
Annual growth rate	50-60	50-60

Cedar River[a]		
No. PIT-tagged	845	597
Recaptured (%)	11	4
Interrogated (%)	21	6
Density[c]	1.18, 1.26	0.45, 0.31
Downstream movement	Aug – Nov, Aug – Nov	N A
Length	131.8	N A
Annual growth rate	40-50	50-60
Rack Creek		
No. PIT-tagged	344	83
Recaptured (%)	29	28
Interrogated (%)	27	19
Density	5.16, 5.56	0.21, 0.16
Downstream movement	May – Oct, July – Nov	N A
Length	120.0	N A
Annual growth rate	40-50	55
Rex River[b]		
No. PIT-tagged	288	594
Recaptured (%)	8	8
Interrogated (%)	N A	N A
Density[c]	0.36, 0.29	1.36, 0.96
Downstream movement	N A	N A
Length	N A	N A
Annual growth rate	20-40	50

[a]Cedar River includes Eagle Ridge Creek, FPC-3, FPC-4, and FPC-5.

[b]Rex River includes Morse and Cabin creeks.

[c]Cedar River and Rex River relative density values represent only mainstem habitat, not floodplain channels or tributary streams.

6.0 Discussion

Previous research on bull trout in the CRMW focused on a variety of topics, including spawning habitats and redd characteristics, fry outmigrations, age class structure, abundance and distribution, diet, and habitat requirements (Reiser et al. 1997; Connor et al. 1997). Information from these studies helped develop a long-term management plan under the HCP for conserving the bull trout population in the CRMW. Our three-year study continued along these lines by addressing the movements, distribution, and growth of juvenile bull trout in major tributaries of CML. Unique to our work was the use of PIT tag technology, which has only recently been developed for use in streams and had not been used previously in the CRMW. Further, our work included rainbow trout to provide an understanding of the ecology of these fish relative to bull trout. Collectively, our results have provided new insight into the ecology and biology of juvenile fish rearing in streams of the upper CRMW that should prove especially useful in developing future management strategies for maintaining healthy fish populations in the reservoir system and its major tributaries within the CRMW.

General catch information and population characteristics

During two and a half years of sampling with two gear types in four major tributaries of CML, we captured over 1,600 juvenile bull trout and 2,200 juvenile rainbow trout. The only other fish species we captured was shorthead sculpin, although spawning pygmy whitefish were observed in the lower reaches of the Cedar River and sampled there as part of a separate, concurrent SPU study. This was the most extensive study of juvenile salmonids yet completed in the CRMW, and it revealed some interesting trends in species numerical dominance and size distributions of fish among the selected streams. Although our study was not designed to estimate fish densities, we used our catch information and habitat information from previous SPU stream surveys to derive relative estimates of fish density in each stream. For bull trout, relative density in Rack Creek was 10 – 12-fold higher than that in the Rex River and Boulder Creek, and for rainbow trout, relative density in Boulder Creek was up to 10-fold higher than that in Rack Creek. These intraspecific differences in relative density of fish in each stream represent the extremes and perhaps warrant further investigation to elucidate causal mechanisms.

We found clear interspecific numerical dominance of bull trout in Rack Creek and dominance of rainbow trout in Boulder Creek. The simplest explanation for the numerical dominance of one species over another in Rack and Boulder creeks may be the relative abundance of preferred or suitable habitat for either bull or rainbow trout. For example, Rack Creek has an abundance of cobble and boulder substrates with interstitial spaces for cover and a relatively cool temperature regime, which is characteristic of good bull trout habitat in other streams (Fraley and Shepard 1989; Rieman et al. 2007). Both streams, however, have habitat that is suitable for either species and the numerical dominance of one species over another is probably a complex phenomenon not easily explained by abiotic factors alone. Previous surveys by SPU indicate that spawning by bull trout is common in Rack Creek at low densities relative to other streams, but spawning is rarely observed in Boulder Creek except in the first 100 m upstream of the Rex River. Thus, more spawning activity and greater spawning success by bull trout would sustain a greater abundance of bull trout over time, leaving rainbow trout little opportunity to establish a population of any significance. The inability of rainbow trout to increase their population size could be due to interspecific interactions, such as predation, and may be an example of biotic resistance exerted by bull trout (sensu Elton 1958). Predation-mediated biotic resistance, which can contribute to invasion or colonization resistance (Harvey et al. 2004; Ward et al. 2008), seems probable given the highly piscivorous nature of bull trout. Similar mechanisms may be contributing to the situation in Boulder Creek, but more research is needed to obtain definitive answers. We did not collect any diet information on fish, but often found bull trout with full, bulging stomachs during times of the year when small (<30mm) rainbow trout were abundant (e.g., Rack Creek; see Appendix 1).

Length-frequency distributions of bull trout in streams of the CRMW were similar and dominated by the presence of age-0 and age-1 fish, which is indicative of healthy populations with good potential for growth. The mean length at age for these fish was about 70 and 120 mm, which is similar to fish in other basins such as the Flathead River (Fraley and Shepard 1989), Metolius River (Ratliff 1992), Kananaskis Lake in Alberta, Canada (Stelfox 1997), and the Jarbidge River, Nevada (M. G. Mesa and P. J. Connolly, unpublished data). We rarely caught fish less than 50 mm or greater than 200 mm, and we noted that the number of age-1 fish generally decreased as fall approached. The lack of very small (e.g., 30 mm) age-0 fish in our catches probably reflects the low vulnerability of this age group to our sampling gear (especially during the high flow and cool temperature conditions when these fish are present) or emigration to the lake, and not poor hatching success or low survival. Indeed, for a given voltage gradient, small fish are less vulnerable to electrofishing than larger fish, they are less visible to netters than large ones, and their small body size facilitates hiding in crevices and small areas (Reynolds 1983). Emigration of small age-0 bull trout has been documented in several watersheds, including the Arrow Lakes in British Columbia (McPhail and Murray 1979), Trestle Creek in Idaho (Downs et al. 2006), and the CRMW (Reiser et al. 1997). In all of these studies, the emigration of these small fish occurred in the spring and sometimes under conditions of high flows and increasing temperatures (e.g., Downs et al. 2006), which begs the question of whether such migrations are intended or inadvertent. Whether the migration of very small age-0 fish is a natural attribute of the life history of bull trout has ecological relevance, particularly given that Downs et al. (2006) showed that age-0 emigrants did not contribute to subsequent adult escapement. As we see it, these small, emigrating age-0 fish represent an alternative life history strategy, which in itself may have a high risk of mortality. This alternative, however, may be advantageous when watershed-level disturbances, such as a large debris flow, occur in natal streams. More information on the emigrations of age-0 bull trout would help define the importance of this life history strategy for fish in the CRMW.

The lack of larger, subadult (e.g., age-2 and age-3) fish in our catches indicates that fish of this size may have migrated to the lake and is evidence for an adfluvial life history for bull trout in the CRMW. Notably, we never caught bull trout between 20 – 30 cm that were in spawning condition, suggesting that a resident life history type is not present in the CRMW, at least in the reaches of streams we sampled. Clearly, we did not sample some of the upper reaches and streams within the CRMW that could reasonably support a resident life history form of bull trout, but we simply do not have evidence that such fish exist. This is intriguing considering the possible evolutionary trade-offs of an adfluvial versus a resident life history. Although an adfluvial life history generally connotes higher growth rate, obtaining a large body size, increased fecundity, and perhaps increased reproductive success, it does require that juveniles migrate to an environment with potentially increased predation pressure. In smaller streams, such as those in the CRMW, fish with a resident life history would likely be subjected to less predation pressure by large piscivores, particularly age-1 and older fish. Fish that live their whole lives in small streams, however, would be exposed to other hazards, such as floods or debris flows, and as is the case in the CRMW, periods of intermittent and subsurface flow conditions. More extensive sampling of streams within the CRMW, particularly in the upper reaches, would help clarify bull trout life history and the potential for existence of resident fish.

For bull trout, we observed no longitudinal gradient in fish size or propensity to emigrate as we progressed from down to upstream areas. We did, however, observe longitudinal gradients in fish size and emigration behavior of rainbow trout in Boulder Creek (which we discuss below). Many have suggested that fish get smaller with the progression upstream because of fish size-stream depth relations observed at the habitat unit scale (e.g., Patrick 1975; Schlosser 1982; Anderson 1985). Hughes (1998), however, argued that the smaller-fish-upstream size gradients do not always exist for drift-feeding stream salmonids and, if they do exist, could only be explained by a fish size-stream depth relation at the extremes of fish and stream size. The reasons for the lack of a longitudinal gradient in bull trout size in our streams is probably due to the relatively small size of our streams and the fact that bull trout show considerable intra-stream movements (see below), which would help distribute fish of different sizes throughout the stream. Also, we did not assess habitat scale features in our study and cannot determine how they affect bull trout distribution in the watershed.

In contrast to bull trout, length frequencies of rainbow trout sometimes indicated the presence of at least four age groups ranging from age-0 to age-3 or older. Our catches were dominated by age-0, age-1, and age-2 fish that had mean lengths similar to those of bull trout. Similar results were reported for the Cedar and Rex rivers during a 1993 survey (Connor et al. 2001). Age-0 rainbow trout started to appear in our catches in July and became more common through September when they were of a size that increased their vulnerability to electrofishing. Notable was the increasing catch of larger fish (> 175 mm) in the late summer and autumn. Fish of this size probably represent reproductively competent individuals and were likely always present in the streams we sampled. Catches of these larger fish increased in the autumn probably because of lower stream flows and more efficient sampling. Like bull trout, the length-frequency distributions of rainbow trout indicate relatively healthy populations, with good seasonal growth rates and large numbers of younger aged fish. The length frequencies, with hypothetical ages assigned to the distinct modes, help define the size ranges of rainbow trout rearing in streams in the CRMW and suggest that an older age class may represent resident individuals in stream systems. Further, these age classes and associated growth rates were validated by the recapture of PIT-tagged fish throughout the CRMW.

PIT tag interrogations and movement of fish

Our PIT tag interrogation systems were effective at detecting upstream and downstream movements of bull trout and rainbow trout in the CRMW under a variety of conditions and over long, sustained periods. Generally, all systems performed admirably from the time of install to the large flood in early November 2006. We benefited from the previous work of Connolly et al. (2005) by using new generation PIT tags and transceivers and improved antenna building technology and anchoring systems to maximize detection efficiency and system integrity. Despite this, the flood in November 2006 destroyed most of our antennas and electronics. We were able to replace some antennas in each stream about a month later, but could not restore the full capability of each system until the summer of 2007. Thus, from early November 2006 until early summer of 2007, our interrogation systems operated with half the number of antennas and probably reduced efficiency. Because calculating detection efficiency of our systems was beyond the scope of our study, we cannot say to what degree efficiencies were reduced after the November flood. Previous work by Connolly et al. (2008) showed that detection efficiencies of multiple antennas arranged in a series of arrays exceeded 96% under a variety of dynamic stream conditions. They attributed this high detection efficiency to advancing technology and a built-in redundancy of multiple antenna arrays, but noted that a loss of one or more antennas resulted in reduced efficiency and precision. In our case, we cannot estimate the reduced efficiency and precision of our systems after we lost an antenna because we did not measure these variables and they are unique to each site and installation. Because our systems were based on the designs used by Connolly et al. (2008) and our streams were of similar size (except for the Cedar River, which was relatively large), we surmise that detection efficiencies of our systems were high when the complete systems were intact. As stated by Connolly et al. (2005, 2008), the technology for detecting PIT-tagged fish in streams is evolving in many ways, including smaller tags with increased read range, development of antennas for use in larger streams, new antenna designs and anchoring systems, and improved data storage and handling capabilities. Such refinements will only improve the efficacy of an already useful technology for describing the movements of stream dwelling fishes. Each site in this study possessed unique challenges (e.g., mobile bed in Boulder Creek, width of Cedar River) and we continued to improve antenna arrangement and anchoring systems at each site throughout the study.

Although bull trout in our streams emigrated downstream throughout the year, the most distinct trend we observed was a pulse of downstream movement in autumn that was most evident in fish from the Cedar River. An autumn pulse of downstream movement by young bull trout has been documented in other systems, including Trestle Creek in Idaho (Downs et al. 2006), Oregon's Grand Ronde River system (Bellerud et al. 1997), and the Arrow Lakes region in British Columbia (McPhail and Murray 1979). Populations of bull trout in Trestle Creek and the Arrow Lakes region represent adfluvial fish, whereas those in the Grand Ronde system are fluvial fish. Recent studies have also documented a fall emigration of larger, adfluvial subadult bull trout in the Flathead River system (Muhlfeld and Marotz 2005) and the Boise River in Idaho (Monnot et al. 2008). Collectively, these studies suggest that the autumn emigration of juvenile bull trout correlates with declining water temperatures. Our results generally concur, but we found that the autumn downstream migration of young bull trout also coincided with declining river discharge. Most of the downstream movement of our fish occurred before the first autumn freshets. In contrast, Fraley and Shepard (1989) reported that juvenile bull trout emigrated from the Flathead River system from June through August. Taken together, results from these studies indicate substantial variation in migration behavior of young and subadult bull trout that is probably related to several factors, including water temperatures, stream discharge, fish size, and food availability, among others. This illustrates the importance of maintaining the connectivity of streams and a diversity of habitats within watersheds containing bull trout to allow full expression of different life history strategies (Muhlfeld and Marotz 2005), one or more of which will prove successful even during extreme conditions.

Bull trout in Rack Creek showed some distinct movements that may be related to the onset and end of subsurface flow in the lower sections in late summer and early autumn. In 2006, from about June through August, a pulse of fish moved downstream, prior to flows going subsurface. After early autumn rains re-established surface flows in Rack Creek, more fish moved downstream. In 2007, subsurface flow occurred earlier (in August) and few fish moved downstream just prior to this. In late September, when the creek was flowing again, a relatively large pulse of fish moved downstream. These patterns of movement suggest two strategies for coping with intermittent streams—either emigrate before the stream becomes dry or take refuge upstream and emigrate after the stream is flowing again. Because fish cannot know or predict when a stream will be dry, we suspect these movements were related to changes in flow, or perhaps water temperature or time or year. Overall, it appears that bull trout in the CRMW move downstream during at least three seasons of the year (i.e., spring through autumn; see Pratt 1992) and that these movements may vary from stream to stream. Bull trout in Rack Creek may be expressing behavioral strategies to cope with the vagaries of living in an intermittent stream during relatively normal flow and thermal conditions.

Based on length-frequency distributions of fish at the time of tagging, it appears that the majority of fish emigrating downstream were age-1 or older. On average, emigrants in Rack Creek were somewhat smaller than fish in other streams, but they still corresponded to age-1 fish or older. Although we cannot know the actual length of a tagged fish at the time of detection, we assumed that the size of fish at tagging was indicative of their size when detected. This was probably a safe assumption because we restricted our analysis of interrogated fish to those that moved within the same year and have recapture data indicating that the growth rates of age-1 and age-2 fish were roughly similar. Clearly, the length-frequency distributions of fish at the time of tagging were skewed toward larger individuals for fish that emigrated relative to those that did not. Our results were consistent with others describing an emigration of younger bull trout (e.g., Fraley and Shepard 1989; Downs et al. 2006; Bellerud et al. 1997), but variation does exist relative to the age and size of juvenile emigrants. For example, Fraley and Shepard (1989) reported that 81% of the emigrating juvenile bull trout from the Flathead River system were ages 2 and 3. Migrating at a larger size has ecological significance because larger fish may have enhanced performance attributes (e.g., burst swim speed ability; Mesa et al. 2004) and would be less vulnerable to predation due to gape limitations of predators. Indeed, Beauchamp and Van Tassell (2001) used field data and model simulations to show that cannibalism by bull trout could remove significant proportions of age-0 and age-1, but not age-2 or older, fish in Lake Billy Chinook, Oregon. It seems likely that a similar situation exists in CML and emigrating at a relatively large size would have survival advantages and may play a role in the persistence of an adfluvial life history. Although others have documented emigrations of smaller age-0 bull trout (McPhail and Murray 1979; Reiser et al. 1997), we suggest that, given the results of Downs et al. (2006; see above), this may not be a typical attribute of bull trout life history, particularly for fluvial or adfluvial fish.

As we noted for bull trout size above, we found no correlation between the location where fish were tagged and their emigration behavior. In other words, there was no longitudinal gradient in emigration behavior of bull trout from any stream we sampled. Although, as we stated above, longitudinal gradients of fish size within streams have been documented (see

Hughes 1998), we are unaware of such gradients in small streams relative to fish migration behavior (however, see discussion for rainbow trout below). Given that larger fish, which would be most likely to show downstream emigration, were found throughout the streams we sampled, it is not surprising that no trend was evident relative to tagging location and emigration. That emigrants came from upper, middle, and lower reaches of our streams underscores the importance of maintaining adequate rearing habitat for juvenile bull trout in all areas.

The only significant movement data for rainbow trout came from Boulder Creek. These fish showed downstream movements throughout the year with a distinct pulse occurring from October through November. Like bull trout, a large number of fish moved downstream in October 2007 after autumn rains ended an almost two-month period when the creek had subsurface flows. Most of the fish that emigrated were age-1 or older, ranging from 90 to over 220 mm in length. The existence of an adfluvial life history type in rainbow trout has been well documented (Behnke 1992; Meka et al. 2003; Holecek and Walters 2007) and our fish probably reflect this. Collectively, our results suggest that rainbow trout in the CRMW show diverse life history types, including adfluvial, fluvial, and resident forms. For example, the relatively large size and older age of emigrants from Boulder Creek most likely represent an adfluvial life history type, or, more properly, a lacustrine-adfluvial form (sensu Varley and Gresswell 1988). These fish would reside in lakes or reservoirs, ascend tributaries to spawn, and are analogous to the life history of bull trout in the watershed. In contrast, we also captured (and recaptured) many fish in Boulder Creek and the Cedar River from July through September 2007 that were relatively large (i.e., greater than 175 mm) and typical of stream-resident rainbow trout. It seems likely that enough suitable habitat exists in these streams for a proportion of the rainbow trout population to adopt a resident or fluvial life history in the lower reaches. Indeed, past SPU distribution surveys in the upper forks of the Cedar River found that most fish were of larger size (>175mm) suggesting these fish may show a resident life history. Future sampling of rainbow trout during the spawning season would help confirm the presence of fluvial or resident forms in the lower and upper reaches of streams within the CRMW.

In contrast to bull trout, rainbow trout showed a longitudinal gradient relative to their propensity to move downstream, but only in Boulder Creek. Thus, the closer a fish was to the lake, the more likely it was to emigrate downstream. Further, the size of rainbow trout in our catches from Boulder Creek generally increased in an upstream direction. The sizes of fish captured in the upper sections of Boulder Creek were typical of resident, reproductively competent individuals in other areas (Erman and Hawethorne 1976; Muhlfeld 2002; Mellina et al. 2005). In the Cedar River, we surmise that resident forms of rainbow trout become more common upstream. When we sampled the Cedar River between river meters 8,000 and 8,400, which was about 7,000 m upstream of our sampling in the lower reaches, less than 10% of the fish moved downstream. Surprisingly, this percentage was similar to that of fish from the lower reaches we sampled, however, we also tagged 158 rainbow trout between river meters 13,000 and 17,000, and none of these fish emigrated downstream. Combined with the movement information from bull trout, our results indicate that an adfluvial life history for fish predominates in the lower reaches of larger rivers, like the Cedar, and in streams of shorter length (e.g., Rack and Boulder creeks) that are proximal to the lake. Although we found no evidence of a resident life history form of bull trout, we did find evidence of resident forms of rainbow trout in Boulder Creek and Cedar River. We believe this finding to be relatively unique because we are unaware of other watersheds where rainbow trout distributions extend further upstream than those of bull trout. In addition, rainbow trout are also known to exist in several tributaries within the upper Cedar basin (within CRMW) upstream of falls that apparently represent the upstream limit of bull trout (SPU unpublished data). Further, it seems unusual that bull trout do not obviously express a resident life history type when supposedly adequate tributary habitat exists.

During our study, there were seven bull trout and four rainbow trout that left the stream in which they were tagged, presumably spent some time in CML, and then migrated up the Cedar River. The time that elapsed between leaving their home stream and entering the Cedar River ranged from less than 30 days to almost 1.5 years. Although the sample is small, we cannot discern anything unique about these fish relative to the whole population—they were of average size and moved at times similar to many other fish. Mogen and Kaeding (2005) also reported inter-stream movements of bull trout in the St. Mary River drainage, Montana, in excess of 10 km, but offered no discussion regarding the potential significance of such movements. We are unsure of the reasons for or significance of the inter-stream movements of fish in CRMW, but wonder whether coincidence alone could explain the fact that all of these fish entered and migrated upstream in the Cedar River. Perhaps it is related to the relative size, temperature regime and flow characteristics of the Cedar River, but definite answers await further research.

In addition, we have indirect evidence of fish—particularly rainbow trout—that left the stream where they were tagged, spent some time in CML, and then returned to their original stream. Unfortunately, the evidence is indirect because, unlike fish that moved between different streams, we cannot be completely sure that fish detected moving downstream and then subsequently detected moving upstream—in the same stream—actually spent time in the reservoir. For some fish that had a long span of time between detection events (see Tables 5 and 8), it seems likely that they spent some time, perhaps a considerable amount, in the lake. For bull trout, the detection event information is either equivocal or actually suggests that fish never left the stream. For example, several bull trout were detected moving downstream in Boulder and Rack creeks prior to the streams going subsurface and were detected moving upstream when the lower sections of the streams had already gone subsurface. We suspect that these fish were in areas just downstream of the antennas and moved upstream when conditions worsened. In contrast, most rainbow trout had upstream detection events that coincided with adequate surface flow in Boulder Creek. This, coupled with the relatively long period between downstream and upstream detections of rainbow trout, suggests these fish probably spent some time in CML.

Movements of recaptured PIT-tagged fish

For documenting the downstream migrations and longer distance movements of young bull trout and rainbow trout, data from our PIT tag interrogation systems were superior to that from physical recaptures of PIT-tagged fish. Although we recaptured many fish downstream of our PIT tag detectors, most had already been detected and capturing them simply confirmed that they indeed passed over the antennas. There were 5 bull trout and 3 rainbow trout that were captured downstream of the systems and not detected, thus the contribution of this data to the more powerful information from the PIT tag interrogators is minimal. The majority of recaptured PIT-tagged fish showed local, intra-stream movements relative to their tagging location. Most, in fact, were recaptured within 200 m of where they were tagged. At first glance, one might think that such information lends support to the theory first proposed by Gerking (1959) that the movements of stream fish are restricted. This restricted movement paradigm (RMP), as coined by Gowan et al. (1994), stated that adult stream fish were sedentary and spent most or all of their lives in small (e.g., < 20 m) sections of stream. As pointed out by Gowan et al. (1994) and Rodriguez (2002), however, numerous studies have shown that relatively long distance movements are common in populations of stream salmonids, thus calling into question the validity of the RMP for these fish. As a hypothetical example, a fish showing extensive but seasonal and cyclical movements would be expected to be recaptured near the site of tagging if the sampling events occurred at a similar time each year. In this case, an investigator might come up with the wrong conclusion that the fish had not moved extensively. Collectively, our results, including PIT tag interrogations, recaptures of marked fish within a stream, and interrogations of fish that made cross-reservoir movements, indicate that the fish populations in the CRMW are quite mobile. Given the proximity of many fish to the lake and the existence of an adfluvial life style, this conclusion is not surprising. More sedentary populations of fish may reside in the upper reaches and headwaters of the Cedar River system, but more information is needed to confirm this notion.

Growth of bull trout and rainbow trout

Our use of two independent techniques to estimate growth of fish in the CRMW provided useful information on both an annual and seasonal basis. Based on our analysis of length frequencies, both bull trout and rainbow trout grew about 40 – 60 mm from age-0 to age-1, which were the most common age classes represented. These growth rates were often, but not always, validated by recaptures of PIT-tagged fish that had about a year elapse between capture events. This underscores the relevance of data derived from recaptures of PIT-tagged fish and instills confidence in our overall assessment of growth. The reasons why the information derived from recaptures did not always validate the length frequencies are probably related to small sample sizes and large individual variation. The growth rates of bull trout in the CRMW were similar to fish in other areas, including bull trout from the Flathead and St. Mary drainages in Montana (Fraley and Shepard 1989; Mogen and Kaeding 2005), the Metolius River in central Oregon (Pratt 1991), and the Athabasca River system in Alberta (Hunt et al. 1997). The annual growth rates of rainbow trout in the CRMW were within the range of values reported elsewhere, including fish from Great Lakes streams (Stauffer 1972), a small Appalachian stream (Whitworth and Strange 1983), and the Wenatchee River drainage in central Washington (Mullan et al. 1992).

Seasonal growth rates of bull trout and rainbow trout were similar among fish in different streams, with a few exceptions. Notably, the streams with the highest relative densities of bull trout and rainbow trout (i.e., Rack and Boulder creeks) had fish with the lowest instantaneous growth rates. This suggests that growth was negatively density-dependent for fish in these streams, but more information is needed to confirm this notion. Density effects on growth in stream resident salmonids have been shown for coho salmon *O. kisutch* and steelhead (Fraser 1969), and for brown trout *Salmo trutta* (Jenkins et al. 1999; Bohlin et al. 2002). Because, as we stated earlier, our sampling was not designed to estimate densities of fish, we consider the information we do have to be preliminary and of limited use for detailed density-dependent analyses. Further, other information, such as trout diet, prey abundance, and survival, would be useful for confirming density-dependent effects. Despite this, the instantaneous growth rates of bull trout and rainbow trout were within the range of values reported in other studies (Fraley and Shepard 1989; Mogen and Kaeding 2005; Mullen et al. 1992).

Summary and recommendations

Our research was successful in documenting some population characteristics of bull trout and rainbow trout in the CRMW, the timing and magnitude of downstream migrations of juvenile fish, annual and seasonal rates of growth, and possible underlying factors contributing to these findings. Both bull trout and rainbow trout from all streams had length-frequency distributions indicative of healthy populations with good potential for growth in number. Both species were found in all streams, but bull trout numerically dominated in Rack Creek and rainbow trout dominated in Boulder Creek. Although bull trout showed some downstream movement during the spring and summer, most of their emigration to CML occurred in the autumn. This pattern was particularly evident in fish from the Cedar River. Rainbow trout moved throughout the year, but also showed a pulse of movement in autumn. The bull trout and rainbow trout that emigrated were mostly age-1 or older, which is typical of these species in other areas. We do not know the extent or timing of emigrations of age-0 fish. The annual and seasonal growth rates of bull trout and rainbow trout in the CRMW were indicative of good habitat conditions and within the range reported for these species elsewhere. For now, it appears that populations of bull trout and rainbow trout in the CRMW are doing well, but there are some issues to consider for the future.

Perhaps the single most important factor contributing to the health of bull trout and rainbow trout populations in the CRMW has been the closure of the watershed to public access and commercial activities since 1908 (Reiser et al. 1997) to protect Seattle's drinking water supply. Other types of disturbance, however, have been present in the basin since the late 1800s, including construction of three dams, water level manipulations in CML, extensive forest road construction for extracting timber, and intensive commercial timber harvest (i.e., clear cutting). All of these activities continued in the watershed into the early 1990s. After more than a century of timber harvest, a moratorium on harvest was placed on all lands owned by Seattle (in 1985), and the development of secondary use policies (in 1989), including habitat protection for fish and wildlife and land acquisition (in 1996), began a trend toward conservation and more informed resource use in the watershed. Another major change occurred in the mid-1990s when Seattle developed a Habitat Conservation Plan (HCP) for the watershed under the Endangered Species Act (ESA) that focused on protection, conservation, and restoration of natural resources and processes, while at the same time preserving the sustainability of Seattle's drinking water supply. The 50-year HCP ended all commercial timber harvest in the watershed and preserved about 14,000 acres of old-growth forest, much of which surrounds upper elevation, headwater streams in the basin. The HCP also contains commitments to decommission forest roads, reduce sediment input to streams, restore natural processes in aquatic and riparian habitats, and accelerate the development of late-successional and old-growth habitat characteristics in second-growth forest. All land management activities in the watershed now focus on conservation, restoration, and improvement of habitat for all threatened and sensitive species, including bull trout. The significance of the conservation and mitigation strategies put forth in the HCP—guiding a wide range of land management activities—cannot be underestimated in terms of their cumulative beneficial effects on the sustainability of healthy fish populations throughout the Cedar River basin.

In fact, closure of the watershed to outside activities alone, and non-exploitation of fish populations, may actually buffer or minimize the potential negative consequences of other actions (such as reservoir level manipulations for water supply—see below) on fish populations, including threatened bull trout. Sustaining good tributary habitat or restoring poor habitat may be the most critical actions for maintaining these fish populations. As we move into the future, the scientific, ecological, and educational value of such a minimally exploited watershed should become readily apparent. Therefore, it is perhaps axiomatic that we strongly recommend that the CRMW remain closed to activities that would negatively impact tributary health.

One of the main reasons for conducting this research was to determine whether current water level management of CML could, in some way, negatively impact the fish populations in the watershed. Our results suggest that current management of CML is allowing bull trout and rainbow trout populations to thrive at respectable levels, but there are three important gaps in our knowledge. We do not know the contribution of different age classes and life history strategies to adult production. Certainly, maintaining the expression of life history diversity, spread over multiple age classes, will help fish populations survive temporal habitat disturbances. The contribution of various life history strategies expressed by juvenile bull trout and rainbow trout could be evaluated, at least in part, by simply maintaining the current network of PIT tag interrogation systems. Much effort was expended to PIT tag thousands of juvenile bull trout and rainbow trout and those with successful life history strategies will mature and be detectable by the interrogators used in this project for years to come, as well as by other types of systems. With a minimum of maintenance, PIT tag interrogators will collect data documenting the timing of spawning migrations and periods when adfluvial, adult fish use river and stream habitat. More information will be forthcoming about the success of different juvenile life histories and from adult fish behavior and use of the CMRW. In addition, and of substantial ecological and management significance, the PIT tag systems and the resultant data they provides will establish a baseline dataset against which SPU may evaluate changes in fish behavior in response to future reservoir operational changes.

While all three PIT tag arrays provided important information on fish movement in the upper CRMW during this study, each documented unique aspects of fish ecology. We found that most information on rainbow trout movement patterns was provided by the Boulder Creek site, and if SPU wishes to continue monitoring these fish, it should consider maintaining this array. The Rack Creek antenna array provided information primarily on the movement of juvenile bull trout. This site may become important for SPU to maintain, at least in the short-term, because of construction and future operation of a pump station facility at the west end of CML. Finally, the Cedar River mainstem site provided information on the movements of bull trout, rainbow trout, and pygmy whitefish, and could be maintained and operated for a variety of reasons. The Cedar River antenna array is located immediately above the zone of inundation (at high lake refill levels) so that we are reasonably certain individuals passing the array move downstream into the reservoir. In addition, the majority of bull trout and pymgy whitefish spawning occurs in the Cedar River and this array will detect the movements of spawning fish and how often they return, providing a long-term data set for monitoring trends in spawning of adfluvial bull trout. Also, the majority of cross-reservoir movements by fish were detected at the Cedar River site and maintenance of this array will increase our knowledge on the occurrence of these events. Overall, maintaining the Cedar River PIT tag system may be the most logistically and financially efficient means by which SPU can monitor the health of bull trout in the future.

The fate of young fish that migrate to the reservoir is currently unknown in the CRMW. Scale analysis of adult bull trout to determine the proportion of adfluvial fish that moved to the reservoir versus those that reared in streams for several years would help evaluate this question. We reason that an induced pattern of drawdown and refilling of the lake affects the production and standing crop of aquatic plants in the littoral zone. It may also affect the availability of refuge offered by large woody debris, by either burying it with sediment or transporting it by floating. Given that many young fish are migrating to CML, the littoral zone could be evaluated and enhanced, if needed, for the protection of young fish that may be particularly vulnerable to predation. This could be in the form of plantings of native vegetation or the placement of artificial or natural structures, such as boulder or wood complexes. We recognize that predation is likely a part of the ecological interactions between fish in CML and our intent is not to dramatically decrease or eliminate those. We are simply suggesting that habitat suitable for all life stages of fish within CML is available and enhanced, if necessary. To understand the fate of juvenile fish that emigrate to the reservoir, a new and creative sampling design will be needed. Such an effort should be directed at gaining information about the habitat of CML and fate of juvenile fish in the lake, with special attention to the dynamic environment of the littoral zone. A focus on the littoral zone is important because it is directly influenced by the natural and artificial fluctuations of reservoir levels.

Finally, we suggest further evaluation of the effects and implications of highly variable water level changes in the reservoir complex on the connectivity of streams with CML. While current water levels of CML appear to allow maintenance of healthy bull trout and rainbow trout populations in the watershed, this could change substantially if global climate change or increased water needs for Seattle require more extreme reservoir management (e.g., greater and more prolonged reservoir drawdown). Increased magnitude or extended periods of drawdown during low flow periods could strand fish for extended periods in streams such as Rack Creek. We suggest that the artificially elevated lake levels may have enhanced the delta areas of at least some tributary streams. It follows that these enhanced delta areas could contribute to the timing, location, and duration of subsurface flows and the disconnection of streams with CML, due to artificially increased deposition of bedload material at such elevated stream-lake confluences, but more research is needed to confirm this notion. If streams become disconnected from the lake, and upstream areas offer little or no flow so that fish movement was constrained, the streams could become unsuitable for meeting the bioenergetic needs of fish (e.g., food requirements). The expressed life history diversity of bull trout and rainbow trout in the CMRW will likely enable them to withstand this kind of disturbance over the short term, but multiple years of drought, increased sediment input from tributary watersheds, or increased water withdrawals, could warrant considerable adaptive management prescriptions.

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Appendix 1: Photographs

Figure 1.1.—Antenna array at Boulder Creek, October 2005. All antennas were pass-by antennas secured to the streambed by straps held to a combination of rebar stakes, fencing stakes, and anchor bolts in the substrate (antennas 1 and 2 at top of photo).

Figure 1.2.—Reinstallation of antenna array at Boulder Creek in late November 2006 after flooding destroyed the entire array. Antenna 3 (upstream) and antenna 4 (downstream) were secured to a cable strung across the streambed in a pass-through configuration. Antennas hung vertically by strapping their bottom edge to fencing stakes in the stream.

Figure 1.3.—Reinstallation of antennas 1, 3, 4, 5 and 6 at Boulder Creek in June 2006. Antenna 1, configured as a pass-by antenna, was secured to the streambed by straps holding it to fencing stakes driven into the streambed. Antennas 3, 4, 5 and 6 were secured to a cable strung across the streambed in a pass-through configuration.

Figure 1.4.—Placement of antennas 1, 2, and 3 (1 at upper right) in the Cedar River, August 2006. Rope and assorted straps secured to a combination of rebar stakes and anchor bolts in larger substrate held the antennas to the streambed.

Figure 1.5.—Placement of antennas 4, 5, and 6 (hybrid antenna 4 in foreground) in the Cedar River, August 2006. Antennas 5 and 6 hung vertically in the water column from a cable strung across the river.

Figure 1.6.—Reinstallation of antenna 4 in the Cedar River following a flood that destroyed the array, November 30, 2006. The flooding occurred in early November. Rope and assorted straps secured to fencing stakes held the antenna to the streambed. The antenna was switched from a hybrid to a pass-by antenna configuration.

Figure 1.7.—Reinstallation of antennas 1, 2, and 3 in the Cedar River site, late August 2007. Antennas were placed in locations similar to those of the original installation, but larger fencing stakes were used as anchor points to secure the antennas.

Figure 1.8.—Antenna array at Rack Creek, October 2005. Antennas 1 and 2, located under the bridge, were pass-through antennas and antennas 3 and 4 were pass-by antennas. All were secured to the streambed by straps held to a combination of rebar stakes and anchor bolts in the substrate.

Figure 1.9.—Antenna array at Rack Creek following flooding that destroyed the array. The flooding occurred in early November and the antennas were reinstalled in late November, 2006. Antennas 1 (upstream) and 4 (downstream) were secured to anchor bolts in the substrate and were pass-through antennas.

Figure 1.10.—Reinstallation of antennas 1, 2, 3, and 4 at Rack Creek, June 2006. Antennas 1 and 2, located upstream of the bridge, were pass-by antennas and antennas 3 and 4 were pass-through antennas. All were secured to the streambed by straps held to a combination of rebar stakes and anchor bolts in the substrate.

Figure 1.11.—Habitat in Eagle Ridge Creek approximately 1,200 meters upstream of the Cedar River confluence looking west. Minnow trapping was used to capture fish in this stream.

Figure 1.12.—Cedar River floodplain channel habitat (FPC-5) located approximately 300 meters upstream of the Cedar River. Habitat is characterized by low gradient riffles and pools with large woody debris providing cover for fish. Minnow trapping was primarily used to capture fish in this stream.

Figure 1.13.—Low streamflow habitat (July 2007) on the Rex River approximately 1,000 meters upstream of Chester Morse Lake. This reach is characterized by low gradient riffles interspersed with larger scour pools created by large woody debris jams. A combination of minnow trapping and electrofishing was used to sample this habitat.

Figure 1.14.—Cedar River habitat located 1,200 meters upstream of Chester Morse Lake. The reach is characterized by low gradient riffles interspersed with larger scour pools created by large woody debris jams. A combination of minnow trapping and electrofishing was used to sample this habitat.

Figure 1.15.—Habitat on Cabin Creek located 700 meters upstream of the Rex River confluence in the middle of a sampled reach. Due to the small channel size and dense understory along this creek, we primarily used minnow traps to capture fish.

Figure 1.16.—Habitat within the wetland portion of Cabin Creek. Most sampling occurred upstream of this reach.

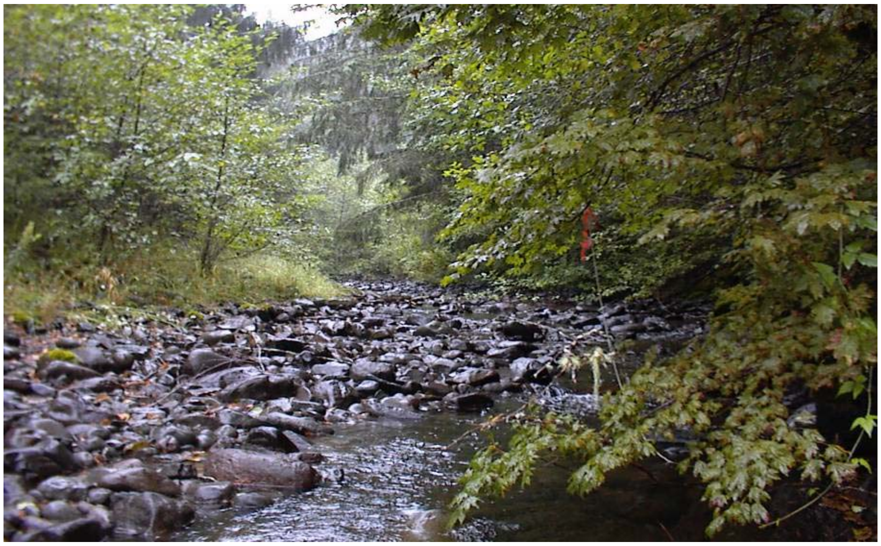

Figure 1.17.—Characteristic habitat in Boulder Creek upstream of the antenna array. This reach was sampled with minnow traps and electrofishing.

Figure 1.18.—View of dry stream channel in Boulder Creek when streamflow went subsurface, July 2007. Stranded fish were observed in several larger pools throughout the subsurface reach indicating that flows dropped relatively quickly.

Figure 1.19.—Characteristic habitat in Rack Creek with large boulder sized substrates and small pocket pools.

Figure 1.20.—Thermoelectric generator, Contico boxes holding multiplexing unit, and propane tank secured in a mobile trailer. The system supplied power to the antenna arrays and was used at all sites.

Figure 1.21.—Hand-held syringes were used to insert 12 mm PIT tags into the body cavity of bull trout and rainbow trout.

Figure 1.22.—Example of an age 1 rainbow trout captured in Rack Creek in July 2007 showing full stomach relative to body length.

Figure 1.23.—Example of an age 0 bull trout captured in Rack Creek in July 2007 showing an extremely full stomach relative to body length.

Figure 1.24.—A representative age 0 bull trout (64 mm fork length) captured on the Rex River in August 2006.

Figure 1.25.—A representative age 1 bull trout (134 mm fork length) captured on the Rex River in August 2006.

Appendix 2: Bull Trout Length Frequencies

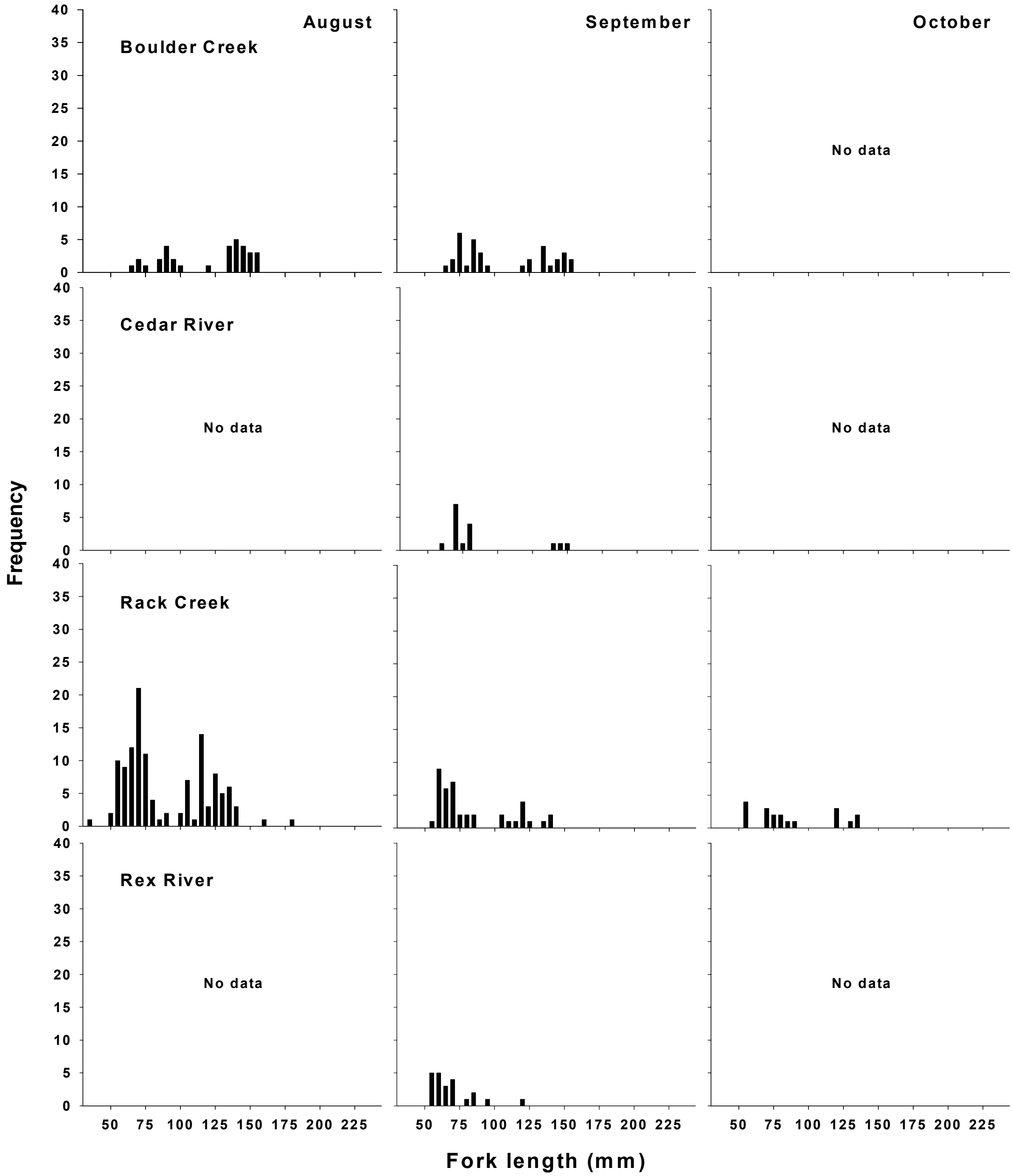

Figure 2.1.—Length frequency distributions of bull trout captured in 2005 by month in four tributaries of the Cedar River Municipal Watershed.

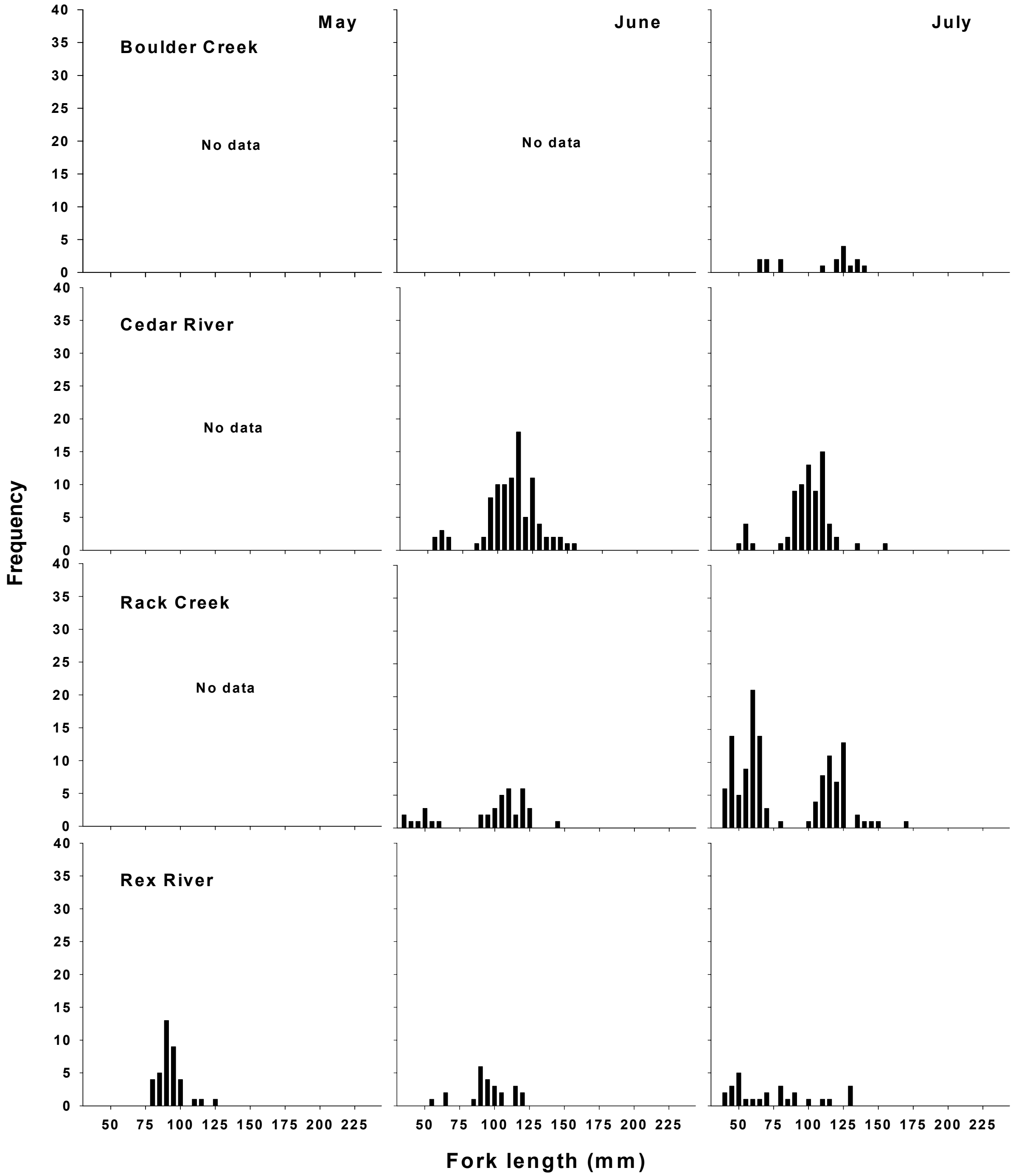

Figure 2.2.—Length frequency distributions of bull trout captured in 2006 by month in four tributaries of the Cedar River Municipal Watershed.

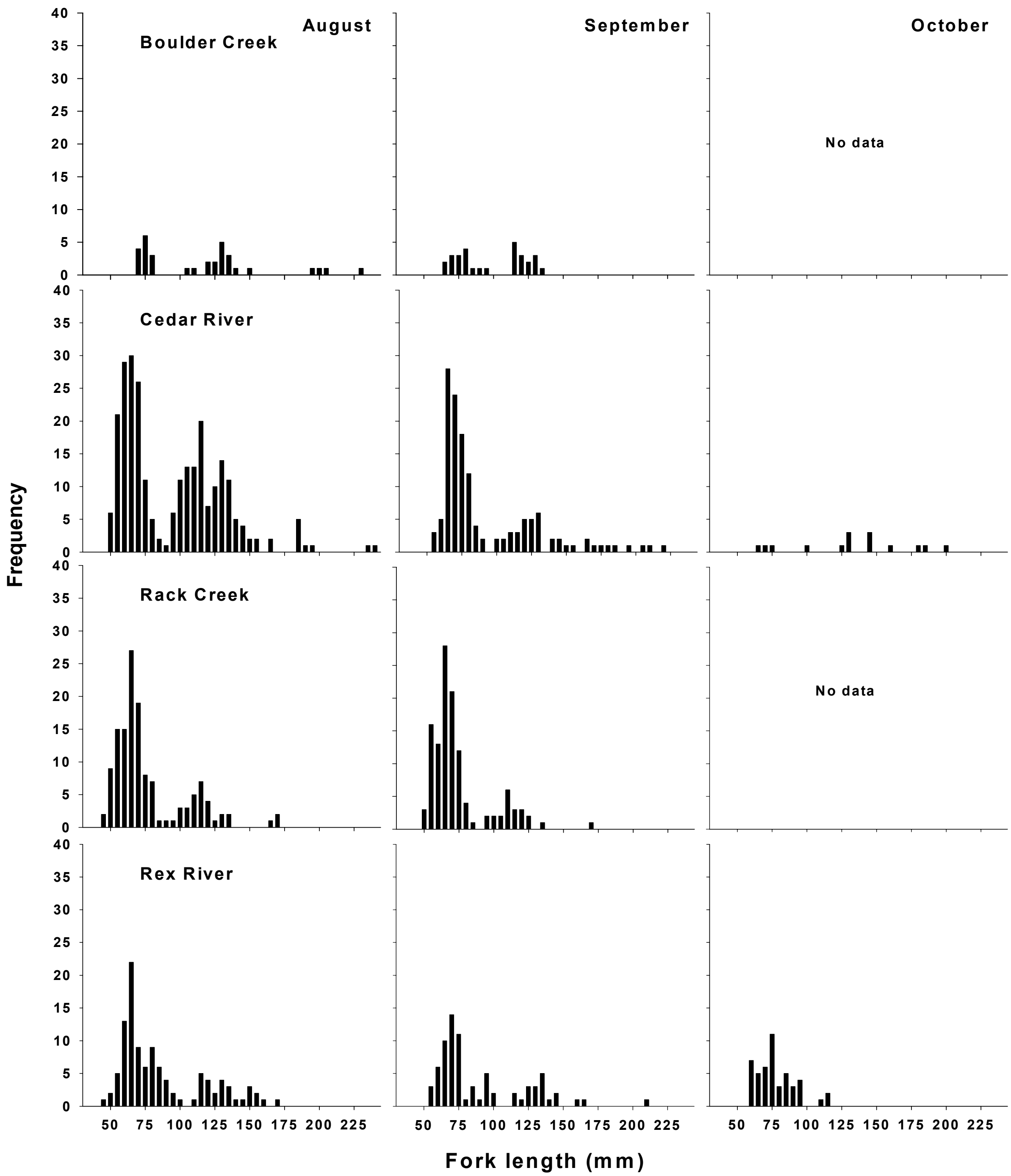

Figure 2.2.—Continued.

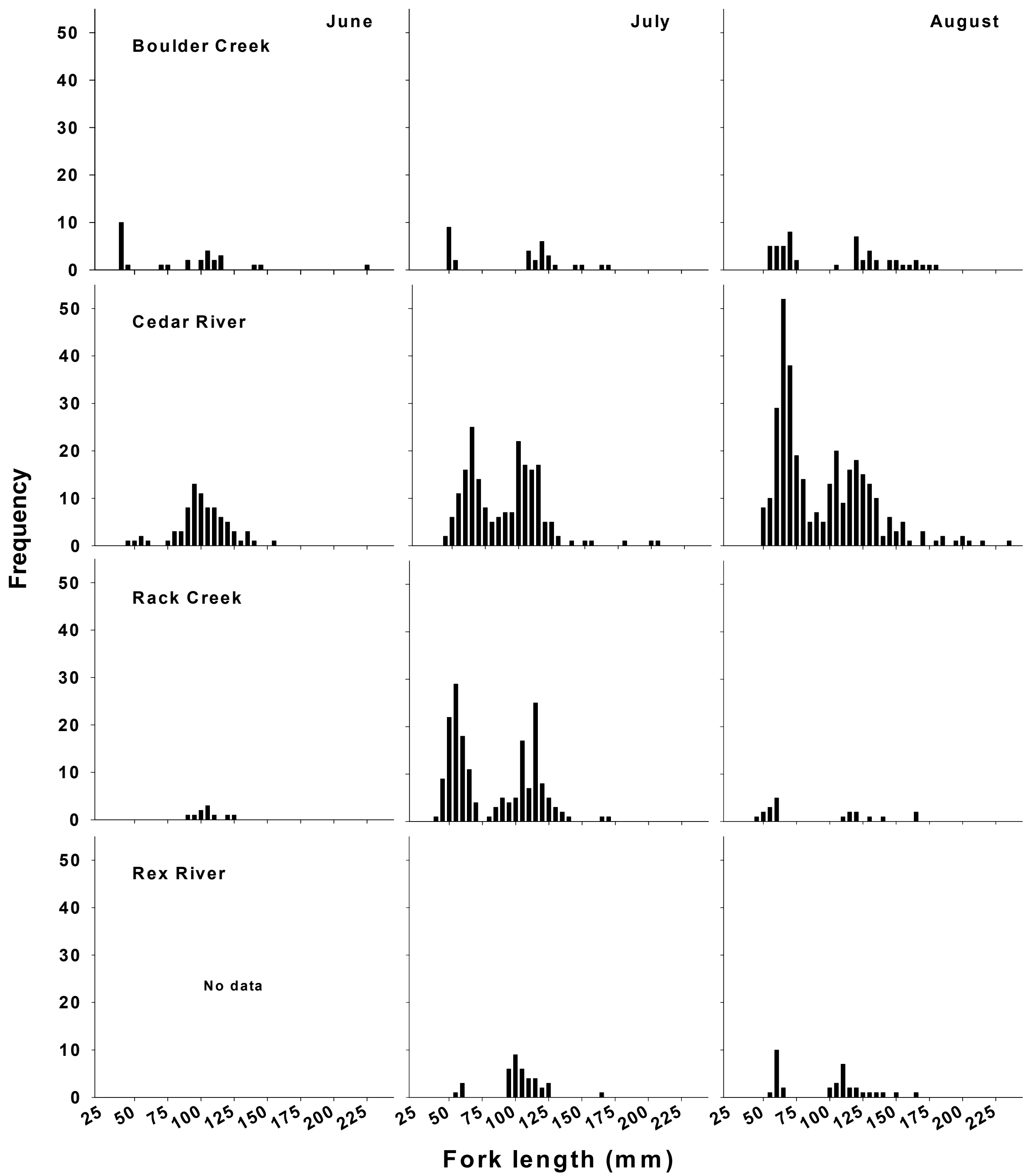

Figure 2.3.—Length frequency distributions of bull trout captured in 2007 by month in four tributaries of the Cedar River Municipal Watershed.

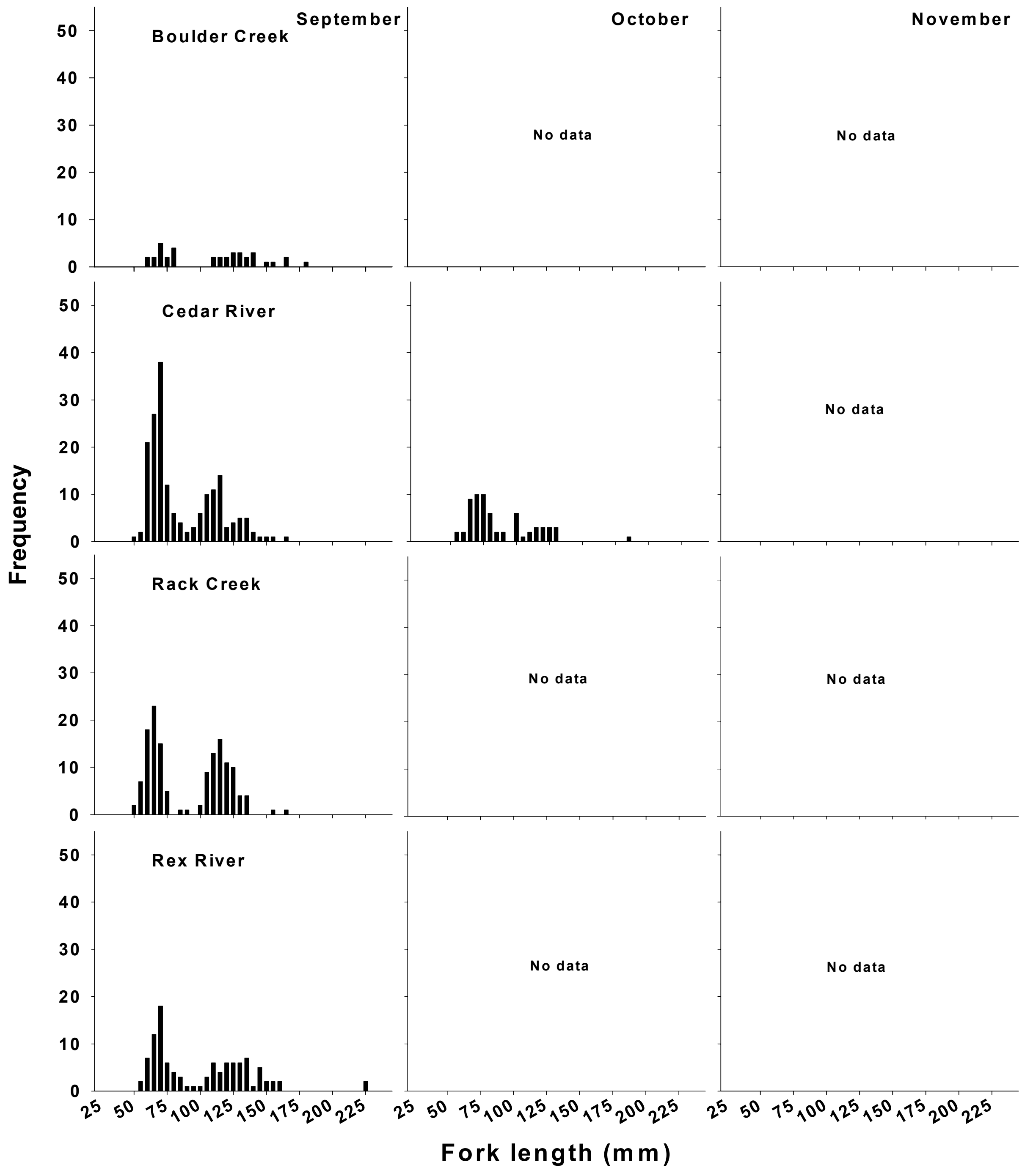

Figure 2.3.—Continued.

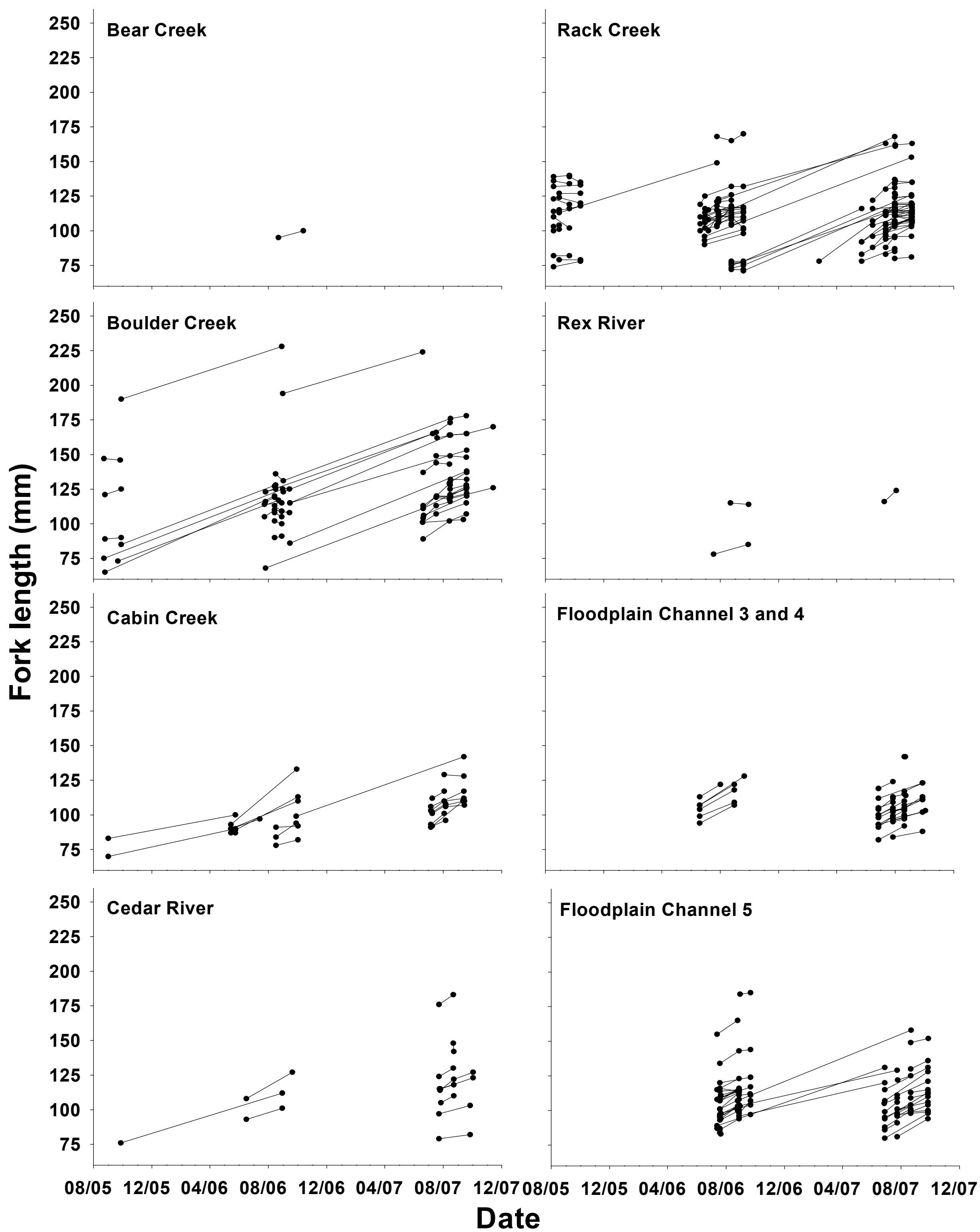

Figure 2.4.—Growth trajectories of bull trout captured in 2005-2007 in eight tributaries of the Cedar River Municipal Watershed. Data were derived from PIT-tagged fish that were marked and recaptured.

Appendix 3: Rainbow Trout Length Frequencies

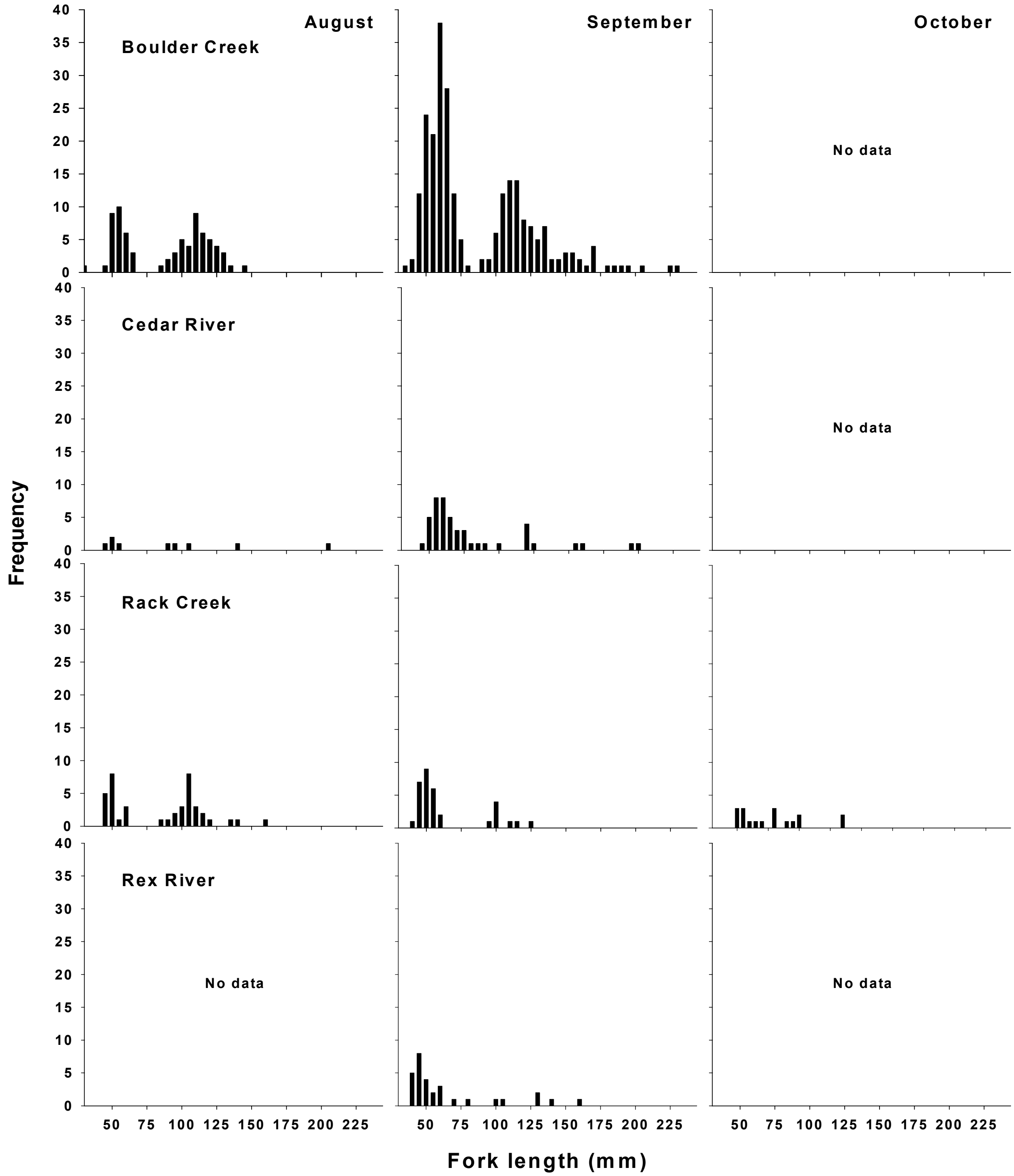

Figure 3.1.—Length frequency distributions of rainbow trout captured in 2005 by month in four tributaries of the Cedar River Municipal Watershed.

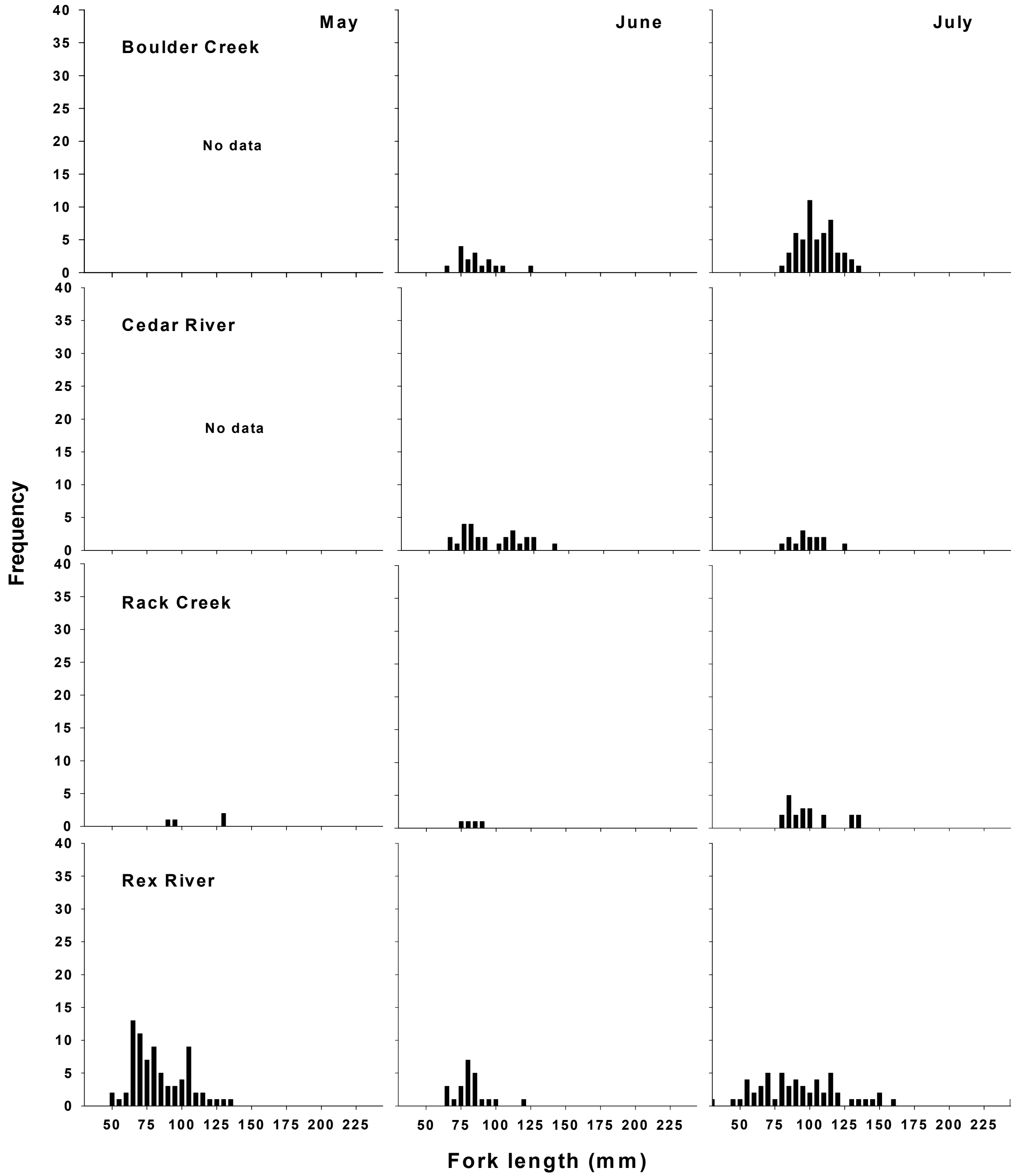

Figure 3.2.—Length frequency distributions of rainbow trout captured in 2006 by month in four tributaries of the Cedar River Municipal Watershed

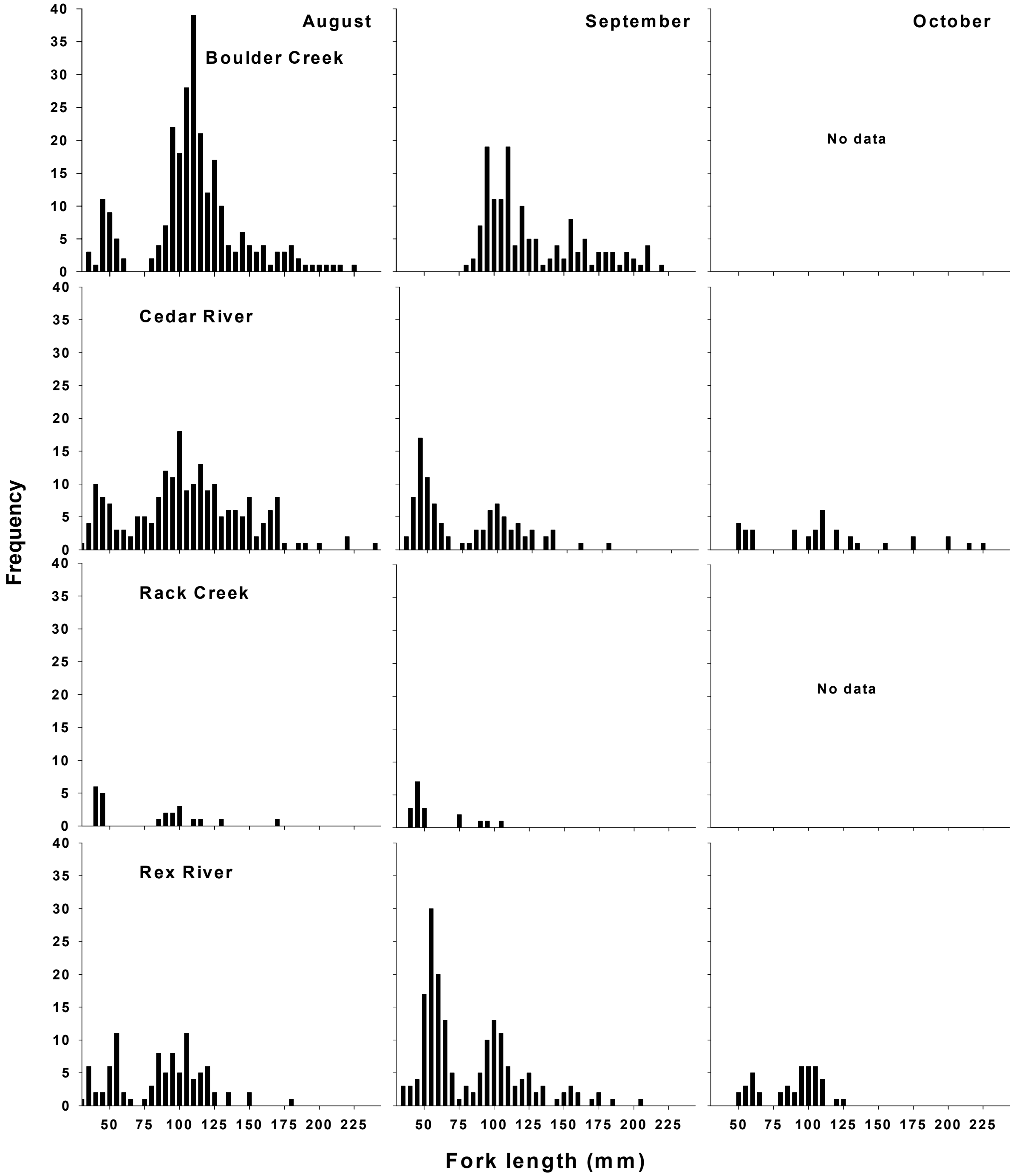

Figure 3.2.—Continued.

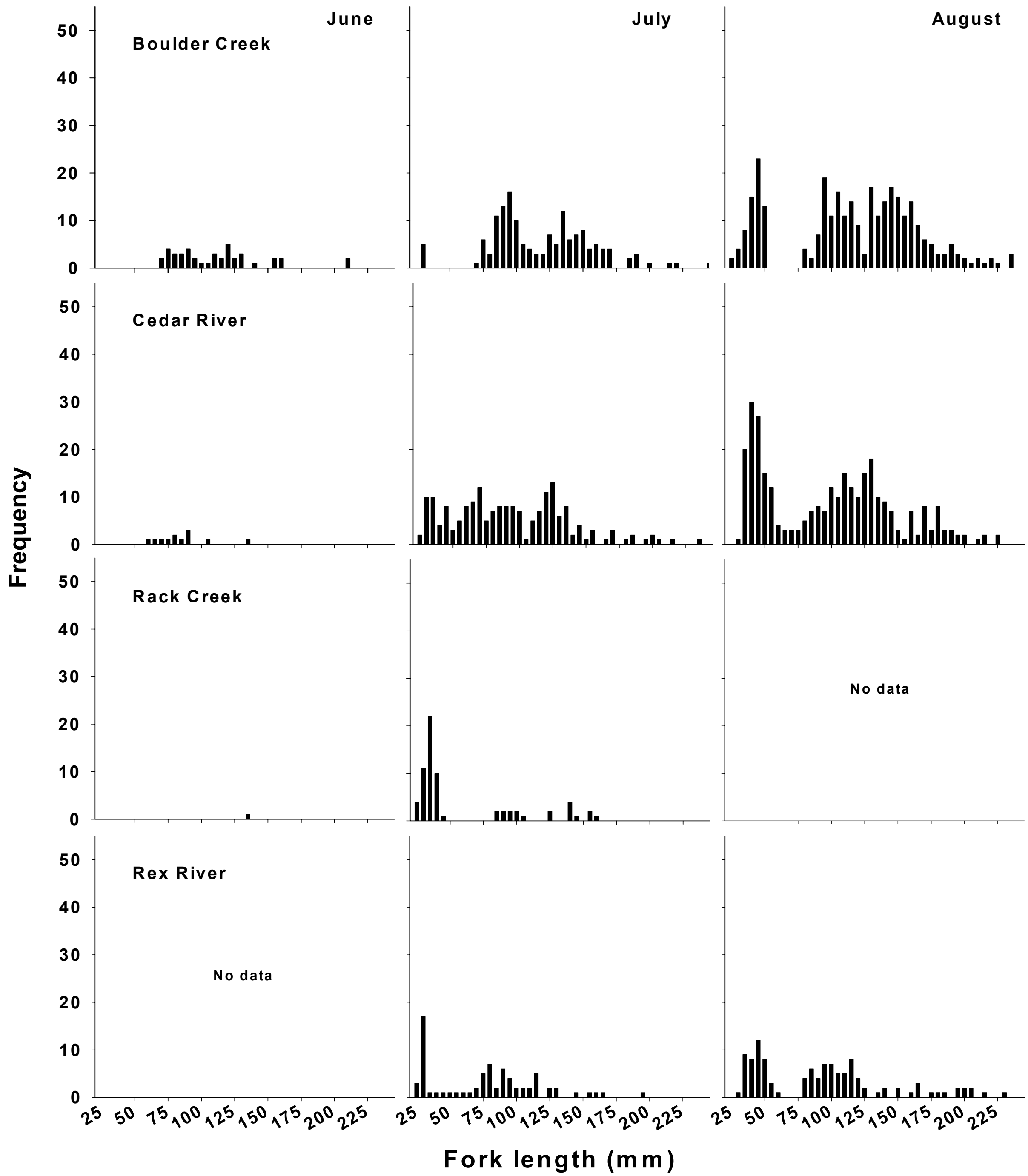

Figure 3.3.—Length frequency distributions of rainbow trout captured in 2007 by month in four tributaries of the Cedar River Municipal Watershed.

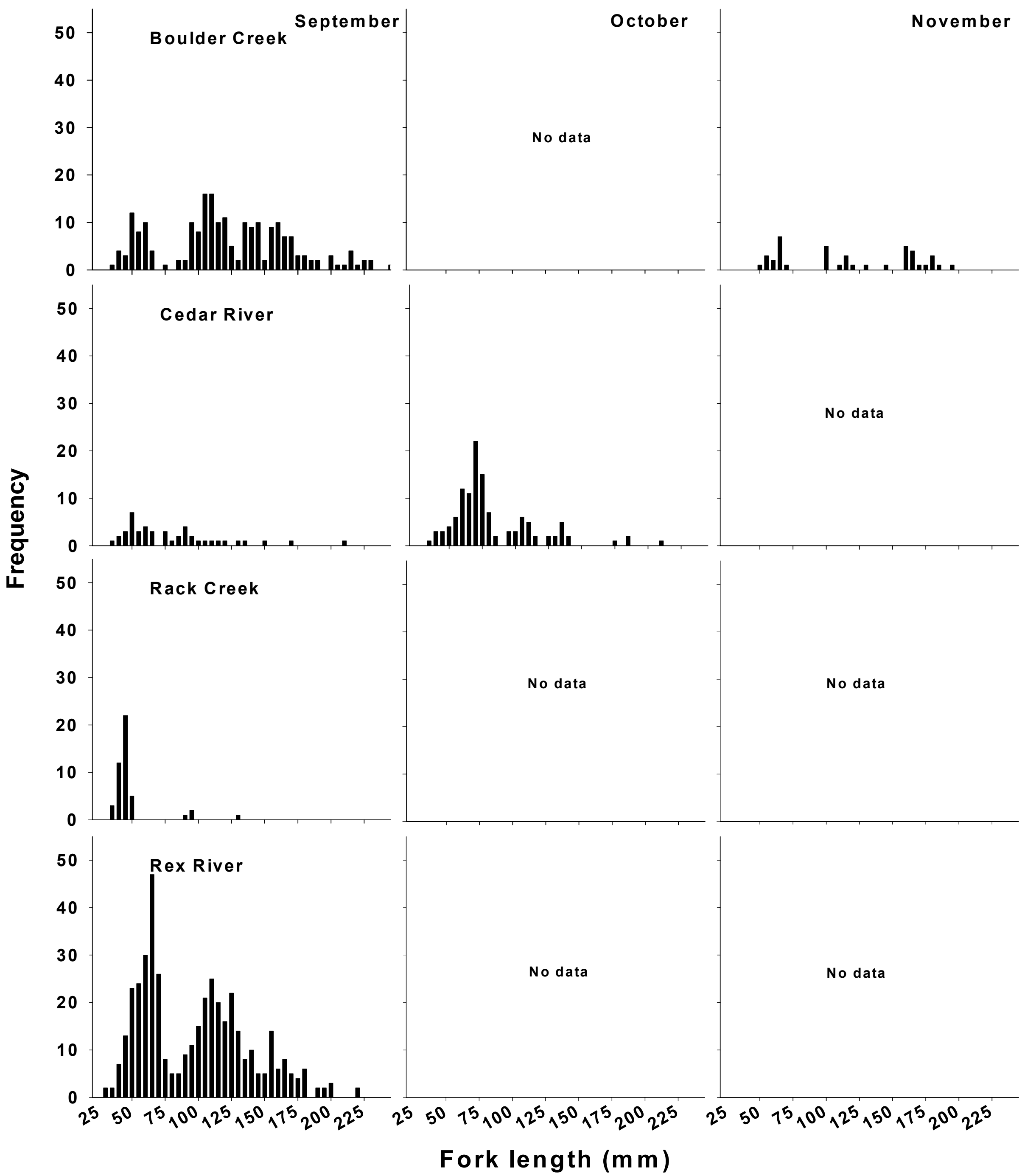

Figure 3.3.—Continued.

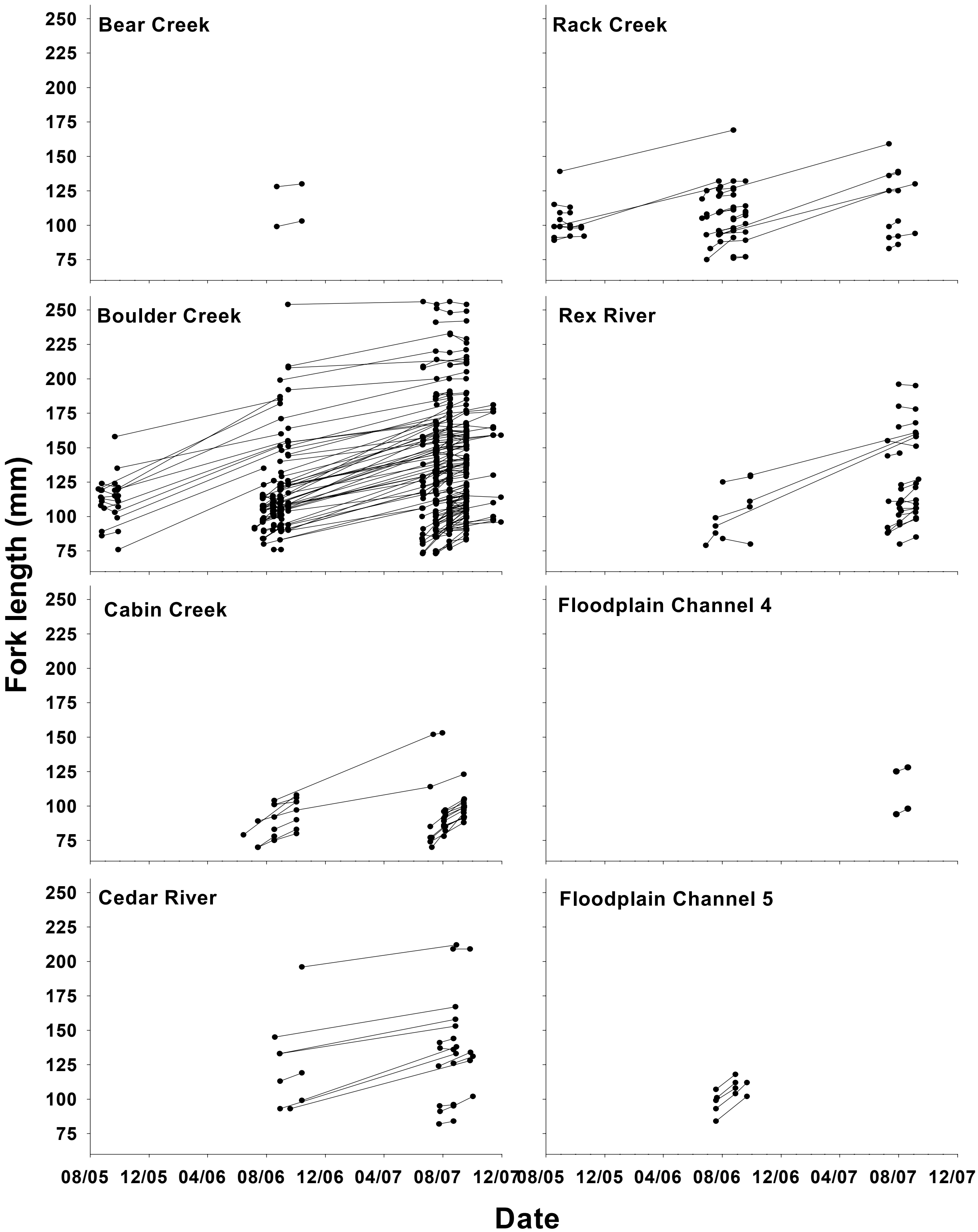

Figure 3.4.—Growth trajectories of rainbow trout captured in 2005-2007 in eight tributaries of the Cedar River Municipal Watershed. Data were derived from PIT-tagged fish that were marked and recaptured.

Appendix 4: fish movements

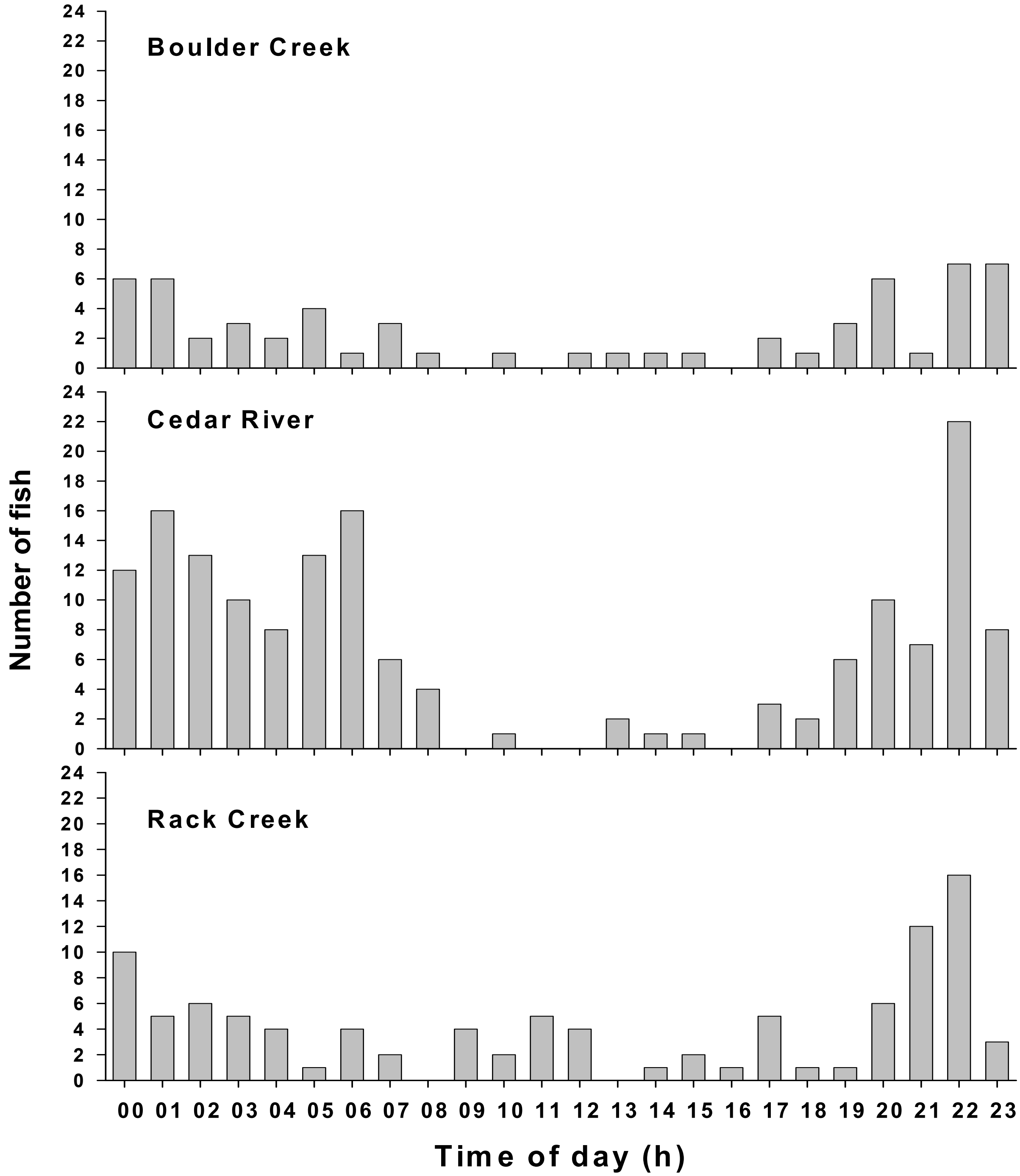

Figure 4.1.—Number of bull trout that emigrated from three streams in the Cedar River Municipal Watershed relative to time of day, 2006 – 2007.

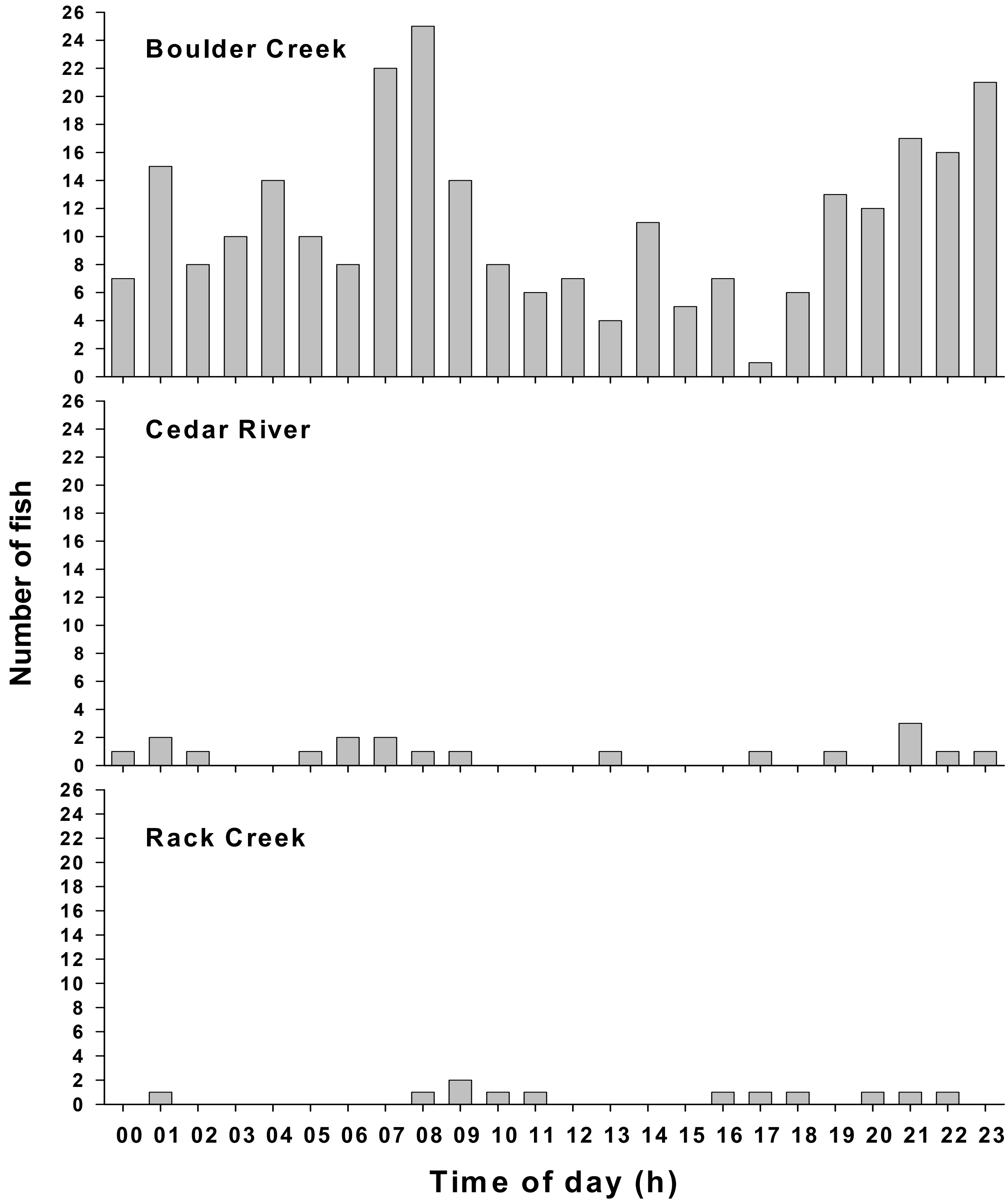

Figure 4.2.—Number of rainbow trout that emigrated from three streams in the Cedar River Municipal Watershed relative to time of day, 2006 – 2007.