Evaluation of the potential for resident bull trout to reestablish the migratory life-form
by M Lee Nelson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:
Though once migratory, many remaining bull trout populations now persist as nonmigratory "residents" isolated in headwater streams. Isolation through habitat changes and the loss of a migratory life-form increases the extinction risk of these populations. The goal of this study was to determine if resident bull trout still produce a downstream dispersing component capable of reestablishing a migratory life-form. Downstream dispersal was evaluated with picket-weir and fry traps on three tributaries to the lower Bitterroot River. Study basins had relatively high densities of bull trout (12 — 30 fish/100 m). In 1996 and 1997, a series of traps was operated spring through fall seasons in stream sections with bull trout and 1.0 to 6.5 km below presumed population boundaries. If these populations maintain both resident and migratory life-forms, then downstream movement should be significant. Alternatively, if selection has favored a nonmigratory life-form, then downstream movement below the resident populations should be absent or rare. A total of 215 bull trout were caught in 1045 trapping days; of these, only six were captured at lower traps considered below resident population boundaries. The capture of five large bull trout (343 — 450 mm) and downstream movement of numerous juveniles suggested one stream still maintains a remnant migratory population. Results indicated dispersal rates from tributary populations to the mainstem river were very low from headwater resident populations. This research suggests reestablishment of a migratory life-form from resident populations may be a slow process, even if those conditions that selected against migration are corrected.

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by

M. Lee Nelson

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APPROVAL

of a thesis submitted by

M. Lee Nelson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Though once migratory, many remaining bull trout populations now persist as nonmigratory "residents" isolated in headwater streams. Isolation through habitat changes and the loss of a migratory life-form increases the extinction risk of these populations. The goal of this study was to determine if resident bull trout still produce a downstream dispersing component capable of reestablishing a migratory life-form. Downstream dispersal was evaluated with picket-weir and fry traps on three tributaries to the lower Bitterroot River. Study basins had relatively high densities of bull trout (12 — 30 fish/100 m). In 1996 and 1997, a series of traps was operated spring through fall seasons in stream sections with bull trout and 1.0 to 6.5 km below presumed population boundaries. If these populations maintain both resident and migratory life-forms, then downstream movement should be significant. Alternatively, if selection has favored a nonmigratory life-form, then downstream movement below the resident populations should be absent or rare. A total of 215 bull trout were caught in 1045 trapping days; of these, only six were captured at lower traps considered below resident population boundaries. The capture of five large bull trout (343 — 450 mm) and downstream movement of numerous juveniles suggested one stream still maintains a remnant migratory population. Results indicated dispersal rates from tributary populations to the mainstem river were very low from headwater resident populations. This research suggests reestablishment of a migratory life-form from resident populations may be a slow process, even if those conditions that selected against migration are corrected.

INTRODUCTION

Bull trout (*Salvelinus confluentus*), like many other native inland salmonids (Behnke 1992; Thurow et al. 1997), now exist as increasingly isolated populations within fragmented patches of suitable habitat (Howell and Buchanan 1992; Thomas 1992; Rieman and McIntyre 1993; Rieman et al. 1997). Historically abundant in all major river basins of western Montana, bull trout now occupy only about 42% of their historic distribution (Thomas 1992). Similar declines have been reported for other populations across their native range of northwestern North America (Rieman et al. 1997), and the U.S. Fish and Wildlife Service has listed the bull trout as threatened under the Endangered Species Act (Federal Register, June 10, 1998).

Like other inland salmonids, bull trout express a high degree of life-history variability. Migratory life-history forms reside as adults in large rivers (fluvial) or lakes (adfluvial) and migrate up smaller streams to spawn. Juveniles typically rear one to three years in tributaries before migrating to lakes or larger rivers (Fraley and Shepard 1989; Ratliff 1992; Elle et al. 1994; Elle 1995, Riehle et al. 1997; Stelfox 1997). At age 5 to 7, adults return to natal tributaries to spawn and complete the cycle (Fraley and Shepard 1989; Elle et al. 1994; Elle 1995; Riehle et al. 1997). Migratory movements by fluvial and adfluvial bull trout are among the longest reported for inland salmonids, with movements up to 250 km reported (Fraley and Shepard 1989). In contrast, the "resident"

life-history form spawns and rears year-round in headwater, low-order streams, with relatively restricted (< 2 km) spawning and over-wintering movements by adults and juveniles (Jakober et al. 1998).

The order Salmonidae exhibits a large degree of flexibility in expression of multiple life-history forms. The genus *Salmo*, *Oncorhynchus*, and *Salvelinus* all express resident, fluvial, adfluvial, and anadromous forms. The expression of multiple life-history patterns can be viewed as an adaptation to variable environments, with each form conferring advantages under different environmental conditions (Northcote 1992). When movement corridors are intact, migratory forms can utilize multiple habitats which maximize survival or growth for various life stages. For bull trout, this entails the use of clean, cold, headwater tributaries for spawning and rearing (Fraley and Shepard 1989), and lakes and larger rivers where a more abundant prey base allows increased size and fecundity, and hence fitness, for adults. Spawning adfluvial bull trout in the Flathead River basin, for example, average 628 mm in length and 5,482 eggs per female (Fraley and Shepard 1989), whereas resident bull trout seldom exceed 305 mm in length and have only a few hundred eggs per female (Goetz 1989). Additionally, with alternate year spawning and sub-adults residing outside headwater tributaries (Fraley and Shepard 1989; Goetz 1989), several cohorts in migratory populations are removed from extirpating stochastic events, e.g., drought, fire, and debris torrents. This "risk-spreading" may reduce the likelihood of local population extinction and enhance rapid recolonization (Rieman and McIntyre 1993).

Where migration is impossible (i.e., waterfalls), or where migratory corridors have been disrupted, selective pressure will favor the nonmigratory resident life-form (Northcote 1992; 1997). Similarly, residency is advantageous if the energetic cost of movement between multiple habitats outweighs the benefits of such movement, as may occur in some streams where adequate spawning, overwintering, and prey availability are in close proximity (Northcote 1992).

Populations which include migratory and resident life-history strategies potentially have a greater chance to persist under variable habitat conditions (Gross 1991; Northcote 1992). However, when habitat conditions favor large migratory fish with their relatively higher reproductive potential, this life-form usually dominates the population. For example, bull trout populations in the McKenzie (Goetz 1997), Metolius (Riehle et al. 1997), and Flathead river systems (Fraley and Shepard 1989) are composed of mostly large fluvial or adfluvial life-history forms, and resident life-forms are rare (J. Ziller, Oregon Department of Fish and Wildlife; M. Riehle, U.S. Forest Service: personal communication; Thomas 1992).

With increased habitat fragmentation, however, the migratory life-form has become absent or rare in many bull trout populations and the resident life-history form predominates (Dambacher et al. 1992; Thomas 1992; Ziller 1992; Jakober et al. 1998). Reduced connectivity with neighboring populations and exposure to stochastic events places these remaining populations at high risk of extinction (Rieman and McIntyre 1993). Historically, bull trout are thought to have formed metapopulations, or collections of local populations spatially and temporally isolated but connected through periodic

dispersal (Hanski and Gilpin 1991; Rieman and McIntyre 1993). Dispersal has been referred to as the "glue" that sustains local populations in a metapopulation, with the rate of dispersal dependent upon the strength and distance between local populations and the availability of migratory corridors (Hansson 1991). For bull trout, connectivity between local populations may include immigration and straying of migratory forms (Rieman and McIntyre 1993). Implicit benefits of dispersal include supporting "sink" populations (Stacey and Taper 1992), maintaining genetic diversity within a metapopulation by increasing exchange between locally adapted populations, and colonizing suitable habitat after local extinctions (Rieman and McIntyre 1993). Consequently, a decrease in dispersal will reduce the stability of a metapopulation by increasing isolation and extinction risks of local populations, thereby moving the entire metapopulation towards extinction.

The bull trout population of the Bitterroot River basin is an example of increased fragmentation and loss of the migratory life-form. Historic accounts of large migratory bull trout in the Bitterroot River (Shields 1889; Evermann 1891) suggest this population once functioned like other fluvial populations: a dominant migratory life-form with adults occupying the main river, and spawning and rearing occurring in tributaries. Historical occurrence of a nonmigratory resident life-form in the drainage is unknown. Currently, however, isolated populations of headwater tributary residents are dominant in the drainage and large migratory bull trout are now rare in the mainstem (Thomas 1992; Montana Bull Trout Scientific Group [MBTSG] 1995).

Human alterations of tributaries and the mainstem river suggest bull trout in the Bitterroot River basin may have undergone selection pressure against migratory behavior since the late 1800's. Large migratory fish appear to have become rare or absent in most of the drainage since the 1930's (C. Clancy, Montana Department of Fish, Wildlife, and Parks [MFWP], personal communication). In some cases, such as populations above lowhead dams, downstream migrants have a low probability of returning to spawn in natal tributaries and the migratory trait may be selected against in a local population. In other populations, migratory fish may remain in low numbers and are periodically successful when conditions allow (Jakober et al. 1998).

A combination of factors appear to have strongly selected against the migratory life-form in the Bitterroot River basin. Bull trout are generally associated with maximum water temperatures of 10 to 15°C (Fraley and Shepard 1989; Ratliff 1992), yet temperatures in the lower main river and valley reaches of tributaries commonly exceed 20° C (MBTSG 1995). Elevated temperatures are, in part, due to residential development, grazing, and seasonal dewatering of the mainstem river and tributaries (MBTSG 1995). Such temperatures potentially limit bull trout distribution in the mainstem river and lower reaches of tributaries, and may represent seasonal barriers to movement. Lowhead irrigation dams, common on tributary streams to the mainstem river, restrict or eliminate upstream migratory movement and potentially divert downstream migrants into irrigation canals. Bull trout migrating downstream to the mainstem river also face competition and predation from nonnative salmonids. Resident bull trout and native westslope cutthroat trout (*Oncorhynchus clarki lewisi*) populations

typically occupy higher gradient, low-order tributary reaches above the valley floor, whereas nonnative salmonids, including brook trout (*S. fontinalis*), brown trout (*Salmo trutta*) and rainbow trout (*O. mykiss*) populations, now dominate the mainstem river and the lower reaches of tributaries. Interaction, either predation or competition, with nonnative salmonids is likely detrimental to bull trout (Dambacher et al. 1992; Rieman and McIntyre 1993). Additionally, hybridization between bull trout and brook trout is common where the species distributions overlap (Kitano et al. 1994). Currently, brook trout are present in about 75% of the streams occupied by bull trout in the basin, though amount of distribution overlap is generally low (MBTSG 1995; Rich 1996). Due to earlier maturation of brook trout and reduced fertility of hybrids, cross-breeding of brook trout and bull trout can result in brook trout-dominated communities (Leary et al. 1983; Leary et al. 1993). These conditions have led to a fragmented bull trout population with little or no interchange between local populations (MBTSG 1995).

The reestablishment of connectivity between remaining bull trout populations and the migratory life-form is considered essential for bull trout persistence in the Bitterroot River basin and elsewhere (Rieman and McIntyre 1993; MBTSG 1995). However, whether the migratory life-form would be reestablished if selective pressures against migration were fixed is unknown. Some evidence suggests that multiple life-forms can be expressed in one population; for example, Nordeng (1983) found that resident Arctic char (*S. alpinus*) can give rise to anadromous forms and vice versa. Similar examples of a flexible life-history have been described for brown trout (Jonsson 1985), and kokanee

and sockeye salmon (Ricker 1938; Rieman et al. 1994). Such flexible life-history response suggests life-history form is not strongly genetically controlled.

In contrast, residency appears to be tightly genetically controlled where long distance movement is deleterious to the fitness of the individual, or when populations reside above impassable barriers (Northcote 1992). When populations exist above impassable barriers, downstream movement over the barrier results in the permanent loss of individuals to the population. Consequently, selection pressure can result in a number morphological and genetic differences between stocks above and below barriers (Northcote and Hartman 1988). Evidence supporting genetic differences between stocks above and below barriers has been described for rheotactic response (Northcote 1981), growth and maturity (Northcote 1981), swimming stamina (Tsuyuki and Williscroft 1977; Northcote and Kelso 1981), and rate of downstream migration (Jonsson 1982; Elliott 1987). Thus, the expression of life-history patterns appears to have two controlling factors. Phenotypic "plasticity" of life-history cued by environmental conditions appears common in salmonid populations where both life-forms can be successful. In other populations where selection strongly favors one life-form, genetic control may predetermine individual life-history.

It is unknown if bull trout populations that have undergone apparent selection pressure for residency and against migration can give rise to a migratory form through phenotypic plasticity. If genetic control of migratory tendencies is strong, it is possible that selection against migration may remove the trait from the population. In this

situation, the reestablishment of the migratory life-form may require evolutionary adaptation, or the introduction of migratory stocks.

In this study, I addressed the question whether remaining bull trout populations in three tributaries to the Bitterroot River basin maintain both resident and migratory tendencies, or if selective pressure has eliminated the migratory component of the population. My main objective was to determine the potential for reestablishing a migratory life-form from resident bull trout populations by assessing the magnitude and timing of dispersal or outmigration from isolated headwater populations. If remaining resident populations maintain both resident and migratory life-forms, then downstream movement from headwater populations should still be significant. Alternatively, if downstream migration has a strong genetic component, then dispersal and outmigration should now be rare and the potential for reestablishing a migratory life-form would be low.

STUDY AREA

The Bitterroot River is formed by the confluence of the East and West Forks of the Bitterroot River near Conner, MT (Figure 1). The river flows 137 km north to its junction with the Clark Fork of the Columbia River near Missoula, MT. The basin encompasses 7,288 km^2 of national forest, wilderness and private lands. Mean annual flow at the mouth is 74 m^3/s (U.S. Geological Survey 1999). No natural fish barriers exist on the mainstem river.

Lack of natural barriers and historical evidence suggest migratory bull trout were once common throughout the Bitterroot River drainage. Evermann (1891) captured "salmon trout" by hook and line weighing up to 6.35 kg near the river mouth. Shields (1889) describes "trout" (presumably bull trout) between 4.1 and 5.2 kg captured in 1883 near Corvallis, MT. It is unknown if these bull trout represented a population of migratory fish from the Bitterroot River, the Clark Fork of the Columbia, or adfluvial fish from Flathead Lake, MT, or Lake Pend Oreille, ID.

Migratory bull trout are now rare in the Bitterroot River basin (MBTSG 1995; Jakober et al. 1998). Small bull trout (< 300 mm) are occasionally captured during MFWP fall electrofishing population estimates in the mainstem river above Victor, MT, but none have been collected downstream since electrofishing estimates began in 1989 (MFWP, data files, Hamilton). Larger bull trout (> 500 mm) are occasionally collected

Figure 1. Distribution and status of bull trout in the Bitterroot River drainage.

during electrofishing estimates in the upper East Fork and West Fork of the Bitterroot rivers, suggesting small, remnant populations of fluvial fish persist in some drainages (MBTSG 1995; Jakober et al. 1998).

Based on evidence from other migratory bull trout populations (e.g., Swanberg 1997), the tributaries to the Bitterroot River historically supported migratory juvenile fish, and seasonally, large adult spawners from the mainstem. However, most remaining populations are now located in upper reaches of larger tributaries ($3^{rd} - 5^{th}$ order) in the Bitterroot National Forest below natural barriers (Figure 1), and appear to spend their entire lives in these streams. Compared to fluvial life-history forms, these resident populations have relatively restricted movement (< 2 km) between spawning and overwintering habitats (Jakober et al. 1998). Additionally, remaining populations are separated by long distances (Figure 1), and by conditions which restrict or prevent movement between the populations (e.g. high temperatures, dewatering, and lowhead dams) (MBTSG 1995).

In addition to bull trout, native species in the drainage include westslope cutthroat trout, mountain whitefish (*Prosopium williamsoni*), longnose sucker (*Catostomus catostomus*), largescale sucker (*C. macrocheilus*), redside shiner (*Richardsonius balteatus*), longnose dace (*Rhinichthys cataractae*), northern squawfish (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), and slimy sculpin (*Cottus cognatus*). Common nonnative species include brook trout, brown trout, and rainbow trout.

I evaluated dispersal from bull trout populations occupying three tributaries to the Bitterroot River: Sweathouse, Skalkaho, and Sleeping Child creeks. Streams were chosen

based on having an abundant resident bull trout population (high potential to produce and detect outmigration), adequate access, and a stream size that allowed for effective trapping. Sweathouse Creek is a third order, 17-km long stream (watershed area 73 km^2) which joins the mainstem Bitterroot River near Victor, MT (Figure 2). The lower 8 km is characterized by a wide valley floor, stream widths of 5 to 13 m, and large pools and low-gradient riffles and runs. Above river km 8, the stream flows through a narrow canyon where wetted widths vary from 3 to 7 m and plunge-pools and high-gradient riffles are the dominant habitat types. Two natural waterfall barriers occur at river km 11 and 11.5. A high-gradient section at river km 8.0, built in the 1960's during mining operations, appears to inhibit upstream movement as indicated by nonnative brook trout common below the site, but rare above. Flow regime in Sweathouse Creek, and other study streams, is typical of Rocky Mountain streams. Peak runoff normally occurs during spring snowmelt (May - June), decreases to base flow by late fall or winter, then increases due to late winter and early spring freshets. Peak discharge exceeded 15 m^3/s at the stream mouth in June 1997. Base flow is about 0.2 m^3/s above irrigation withdrawals. Irrigation withdrawals occur throughout the lower 8 km of stream; however, flow is generally present through the year to the mouth. Peak summer temperature ranges from 14° C at river km 7.3, to 21° C at the stream mouth.

Sweathouse Creek has a relatively abundant, but restricted, bull trout population numbering about 1000 - 2000 fish (Figure 3). The population is mostly confined to the 3 km section between the manmade high-gradient section and the first falls (Figure 2). Cutthroat trout are abundant above river km 7, but are uncommon below (Figure 3).

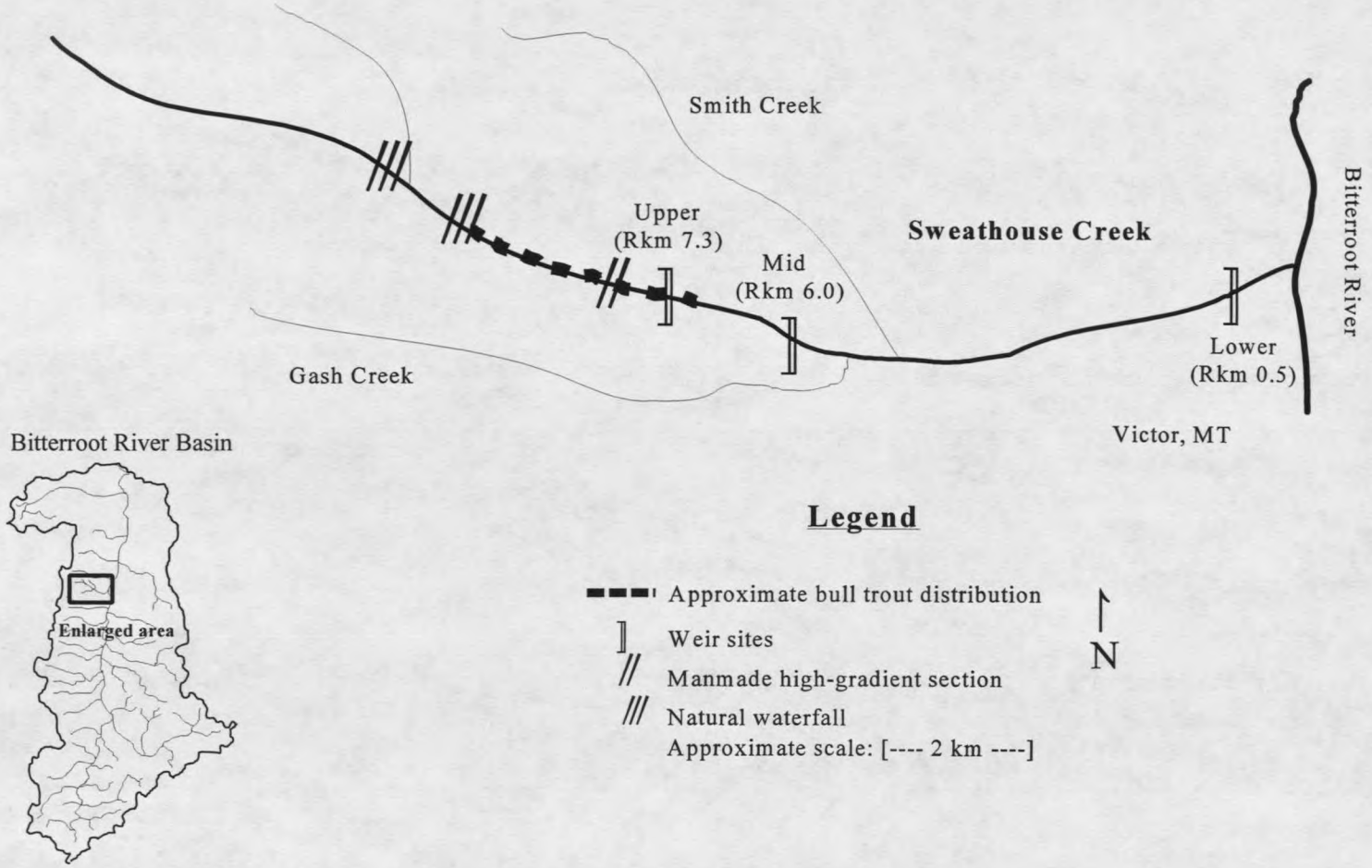

Figure 2. Bull trout distribution and trapping sites on Sweathouse Creek, Ravalli County, MT.

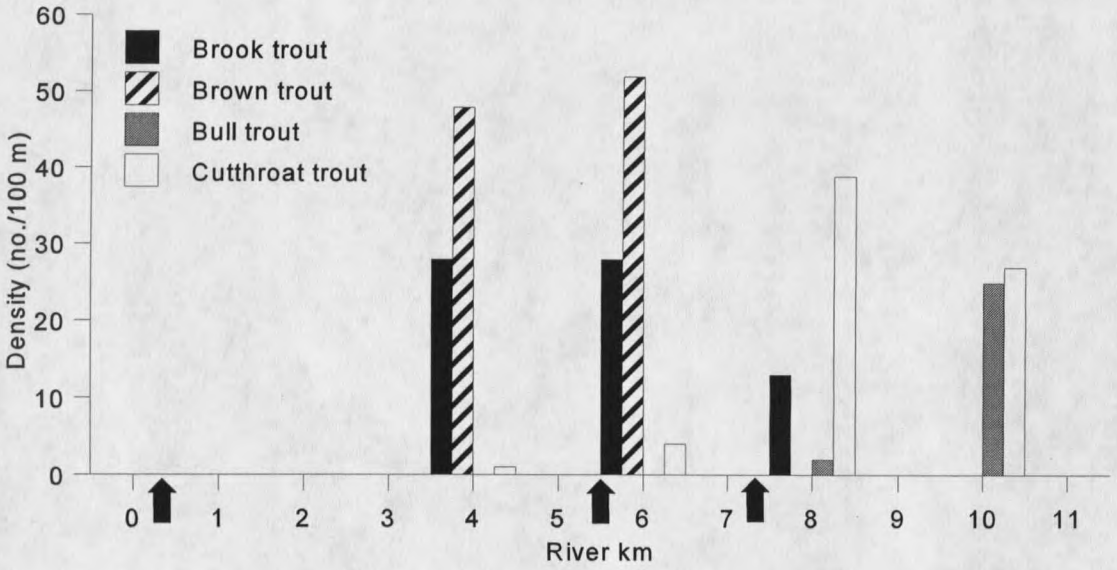

Figure 3. Salmonid densities by river section along Sweathouse Creek. Data obtained from electrofishing estimates, 1991— 1996 (MFWP, data files, Hamilton). Arrows denote locations of weirs.

Unlike bull trout, cutthroat are found above the falls. Brook trout, brown trout, and rainbow trout are common in the first 7 km, but are rare where bull trout are found. Detailed population estimates for all salmonids for study streams are listed in Appendix A, Table 4.

Skalkaho Creek is a fifth-order, 43-km long stream (watershed area 228 km^2) which joins the Bitterroot River near Hamilton, MT (Figure 4). The lower 19 km flows through a wide valley floor and the stream is characterized by low gradient riffles and runs, and stream widths of 10 to 15 m. Above river km 19, the stream flows through a constrained valley, and is characterized by fast water habitats. Several low-head dams

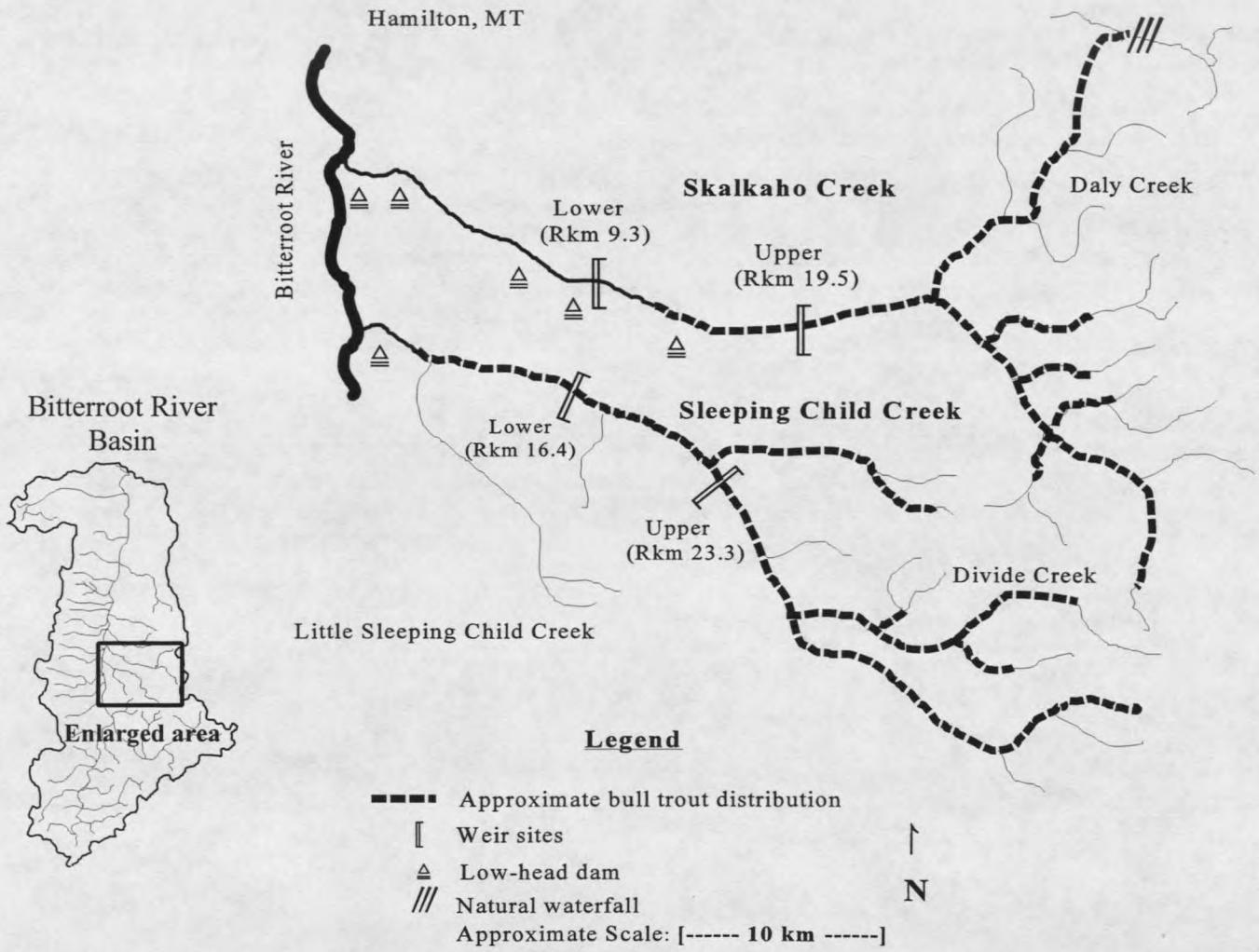

Figure 4. Bull trout distribution and trapping sites on Skalkaho and Sleeping Child creeks, Ravalli County, MT.

and irrigation water withdrawal structures, built between 1892 and 1942, are located in the lower 14 km of the Skalkaho Creek (Figure 4). Above irrigation withdrawals, discharge ranges from about 30 m^3/s in spring runoff to 0.9 m^3/s in late fall (U.S. Forest Service, unpublished data). In 1996 and 1997, upstream movement by fish over dams at river km 2 and 8.2 was unlikely between mid-June to mid-September due to low flows, including periods in August and September 1996 when the stream was completely dry at river km 2. Additionally, fish screens are not employed on the four major irrigation canals which draw water from Skalkaho Creek. I observed substantial numbers of fish occupying these canals during the irrigation season (June - September). A gradual shutdown of the uppermost canal is employed at the end of the irrigation season to allow fish to return to the stream. A maximum water temperature of 16.7 °C was recorded in the lower section (river km 9.3), but water temperature rarely exceeded 13°C in the upper section (river km 19.5).

Skalkaho Creek and its tributaries support a large population of resident bull trout (about 8000 - 15,000 fish) above river km 10 (Figures 4 and 5). Bull trout densities above river km 20 in Skalkaho Creek are among the highest recorded among remaining bull trout populations in the Bitterroot River basin (MFWP, data files, Hamilton). Population densities decline downstream of the confluence with Daly Creek, and bull trout are rare or absent below river km 10 (Figure 5). In contrast, cutthroat trout are abundant downstream to river km 8.2, above where substantial irrigation withdrawals occur. Brown trout dominate the fish community in the lower 10 km, but are rare above

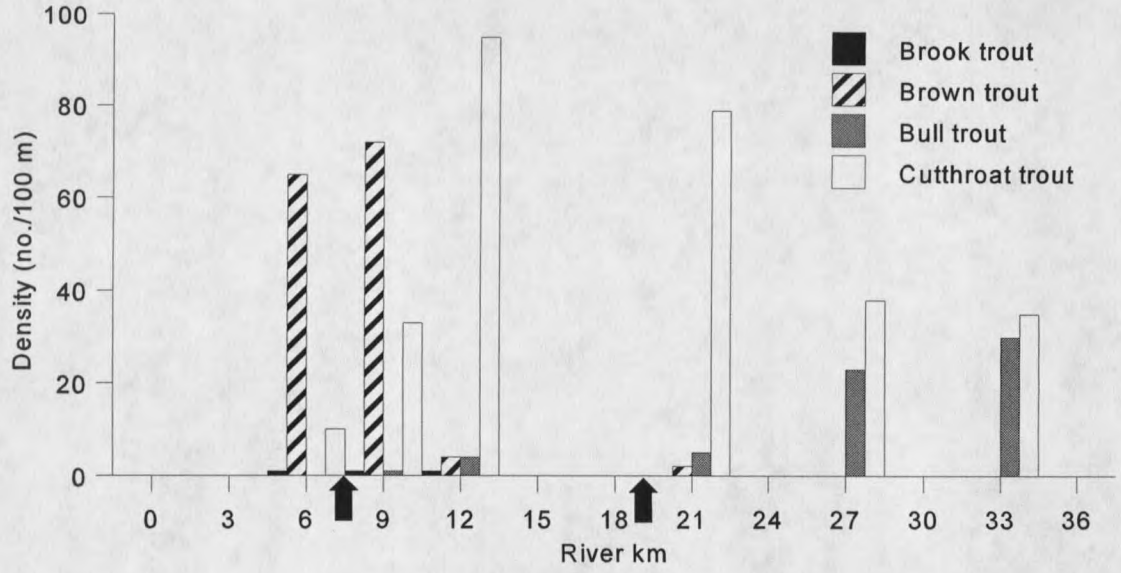

Figure 5. Salmonid densities by river section along Skalkaho Creek. Data obtained from electrofishing estimates, 1989— 1997 (MFWP, data files, Hamilton). Arrows denote locations of weirs.

river km 12. Brook trout and rainbow trout are common below the first lowhead dam at river km 2, but are rare upstream.

Sleeping Child Creek is a fourth order, 41-km long stream just south of the Skalkaho Creek drainage (Figure 4). The stream averages 2.2 to 7.5 m wetted width, and has a watershed area of 170 km^2. The lower 16 km of Sleeping Child Creek flows though a wide valley and the stream is characterized by runs and large pools. Like other study streams, the upper reach flows through a narrow canyon on the Bitterroot National Forest, and moderate-gradient riffles and runs dominate the section of the stream. A lowhead dam at river km 1.7, built prior to the 1950's, is likely a barrier to upstream movement during low flows. Discharge ranges from about 15 m^3/s in spring runoff to 0.2 m^3/s in

late fall (U.S. Forest Service, Bitterroot Forest, unpublished data, Hamilton). Irrigation withdrawals occur throughout the lower reach, however flow is maintained throughout the year to the mouth. Maximum daily temperature was often > 15.0°C (peak of 17.4°C) during July and August in the lower reach (river km 16.4), but rarely exceeded 13.0°C in the upper reach (river km 23.3).

Maximum densities of bull trout in Sleeping Child Creek are about half those found in Sweathouse and Skalkaho creeks (Figure 6). Unlike other study streams, bull trout in Sleeping Child Creek are not confined to the upper stream reaches; however, densities in the lower reaches are relatively low. An estimate of about 2000 - 5,000 bull trout occupies the basin. Cutthroat trout are common throughout the drainage,

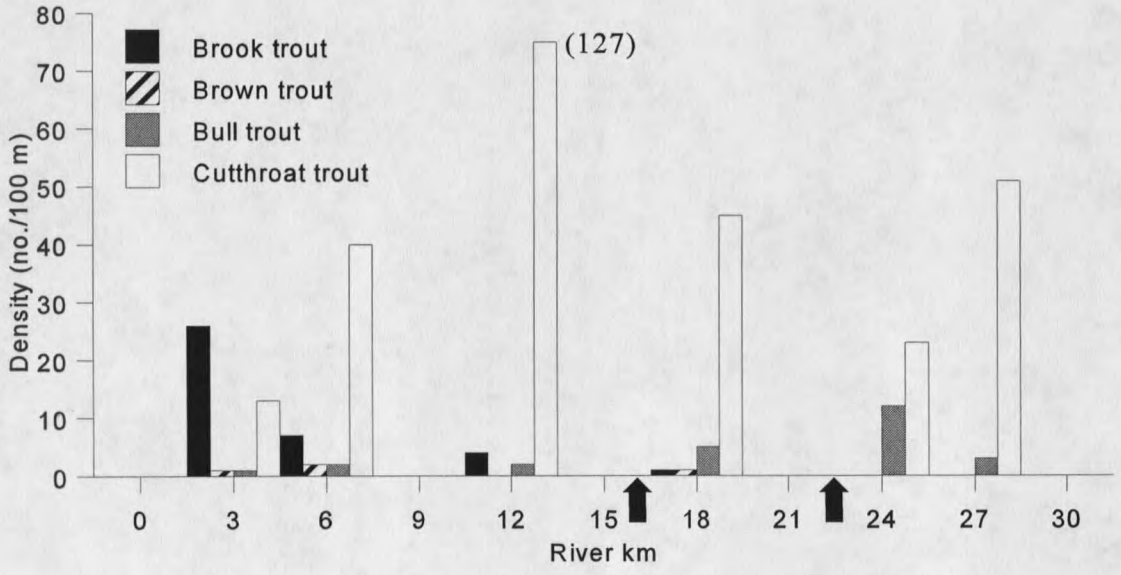

Figure 6. Salmonid densities by river section along Sleeping Child Creek. Data obtained from electrofishing estimates, 1986— 1997 (MFWP, data files, Hamilton). Arrows denote locations of weirs.

whereas brook trout are common only in the lower 3 km and rare above river km 13 (Figure 6). Rainbow trout and brown trout are present in low numbers in the lower 7 km, but rare above the lowhead dam at river km 1.7.

METHODS

To assess timing and magnitude of movement in resident bull trout populations, I positioned a series of weirs within and downstream of known population boundaries on Sweathouse, Skalkaho, and Sleeping Child creeks (Figures 2– 6). To assess intra-population movement, upper weirs were positioned within or near areas of high abundance. To assess dispersal from a population, 1— 2 weirs were placed 1.3 to 10.2 km downstream of the upper weir site and below the core population area (Figures 3, 5, and 6). An exception was Sleeping Child Creek where bull trout occupied a greater proportion of the drainage and there was no clearly distinct lower population boundary compared to other study streams. In this case, I positioned the lowermost weir upstream from a section with substantial irrigation withdrawal. I estimated > 95% of the bull trout population occurred above this site.

A "picket-fence" weir was erected across the length of the stream (6.0 to 21-m length) at each site. Weirs were constructed of 18-mm diameter aluminum conduit pipe spaced 11-mm apart in steel frames (Figure 7). Frames were held in a 45° angle upright position with attached legs. Steel fence posts were driven into the substrate for additional support. To determine if resident bull trout populations produce outmigrants, my trap design needed to effectively sample downstream moving salmonids between 107— 200 mm, which is the reported length range for most juvenile outmigrants from migratory bull

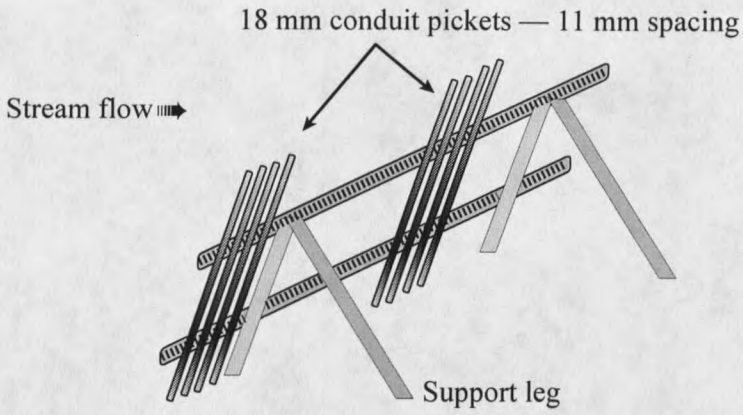

Figure 7. "Picket-style" weirs used to capture upstream and downstream migrants.

trout populations (Fraley and Shepard 1989; Ratliff 1992; Elle et al. 1994; Elle 1995, Riehle et al. 1997; Stelfox 1997). To aid in trapping small fish, 13-mm square plastic "vexar" mesh was placed on the weir face during periods of low debris flow. Similar weirs used on the Rapid River, ID, were effective at sampling outmigrating juvenile fluvial bull trout (Elle et al. 1994; Elle 1995).

Upstream and downstream trap boxes attached to weirs were used to capture migrant fish. Trap boxes were constructed of 13-mm plywood and 7-mm square plastic mesh. To reduce escapement of trapped fish, both boxes included conical shaped entrances which forced fish to swim slightly upwards as they entered the box (Figure 8). The downstream box also incorporated a nylon mesh sock which extended from the entrance to an interior baffle. Held perpendicular in the water column, this flexible sock allowed fish to enter the box, but reduced their ability to escape once inside. Similarly, a hinged plastic mesh door on the upstream trap box entrance allowed fish to enter, but

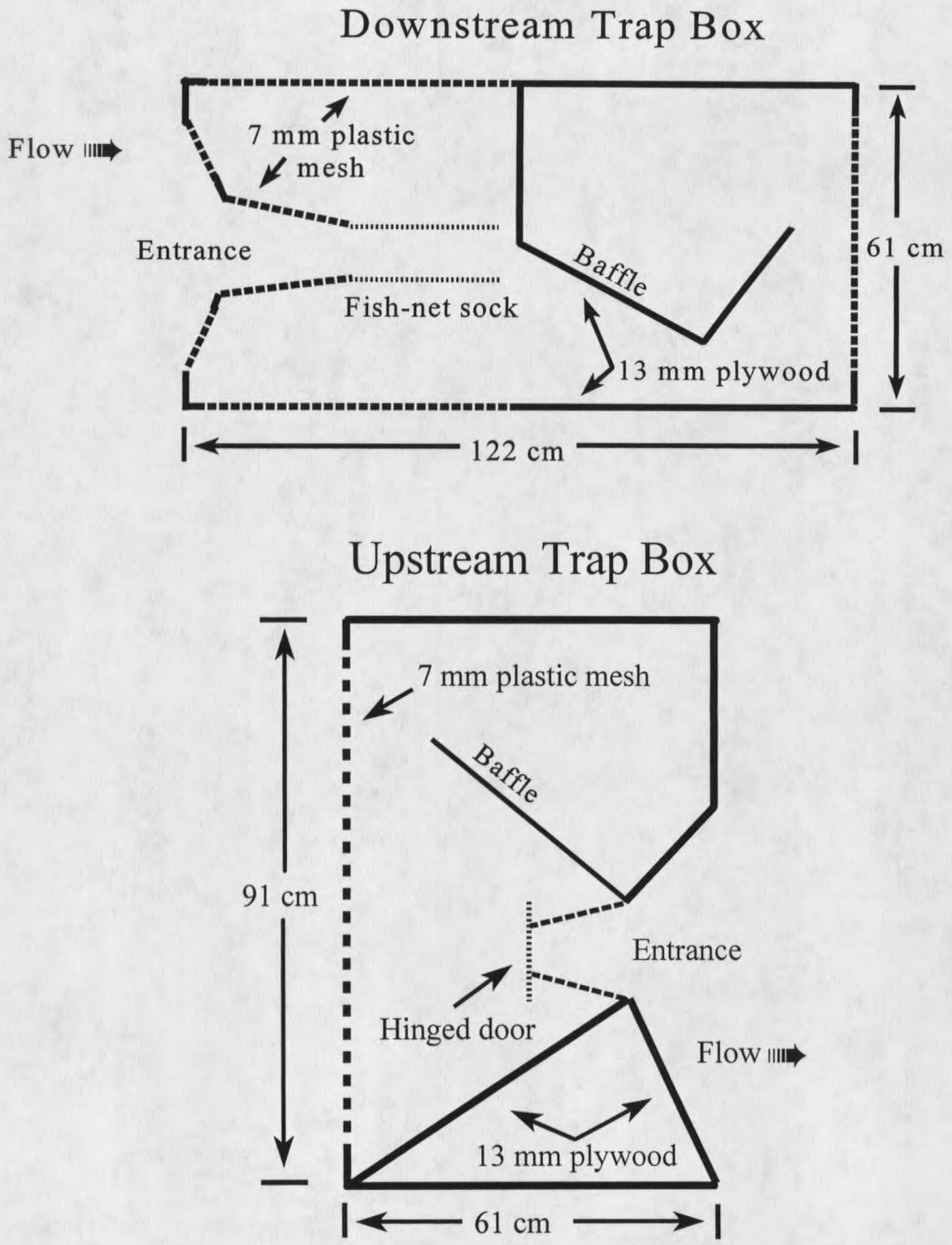

Figure 8. Topside view of downstream and upstream trap boxes.

closed behind them to reduce trap escapement. A small space remained below the door to allow smaller fish to enter unhindered. To enhance attraction of fish to the upstream box entrance, the box was designed to capture a large amount of water and force it through a much smaller entrance area, thereby increasing velocity at the entrance relative to the stream velocity. To reduce stress and mortality, both boxes included baffles to decrease current velocities. Boxes were attached to the weir with 13-mm plastic mesh, and held in place with steel fence posts.

Weirs were placed diagonally (angle $\geq 45^{o}$) in the stream current to lead fish to the appropriate trap box (Figure 9). Weirs were generally placed in shallow (0.3 to 0.75 m), low-gradient (< 2.0%) runs (velocities of 0.3 to 1.0 m/s) with uniform depths. The downstream trap box was typically placed in the thalweg. During low flow periods, rock weirs were occasionally constructed to deflect water towards, and increase flow through,

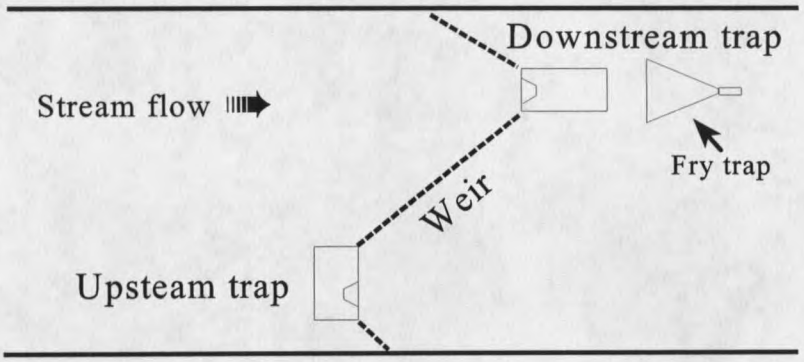

Figure 9. Weir and trap placement used to capture migrant fish in study streams.

the upstream trap box. During spring runoff (mid-April through June), full stream width spanning weirs became clogged with debris and collapsed. Thus, I only used partial weirs placed along stream margins (weirs spanning 1/4 to 3/4 stream width) and trapped only downstream moving migrants.

Wire-mesh fyke nets were periodically operated in conjunction with weirs to enhance capture of small downstream migrant fish. Fykes nets were constructed from 6-mm and 3-mm square mesh and tapered from a 91-cm^2 opening to a 15-cm diameter cod end. Fish were collected in a 60-cm long nylon bag (2-mm mesh) secured to the cod end with 15-cm plastic screw collar. Plastic funnels were attached to the interior of the collection bag to reduce velocities. Fry traps were usually set directly below the downstream trap box (Figure 9). This placement allowed some filtering of larger debris, and likely directed more fry to the trap. During low-flows, fry traps were occasionally placed in pool tail-outs where a majority of stream flow would be captured.

Trapping was conducted over a two year period from July 1996 to November 1997. Weir operation was nearly continuous during low-flow, ice-free periods (mid-July to late September) and was intermittent during high flows in spring, and leaf-fall in fall (specific dates are given in Appendix B, Table 5). When flow or debris conditions prohibited maintenance of weirs at all sites, only lowermost traps were operated. During heavy leaf-fall (late September through mid-November) on Skalkaho Creek, the weir clogged rapidly and was operated only during nighttime hours when potential to detect bull trout movement was greatest (M. Riehle, U.S. Forest Service, OR, personal communication); all other sites were operated 24 hours/day during the trapping periods.

Fry trap operation was mostly limited to low-flow and low-debris periods (Appendix B, Table 5).

Weir efficiency was measured by releasing known numbers of marked salmonids above the lower Sweathouse weir. Nineteen adipose clipped brown trout and rainbow trout (fork length [FL] range 78– 199 mm, median = 112 mm) were released 125 m above the trap after initial capture in July 1996. Plastic mesh was not used on the weir face during the efficiency trial. Lower Sweathouse Creek was chosen for efficiency trials because downstream moving juvenile migrants were common at the site, and because these migrants were fluvial life-forms, it was believed they would continue a characteristic downstream "outmigration" movement after re-release above the weir. Relatively low catches of juveniles at other weir sites, and the predominance of resident life-forms, prevented weir efficiency trials at other sites. In 1997, I was unable to complete more extensive weir efficiency trials because high flows during spring and early summer prevented the operation of a full-stream width weir at the lower Sweathouse site. The weir was removed and set on a different stream in July.

Trap box escapement was evaluated periodically by leaving marked salmonids (n=45 downstream box; n=17 upstream box; 1 to 6 per trial; FL range 85– 270 mm) in each trap box an additional night after capture. Escapement was evaluated in low discharge conditions of late summer and early fall in 1996 and 1997.

Trap loss to mink (*Mustela vison*) predation also occurred occasionally at all sites during both years as evidenced by entry holes in trap box screens. In 1996, I applied commercial coyote urine scent on holding boxes to discourage mink entrance. Mink

activity decreased, but was not eliminated. In 1997, a live-animal trap was used to capture and relocate four mink from Sleeping Child Creek sites. Removal of mink from other sites, located on private properties, was considered inappropriate.

Fry trap efficiency was not assessed during this study. However, with identical traps, Clancy (1991) determined an average of 15% recapture rate of marked fry and floats released above traps on streams similar in size to Sweathouse Creek. Capture rates were likely higher during this study when fry traps were operated in conjunction with the weir and its funneling effects.

Traps were checked at least once daily during low flows, but more frequently in spring and fall when debris flows clogged weirs rapidly. Captured fish were anesthetized with MS 222 (tricaine methanesulfonate), measured (fork length) to the nearest millimeter, weighed to the nearest gram, and checked for previous marks or tags. To indicate weir of capture, the distal half of either the left or right pelvic fin, or the entire adipose fin was removed from salmonids, catostomids, and cyprinids > 60 mm. In addition to fin clips, bull trout and other salmonids > 185 mm FL received Visual Implant (VI) tags (Northwest Marine Technologies, Seattle, WA, U.S.A.). Tags were inserted into post-ocular adipose tissue. Scales were taken from 27 bull trout (FL range, 126–450 mm) for ageing purposes. Scales were removed from below the dorsal fin, mounted between thin sheets of plastic, and viewed with a microfiche reader. Fish were released upstream or downstream of the weir, depending on direction of movement.

To assess factors affecting timing and magnitude of movement, discharge and temperature were monitored daily near each trapping site during both field seasons.

Established U.S. Forest Service continuous-recording gauge sites near upper traps on Skalkaho and Sleeping Child creeks recorded discharge from mid-March to late October. At other sites, stage height was recorded daily from staff gauges. Rating curves for staff gauges were developed from three or more discharge calculations using a Model 201 Marsh-McBirney electromagnetic current meter and the velocity-area method. Electronic thermographs (Onset Inc., Pocasset, MA, U.S.A.) were used in each study stream to determine daily maximum, minimum, and average temperatures. Thermographs recorded temperatures every 1.6 to 3.2 hours and were operated continuously at each trap site through the trapping periods. When available, additional thermographs were evenly spaced at sites above and below traps locations.

RESULTS

Trap Efficiency and Trapping Conditions

The total number of fish (4,108), variety of species collected (12), and size range of captured fish (19– 635 mm) suggest the traps were effective at catching upstream and downstream migrants (Tables 1 and 2; Figure 10). Two results indicate downstream moving juvenile salmonids (100— 200 mm) were effectively sampled when present. First, 81% (1,860 of 2,292; Figure 10) of salmonids collected and measured moving downstream were < 200 mm, including 83 bull trout. Second, I was able to recapture 47% (9 of 19) of marked juvenile salmonids during efficiency trials for downstream moving migrants (median FL 112 mm) within five days. Plastic mesh, typically used on weirs in Sweathouse and Sleeping Child creeks, was not used during the efficiency trial and would have likely increased number of recaptures. Overall, 2,312 salmonids were captured moving downstream (median FL 92 mm, range 19– 521 mm), and 1,191 were captured moving upstream (median FL 165 mm, range 40– 635 mm).

To maintain high capture efficiencies, I operated full-width weirs on Sweathouse Creek and Skalkaho Creek in flows up to about 2 and 4 m^3/s, respectfully. Above these flows, partial-width weirs were employed (late-April to June or July; Appendix B, Table 5). I did not attempt to evaluate efficiency of partial weirs because discharge, debris flow, and weir length continuously changed; however, 155 salmonids were captured

Table 1. Species and total number of fish caught moving downstream at weir sites in 1996 and 1997. Parentheses indicate number of days downstream trapping was conducted.

	Stream						
	Sweathouse			Skalkaho		Sleeping Child	
Species	**Lower** (176)	**Mid** (281)	**Upper** (96)	**Lower** (179)	**Upper** (97)	**Lower** (109)	**Upper** (107)
Bull trout		2	1	4	26	28	73
Brook trout	8	130	41			16	2
Brown trout	292	71	5	36	2	1	
Cutthroat trout	2	49	9	419	63	34	54
Rainbow trout	144			1			
Bull x Brook				2	3		
Cutthroat x Rainbow	1			6		3	
Mountain whitefish	780	4					
Slimy sculpin	17	57	3	44	8	27	2
Longnose sucker	56	2				10	2
Large-scale sucker	42						
Longnose dace	82	2					
Northern squawfish	19						
Redside shiner	16						
Unidentified fry	9	19				1	

Table 2. Species and total number of fish caught moving upstream at weir sites in 1996 and 1997. Parentheses indicate number of days upstream trapping was conducted.

	Stream						
	Sweathouse			Skalkaho		Sleeping Child	
Species	**Lower** (113)	**Mid** (210)	**Upper** (92)	**Lower** (144)	**Upper** (97)	**Lower** (109)	**Upper** (101)
Bull trout		1	1		45	11	23
Brook trout	7	221	66		2	35	7
Brown trout	86	55	10	52	12	4	
Cutthroat trout		12	11	50	114	72	43
Rainbow trout	33	1		1			
Bull x Brook				1	2		
Cutthroat x Rainbow				1		3	
Mountain whitefish	209						
Slimy sculpin		33	5	10	4	61	
Longnose sucker	6	2				50	4
Large-scale sucker	3						
Longnose dace	3						
Northern squawfish	2						
Redside shiner	4						
Unidentified fry							

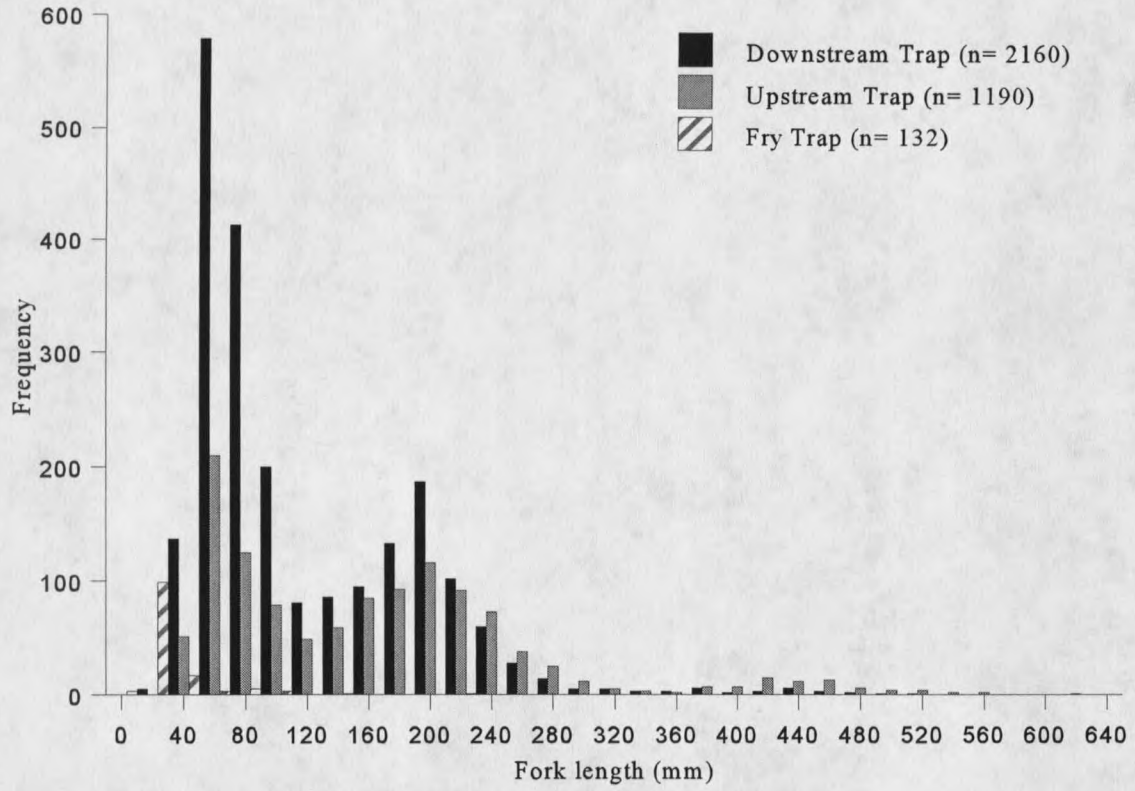

Figure 10. Length-frequency of all salmonids captured by fry traps, and downstream and upstream weir traps.

when partial-weirs were employed, including 147 juvenile salmonids collected at the lower Sweathouse weir. The few captures of salmonids with partial-weirs at mid Sweathouse (n= 3) and lower Skalkaho (n= 5) weirs was likely indicative of low downstream movement of juveniles during the high-flow period in those stream reaches. All salmonids captured by partial-weirs were < 200 mm, suggesting larger fish probably could avoid this structure.

Trap boxes were effective at holding migrants after capture. About 91% (41 of 45) of salmonids were retained overnight in the downstream box during efficiency trials,

while 88% (15 of 17) were retained in the upstream box. Due to their small body size, escapement by salmonids < 50 mm was likely high through the 7-mm plastic mesh. Mortalities in trap boxes were infrequent. Overall, 4% of fish were found dead in the downstream boxes, and 1% in upstream boxes. Mortality was greatest in mountain whitefish young-of-year (YOY) (71% of all mortalities), and in fish < 100 mm (92% of all mortalities). About 50% (55 of 109) of downstream box mortalities, all mountain whitefish YOY, occurred in one high flow event at the lower Sweathouse weir.

Relatively few fish were captured in fry traps. A total of 113 salmonid fry (FL range 19 – 48 mm), and 19 larger salmonids (FL range 51– 241 mm) were collected in 343 fry trapping days. Of all fry caught, only four were bull trout (FL range 32– 40 mm). While salmonids > 50 mm were occasionally captured, it is likely most could avoid the trap by swimming upstream and around the frame. Overall, a 10% (15 of 156) mortality rate was observed in fry traps.

Trapping was conducted during all flow and water temperature conditions except winter ice-cover (Figure 11). In both years, streams were trapped during the declining limb of spring-runoff (late June - mid-August) until near base-flow conditions in November. Average daily water temperatures (at upper sites) peaked at about 14°C in late August and dropped below 5°C by mid-October. Surface ice started forming on streams in late October as low daily water temperatures neared 0°C. In 1997, I trapped before and during spring-runoff on Sweathouse (mid-March to late June) and Skalkaho Creek (mid-March to mid-July). Freshets were common prior to spring-runoff and water temperatures ranged from 1– 5°C. Except for a three day period, 28– 30 May, high flow

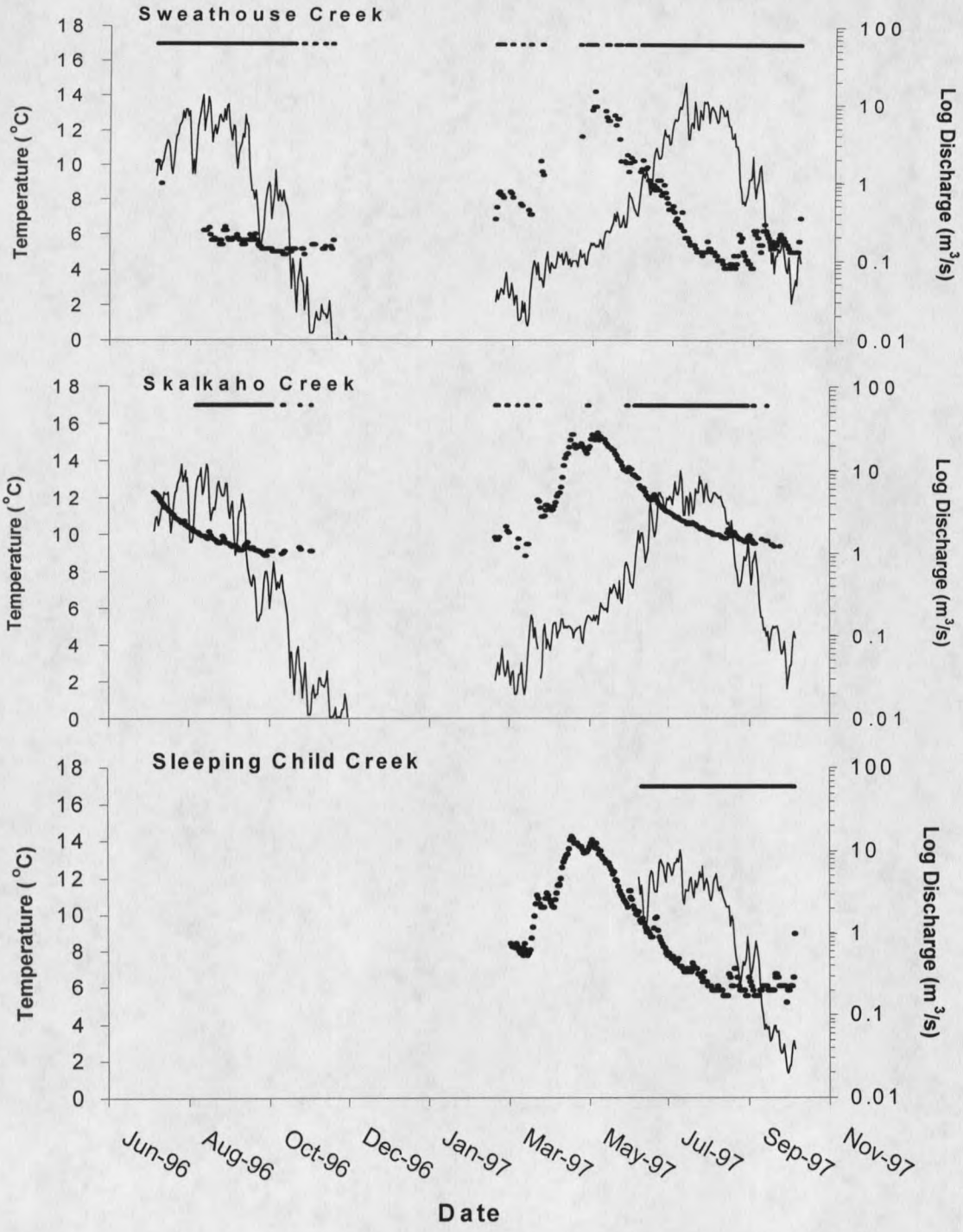

Figure 11. Average daily water temperature (——) and discharge (●) on study streams in 1996 and 1997. Horizontal line indicates periods of weir operation.

(to 27 m^3/s) prevented trapping on Skalkaho Creek between 23 April and 27 June. Water temperatures during the period ranged from 2– 6°C in both streams.

During the study, greater than average snowpack in the Bitterroot River basin resulted in higher peak and daily flows, and extended spring runoff conditions in the drainage (U.S. Geological Survey 1999). In both 1996 and 1997, mean daily flow in the Bitterroot River was about 31% greater than the 50 year average (U.S. Geological Survey 1999). This would suggest a correspondingly above average flow on study streams during this period. Between study years, the difference in mean daily flow over similar trapped periods on Sweathouse Creek was small (0.17 vs. 0.15 m^3/s), and the hydrographs were similar (Figure 11). In contrast, while the hydrograph was comparable between years on Skalkaho Creek, mean daily flow over the sampling period was 65% greater in 1997 than 1996 (2.06 vs. 1.25 m^3/s).

Movement

A total of 4,108 fish representing 12 species and three salmonid hybrids were captured during 1,045 downstream and 866 upstream trapping days on Sweathouse, Skalkaho, and Sleeping Child creeks (Tables 1 and 2). A majority (85%) of the total catch consisted of the three native (cutthroat trout, bull trout, and mountain whitefish, n= 2,140) and three nonnative salmonids (brook trout, brown trout, and rainbow trout, n= 1,341) present in the stream basin. However, bull trout represented only a small proportion (5%, n=215) of the total catch, and only six (< 0.01 % of the total catch) were captured at lower weirs considered downstream of resident bull trout populations (Figures

2 and 4). Mountain whitefish was the most abundant (n= 993) species, and 99% of these were captured at the lower Sweathouse weir. Greatest diversity (11 species) and number of fish (44% of total) also occurred at the lower Sweathouse weir. Two species, the cutthroat trout and slimy sculpin, were captured at all trapping sites. With the exception of the peamouth, all native species to the Bitterroot River drainage were captured during the study.

Sweathouse Creek

Among study streams, Sweathouse Creek had the greatest number of fish captured (64% of total catch) and the highest species diversity (12) (Tables 1 and 2); however, catch composition was substantially different between the lower weir (located within 0.5 km from the Bitterroot River), and the mid and upper weirs (Figure 2). The combined catch at the lower weir included all species captured during the study (excluding bull trout) and represented 69% of the total catch on the stream. While nonsalmonids were occasionally captured at the lower weir (14% of total weir catch), the catch was dominated (59%) by downstream moving juvenile salmonids < 200 mm (Figure 12). These included 683 mountain whitefish, 277 brown trout, and 114 juvenile rainbow trout. Brown trout adults were also common (n= 73, FL range 319— 635 mm), moving upstream during the fall spawning run, but relatively few adult mountain whitefish (n= 32) or rainbow trout (n= 2) were captured. Bull trout were not captured at the lower weir, and brook trout and cutthroat trout were rare (< 0.01% of total weir catch), despite their abundance in the upper watershed (Figure 3).

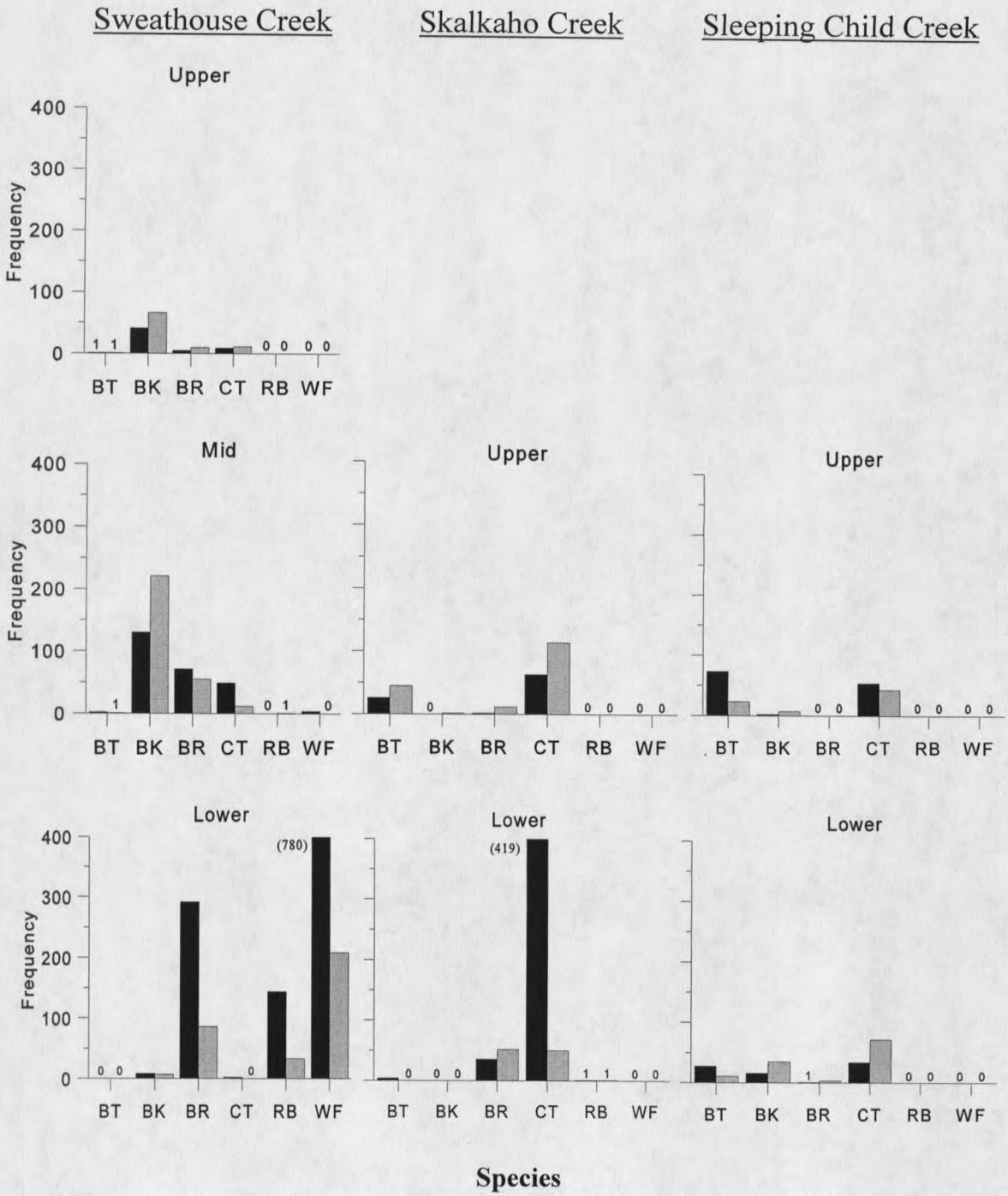

Figure 12. Number of salmonids caught moving downstream (■) and upstream (▒) at trap sites on Sweathouse, Skalkaho, and Sleeping Child creeks. BT= bull trout, BK= brook trout, BR= brown trout, CT= cutthroat trout, RB= rainbow trout, WF= mountain whitefish.

Total catch at mid and upper Sweathouse weirs was substantially less than at the lower weir, despite having 201 more trapping days (Tables 1 and 2). Like the lower weir, salmonids dominated the catch at the mid and upper sites (85% of total catch), however, diversity was less (8 and 4 species, respectively) and the slimy sculpin was the only nonsalmonid substantially represented. Brook trout and brown trout represented 84% of the total fish caught at mid and upper weirs; however, cutthroat trout and bull trout were relatively rare (10 and < 0.01% of total weir catches, respectively).

Three bull trout (two fish recaptured at the same weir) were captured in Sweathouse Creek (Tables 1 and 2). A 60 mm juvenile was captured moving downstream at the mid site in August 1996. A 200 mm gravid female was initially captured moving upstream and subsequently downstream (next day) at the upper trap site in August 1996. Similarly, a 172 mm juvenile (age 3) was captured moving upstream then downstream at the mid trap site in August 1997.

No bull trout moved between trap sites on Sweathouse Creek; however, several large brown trout moved from the lower to mid weirs, and one brook trout moved from the mid to upper weir (Figure 2). This indicates there are no migratory barriers in lower Sweathouse Creek.

Skalkaho Creek

The total catch in Skalkaho Creek was dominated (93%) by the four trout species, however, unlike Sweathouse Creek, the only nonsalmonid captured was the slimy sculpin (Tables 1 and 2). Cutthroat trout represented the greatest number of fish caught (71% of

stream total), and most (65%) were caught moving downstream at the lower weir (Figure 12). Brook trout and brown trout comprised only a small proportion (11%) of the total catch at both weirs.

Bull trout represented 8% (n=75) of the total Skalkaho Creek catch, however, most (95%) were captured at the upper weir (Tables 1 and 2). Like Sweathouse Creek, few bull trout were captured downstream of the resident population on Skalkaho Creek (Figure 12). Only four bull trout were captured in 179 trapping days at the lower weir. All four migrants were captured moving downstream during the declining limb of spring-runoff (13 July– 8 August, 1997), and included three YOY (32– 40 mm) and one juvenile (134 mm, age 2).

In contrast, large numbers of adult and juvenile bull trout were captured moving upstream and downstream at the upper Skalkaho weir (Figure 12), despite relatively low bull trout densities in the stream reach (Figure 5). In 1996, 45 migrants were captured moving upstream and 21 moving downstream in 51 trapping days. Upstream and downstream captures were relatively constant over the trapping period, and no distinct movement peaks related to flow or water temperature were apparent (Figure 13). Median length for upstream moving migrants was 242 mm (range 158– 300 mm), and the most (95%) were > 200 mm (Figure 14). Sexually mature bull trout were captured moving upstream throughout the trapping period, 19 were males (FL range 217– 300 mm) and three females (FL range 225– 293 mm). Median length for downstream migrants was 106 mm (range 94– 293 mm), and most (78%) were less than 150 mm (age 1 and 2 years) (Figure 14). Nine percent (n=7) of bull trout captured at the upper Skalkaho weir were

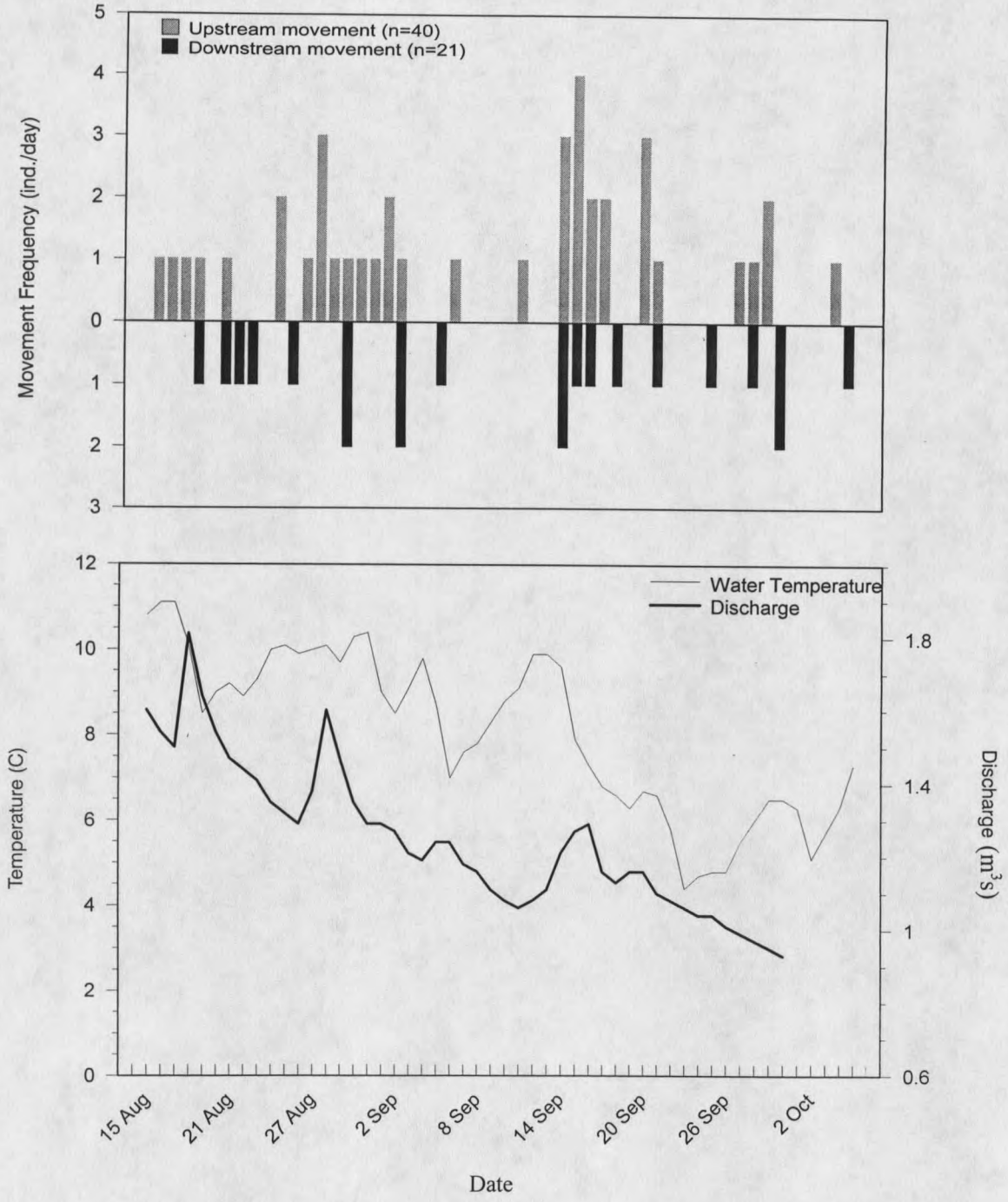

Figure 13. Direction and timing of movement displayed by bull trout in relation to average daily water temperature and discharge at the upper Skalkaho Creek weir, 1996.

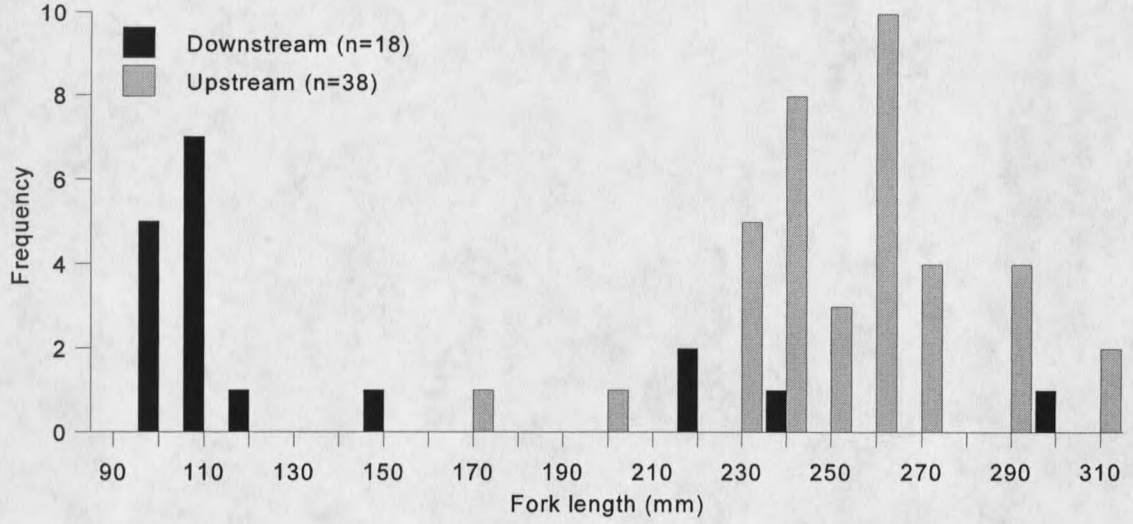

Figure 14. Length-frequency of bull trout captured moving upstream and downstream at upper Skalkaho Creek weir, 1996.

captured more than once; however, no bull trout, or other species, were captured moving between the upper and lower weirs.

In 1997, notably fewer bull trout were captured moving upstream (n=5, FL range 186– 274) and downstream (n=5, FL range 105– 250 mm) at the upper Skalkaho weir in 46 days of trapping; these represent a 88% decline in upstream migrants and a 76% decline in downstream migrants from 1996. Larger bull trout were occasionally observed below the weir in September (1 or 2 at a time), however, few of these fish were captured in the trap box. This suggests changes in flow through the upstream box reduced attraction, and thus, collection of upstream moving fish. No such obstruction would have resulted in the decrease in downstream captures. Captures of cutthroat trout were

similarly reduced between 1996 and 1997 for upstream (95% decline) and downstream (57% decline) migrants.

Sleeping Child Creek

Like other study streams, salmonids made up the greatest proportion (72%) of the total catch on Sleeping Child Creek (Table 1 and 2). In addition to four trout species present, the slimy sculpin and longnose sucker comprised a large proportion of the total catch at the lower weir (25 and 17%, respectively), but were rare at the upper weir (< 3%). More cutthroat trout were trapped (36% of total catch) than any other species, and they were commonly captured at both weirs. Brook trout and brown trout were only commonly caught at the lower weir. Unlike the other two study streams, bull trout were a significant proportion of the total catch at both the upper (46%) and lower weirs (11%).

More bull trout were captured in Sleeping Child Creek than the other two study streams (Tables 1 and 2), despite relatively low bull trout densities near the weir sites (Figure 6). In contrast to Skalkaho Creek, most bull trout migrants on Sleeping Creek moved downstream (Figure 12) and seasonal movement patterns were more distinctive. A total of 101 bull trout were captured moving downstream and 34 moving upstream in 216 trapping days on Sleeping Child Creek (Figure 12). While most (71%) migrants were captured at the upper trap site, direction and timing of movement, and length distribution was similar between trap sites (Figures 15, 16, and 17).

Bull trout displayed seasonal movement patterns on Sleeping Child Creek, especially at the upper trap site (Figures 15 and 16). A small, yet consistent upstream

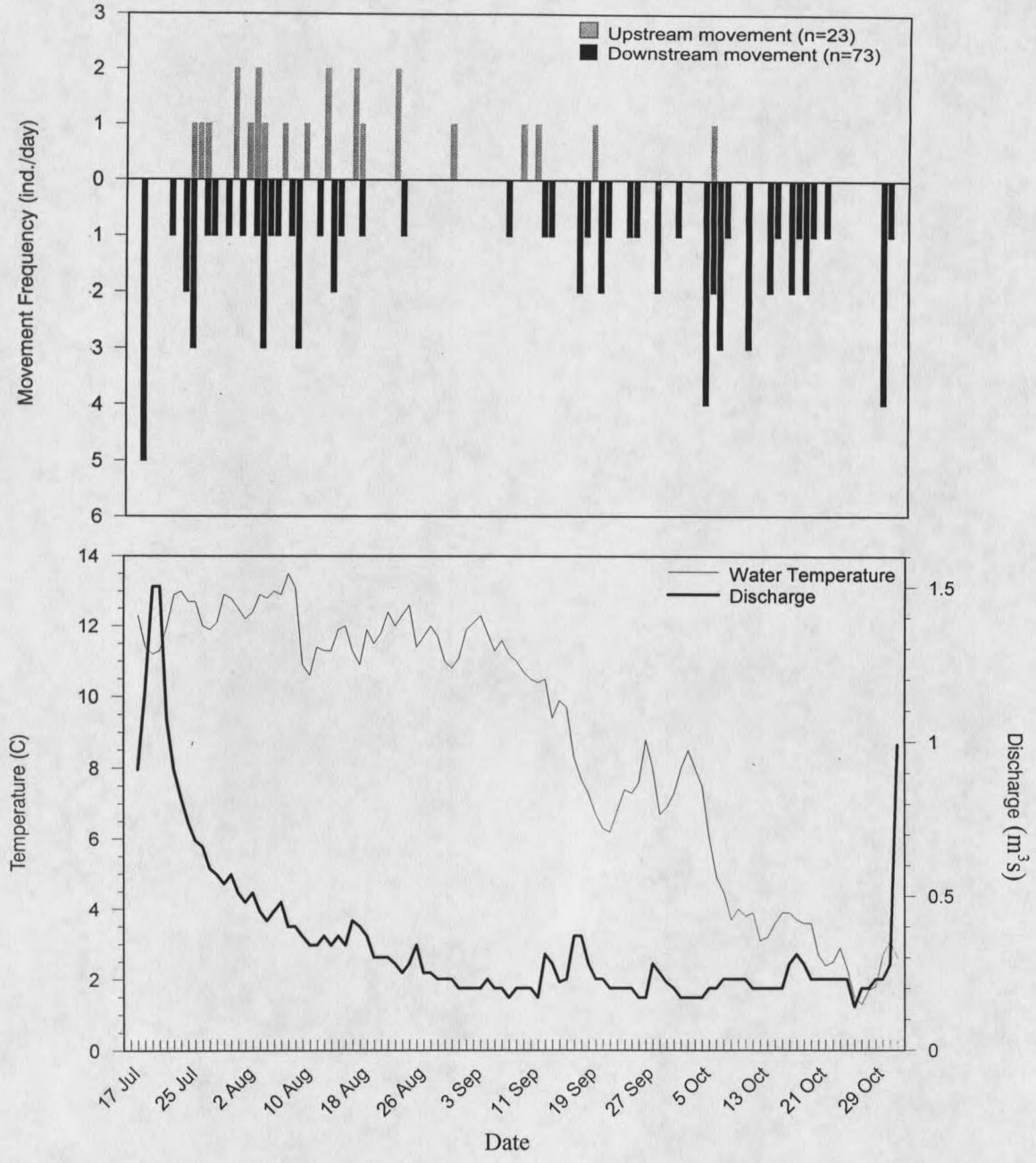

Figure 15. Direction and timing of movement displayed by bull trout in relation to average daily water temperature and discharge at the upper Sleeping Child Creek weir, 1997.

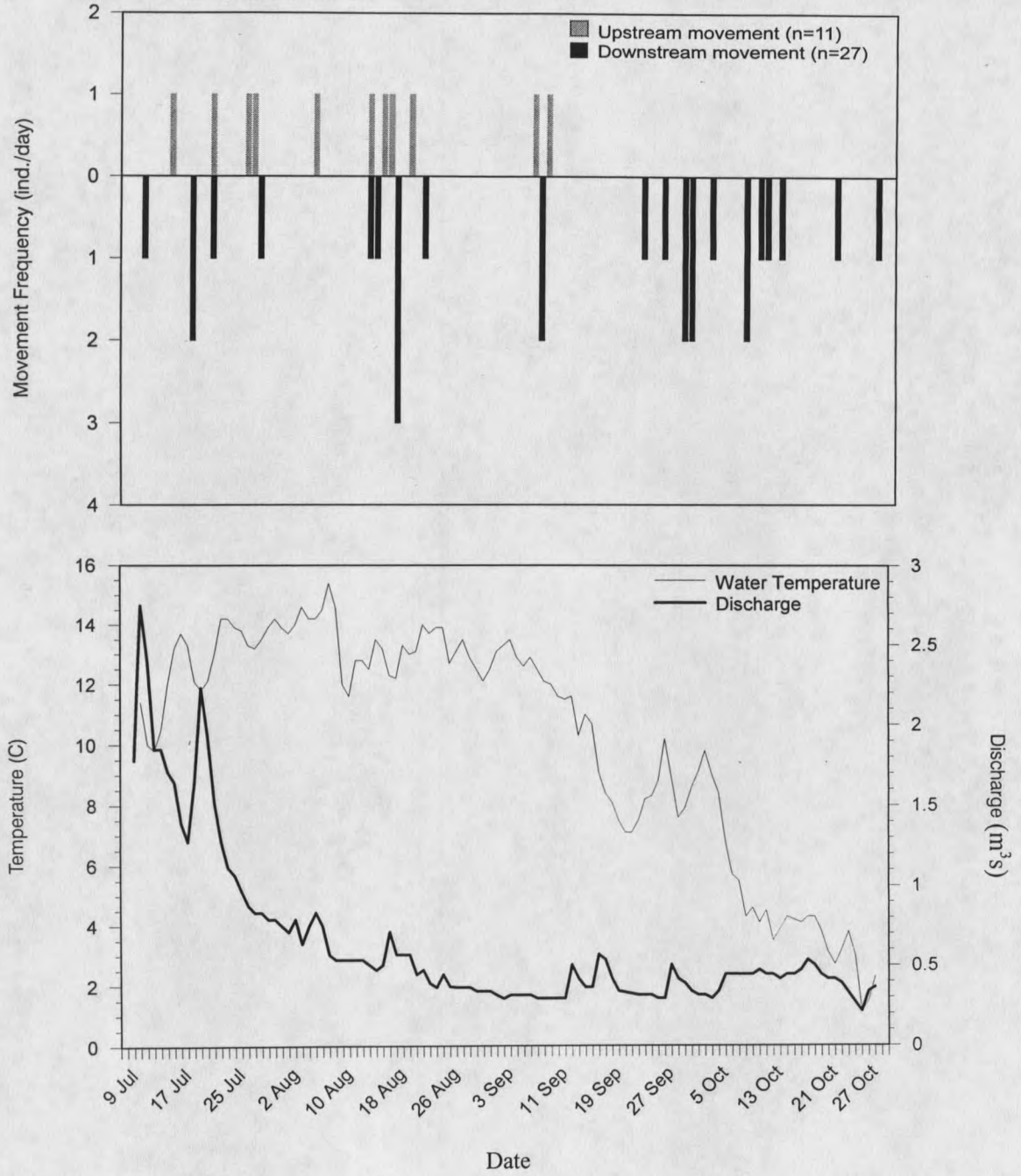

Figure 16. Direction and timing of movement displayed by bull trout in relation to average daily water temperature and discharge at the lower Sleeping Child Creek weir, 1997.

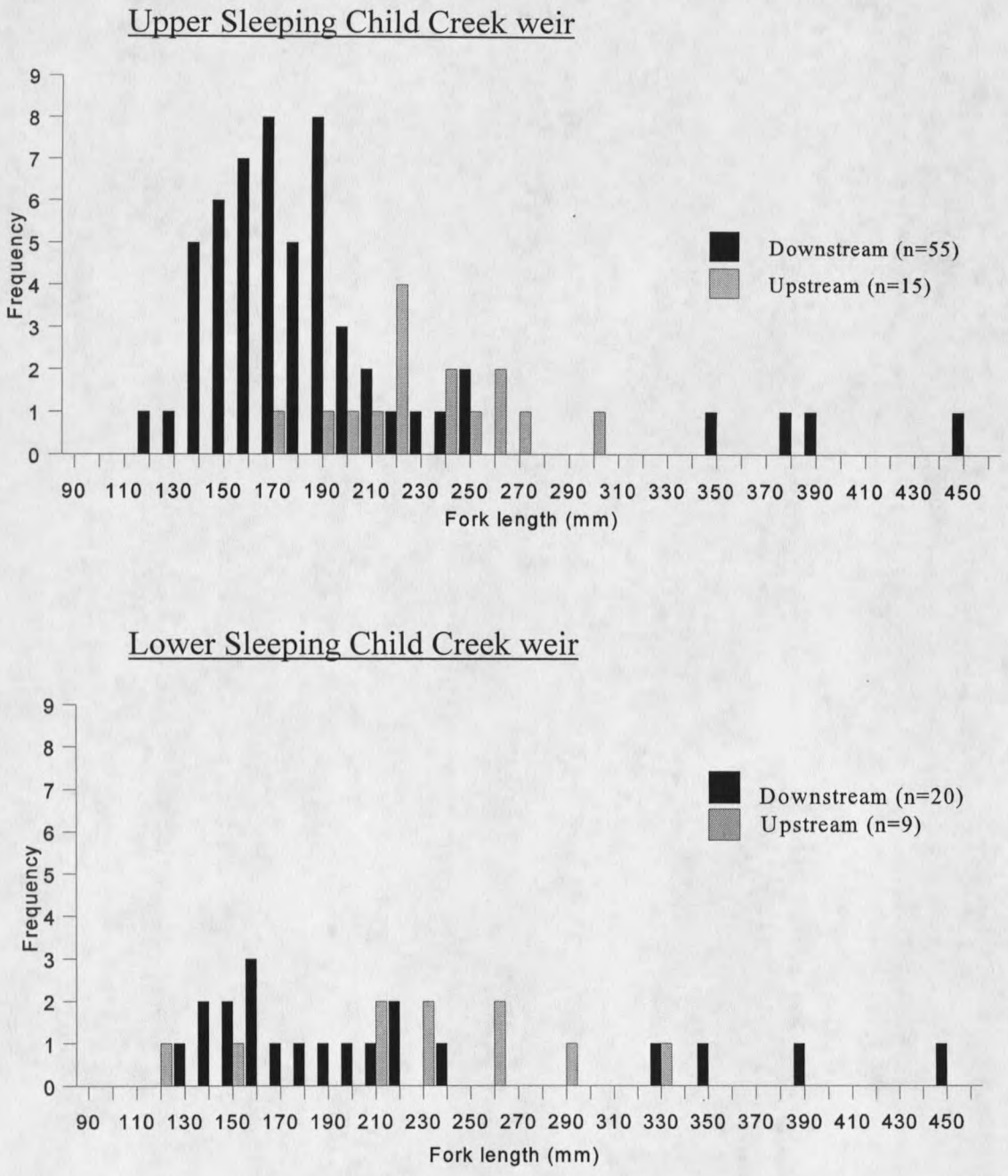

Figure 17. Length-frequency of bull trout captured moving upstream and downstream at upper and lower weirs on Sleeping Child Creek, 1997.

movement by adults occurred as traps were deployed in late July, and continued through mid-September. Median length for upstream moving migrants was 223 mm (range 114–300 mm) and most (79%) were > 200 mm (Figure 17). Three upstream moving migrants were identified as mature: a 251 mm male, and females of 220 and 300 mm. Downstream movement by bull trout on Sleeping Child Creek occurred primarily in two periods: just after trap placement during the declining limb of spring runoff (mid-July to early August), and as water temperatures dropped below 10°C in mid-September (Figures 15 and 16). Median length for downstream moving migrants was 171 mm (range 114–450), and most (72%) were < 200 mm (age 2 and 3) (Figure 17).

In September 1997, two large bull trout (390 and 450 mm FL) were captured moving downstream at the upper weir on Sleeping Child Creek. These were probably adult fish and were recaptured at the lower weir (6.9 km downstream; Figure 4) in 2 and 4 days, respectfully. Three additional large bull trout were captured moving downstream at the upper weir (343 and 372 mm) and lower weir (350 mm).

Thirty percent (n=41) of the bull trout captured on Sleeping Child Creek were captured more than once. While most (37 of 41) recaptured fish were trapped at the same weir site of original capture, four fish captured at the upper weir were recaptured at the lower weir (Figure 4). These include the two large adults described above, and two juveniles (155 and 165 mm) recaptured in October.

DISCUSSION

Juvenile outmigration from natal streams to larger rivers or lakes is a characteristic of migratory bull trout populations. This innate or environmentally-controlled downstream movement allows individuals to utilize multiple habitats to maximize fitness, reduces exposure of populations to stochastic events, permits demographic support between neighboring populations, and may result in colonization of unoccupied habitats (Rieman and McIntyre 1993). My findings suggest such downstream movement by juvenile or adult bull trout is now absent or rare in populations of formerly migratory bull trout that are now isolated in headwater tributaries.

In this study, the rate of downstream movement within and below core population areas of bull trout was less than reported from tributaries supporting fluvial and adfluvial bull trout populations (Table 3). I found significant downstream movement only at weirs positioned within Skalkaho Creek and Sleeping Child Creek core areas; however, even these rates were less than found in other studies that measured outmigration from migratory bull trout populations. For example, in the Rapid River (Elle et al. 1994; Elle 1995), the observed outmigration was about five times greater than the highest downstream movement in Sleeping Child Creek, and 16 times greater than in Skalkaho Creek (Table 3). Only at the upper Sleeping Child Creek weir was downstream movement comparable to outmigration in Flathead River basin streams (Shepard et al.

Table 3. Average daily movement of bull trout (< 300 mm) moving downstream, by month, in the Bitterroot River drainage (this study), Rapid River, ID (Elle et al. 1994; Elle 1995), and Bear, Big, Coal, Red Meadow, Trail and Whale creeks in the Upper Flathead River Basin, MT (Shepard et al. 1984). Dominant life history indicated as resident (R), fluvial (F), and adfluvial (A). Streams were trapped with full stream width picket-weirs (this study, Rapid River) or full stream width wire-mesh weirs (Flathead River Basin).

				Fish/day								
Stream	Life history	Year	Weir	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
Sweathouse	R	1996, 97	lower	0	0	0	0	0	0	0	0	0
			mid	0	0	0	0	0	0.03	0	0	0
		1996	upper						0.03	0	0	0
Skalkaho	R	1996, 97	lower	0	0	0	0	0.10	0.02	0	0	0
			upper						0.24	0.31	0.20	
Sleeping Child	R and F	1997	lower					0.22	0.19	0.17	0.32	
			upper					1.00	0.52	0.33	0.90	
Rapid River	F	1993, 94						3.75	0.87	5.57	4.88	
Big	A	1977						0.81	1.58	0.07	0.10	
Coal	A	1977						1.06	0.23	0.23	0.10	
Red Meadow	A	1976-79					1.27	1.72	0.58	0.03	0	
Trail	A	1977, 79					4.40	4.40	1.71	1.02	0	
Whale	A	1977					1.00	0.71	1.90	0.37	0	

1984); however, this included within-population movement, and did not appear reflective of total outmigration or dispersal from the stream since few of these juvenile fish (n=2) were subsequently captured at the downstream weir. Movement from core population areas on Sweathouse and Skalkaho creeks was nearly absent (Table 3). Only four bull trout were captured moving downstream in 179 trapping days at the lower weir on Skalkaho Creek, and only three bull trout were captured moving downstream in 553 trapping days on Sweathouse Creek (all weirs) (Tables 1). In addition, no bull trout were captured in either stream moving from upper to lower weirs, and no large bull trout that could be considered as fluvial adults were captured. These data indicate there is a lack of evidence for maintenance of fluvial life-history forms in Sweathouse and Skalkaho creeks. This was particularly surprising on Sweathouse Creek since the stream is connected year-round to the mainstem, and no barriers restrict movement in its lower reach.

In contrast, the greater downstream movement rate, longer movement distances, larger size of migrants, and greater number of downstream moving migrants captured at the lower weir, indicate that a small migratory population probably coexists with a resident population in Sleeping Child Creek. When Sleeping Child Creek was added to the study in 1997, it was assumed a lowhead dam would prevent upstream migration. However, the capture of five large bull trout (340— 450 mm FL) suggest the continued presence of a migratory component. I suspect these large bull trout are fluvial life-forms because they are greater in length than reported for resident bull trout in other populations of the Bitterroot River drainage (MFWP, data files, Hamilton) and other systems (Goetz

1989), and because two of these large fish (390 and 450 mm) moved the long distance between weir sites rapidly (6.9 km in 2 and 4 days, respectively) (Figure 4). Two juvenile bull trout (155 and 165 mm) also moved from the upper weir to the lower weir. Further indications of a migratory population include the timing (July to October) (Figures 13 and 14) and size (median FL 171 mm, age 2 to 3 years) of downstream migrants which are similar to reported in most migratory populations (Fraley and Shepard 1989; Ratliff 1992; Elle et al. 1994; Elle 1995; Riehle et al. 1997; Stelfox 1997). Most downstream migrants were captured at the upper weir (Table 1), and only four moved from the upper to the lower weir. Some of the remaining migrants may have continued downstream after the lower weir was removed, or possibly, the migration was halted by the onset of cold water temperatures and ice (Figures 15 and 16). Migrants might have resumed outmigration in the spring. Alternatively, it is possible these migrants remained in the stream as residents. Three mature resident bull trout, as identified by length (220— 300 mm), were also captured in the stream.

Despite bull trout being common in the upper reaches of all study streams (Figures 3, 5, and 6), they represented only a small proportion (6%, n= 215) of the total salmonid catch (n= 3,503) (Tables 1 and 2). Only 32 bull trout were captured moving downstream at lower weirs, 28 of which were captured in Sleeping Child Creek (Figure 12). These fish represent the total possible outmigration or dispersal observed from bull trout in this study. In contrast, 1,745 other salmonids were captured moving downstream at lower weirs, suggesting large numbers of migratory or dispersing individuals. In particular, downstream-moving juvenile mountain whitefish, brown trout, and rainbow

trout represented 59% (n= 1074) of the catch at the lower Sweathouse Creek weir. These fish likely represent outmigrating fluvial life-forms. Downstream-moving cutthroat trout were the most common (67% of total catch, n= 419) species at the lower Skalkaho Creek weir (Figure 12), and large size of many of these fish (52% > 200 mm) may indicate dispersal of larger fish seeking more productive habitats. Therefore, while downstream moving bull trout were nearly absent at lower weirs on Sweathouse and Skalkaho creeks, other species were present in large numbers.

Several factors may have influenced the low level of dispersal or outmigration from the streams in this study. First, low sampling efficiency could have biased results. However, for several reasons I do not believe this to be the case. The picket-weirs used in this study have been used to capture juvenile salmonids, including bull trout (Elle et al. 1994; Elle 1995), and I calculated a relatively high weir efficiency rate of 47% for downstream migrant salmonids at the lower Sweathouse Creek weir. This efficiency is difficult to compare between trap sites and other studies due to varying trapping techniques and trapping conditions (e.g., discharge and debris flow). Efficiency rates were likely higher during summer and fall periods on Sweathouse and Sleeping Child creeks when full width weirs with plastic-mesh were used, and possibly lower on Skalkaho Creek where the relatively longer weir length allowed fish more opportunity to find gaps in the weir. Lowest efficiency was likely during spring runoff on Sweathouse and Skalkaho creeks when partial weirs were used; although the weir did prove effective at catching a relatively large number (n= 155) of outmigrating juvenile mountain whitefish, brown trout and rainbow trout. Overall, the large number (n= 2,312) of

downstream moving salmonids captured indicates that the trapping method was effective at catching available migrants. The method used was also effective at trapping small downstream moving migrants, as shown by their relatively small median length (92 mm) (Figure 10). This is smaller than the common size reported for most outmigrating migratory juvenile bull trout (length range 107— 200 mm, age 2 and 3 years) (Fraley and Shepard 1989; Ratliff 1992; Elle et al. 1994; Elle 1995; Riehle et al. 1997; Stelfox 1997). These data therefore suggests that a "significant" outmigration of salmonids would have been detected by the sampling method, and that the level of outmigration or dispersal by bull trout, if it occurred, was small during the periods of weir operation.

Lack of sampling during peak downstream movement is a second factor which may have resulted in the observed low dispersal or outmigration rates. Previous research has established outmigration of young bull trout from migratory populations generally occurs in two forms: by newly emerged fry from March to April (Reiser et al. 1997; Riehle et al. 1997), and by predominantly age 2 and 3 year old juveniles from June to October (Table 3) (Shepard et al. 1984; Fraley and Shepard 1989; Elle et al. 1994; Elle 1995; Riehle et al. 1997; Stelfox 1997). In my study, weirs were operated from late March through mid-November, with periods of sampling restricted or ceased during periods of high flow (Figure 11). This trapping period included water conditions ranging from base flow and 0°C in March and November, to peak-flow in June, and temperatures above 15°C in August. During the highest flows (May - June), trapping was only conducted on the smallest study stream, Sweathouse Creek, and weirs were set on Skalkaho and Sleeping Child Creeks as flows decreased in July. While no bull trout were

captured during spring-runoff on Sweathouse Creek, 3 of 4 bull trout captured at the lower Skalkaho Creek weir and about half of those collected on Sleeping Child Creek (Figures 15 and 16) were captured as weirs were first deployed in July. This would suggest downstream movement was occurring prior to trap placement.

I cannot discount the possibility that some bull trout moved downstream past lower weir sites during periods that were not sampled. However, evidence from this and other studies suggests outmigration of juvenile bull trout occurs over a several month period; in particular, the periods following spring-runoff and declining temperatures in the fall (Shepard et al. 1984; Elle et al. 1994; Elle 1995) (Table 3). These are periods which were effectively sampled during this study, and correspond with the downstream juvenile movement observed on Sleeping Child Creek. Few studies have attempted to capture migrant bull trout fry during spring-runoff on streams dominated by snow-melt, most likely, because debris inhibits use of fry traps during this period. In my study, fry traps were operated in Sweathouse Creek during spring-runoff (May and June), but were only operated during low debris-flow periods on Skalkaho and Sleeping Child creeks (July - September). If newly emerged fry moved downstream prior to this period, they were not captured by the weir traps. In the spring-fed Metolius system, large numbers of fry were trapped during spring and early summer; however, fry were only one element of the outmigration, and most (81%) migrants were juveniles moving downstream in spring to early fall (Riehle et al. 1997). Evidence from this and other studies suggest I effectively sampled during the periods when the largest outmigration would be expected.

Bull trout are considered to be one of the most migratory of nonanadromous salmonids, and historically, the migratory life-history form was likely dominant among most populations. However, the nonmigratory life form is now the common life-form in many remaining populations (Dambacher et al. 1992; Thomas 1992; Ziller 1992). To my knowledge, this is the first measure of outmigration or dispersal from these populations. The very low rate of downstream movement by juveniles, and upstream movement of spawning adults, particularly in Sweathouse and Skalkaho creeks, suggests that selective pressure has favored the nonmigratory life-form, and migratory fish are now absent or rare in these populations.

The lack of outmigration and dispersal from my study populations was surprising given the high life-history variation exhibited by salmonids, even within the same population (Ricker 1938; Nordeng 1983; Jonsson 1985; Hindar et al. 1991; Rieman et al. 1994). Life-history variation in populations and dispersal of individuals is a complex interaction between genetics and the environment, and several scenarios could account for the loss of the migratory life-form in bull trout populations. First, migratory and resident bull trout represent different genotypes, and historically coexisted, as has been described for rainbow and steelhead trout (Neave 1949), Atlantic salmon (*S. salar*) (Verspoor and Cole 1988), and sockeye and kokanee salmon (Foote et al. 1989; Wood and Foote 1996). The migratory genotype would likely dominate these populations due to the reproductive advantages of migration. Habitat changes and disruption of migratory corridors have now reversed this pattern of dominance due to strong selection against migration. A second scenario is that migratory and resident life-forms were spatially

isolated, with migratory life-forms using the lower reaches of tributaries for spawning and rearing, and the resident forms isolated in the upper reaches. As suggested above, the migratory form may have been selected against, leaving the resident life-form. Finally, a third scenario is that multiple life-history forms can arise from the same genotype, as has been documented for Arctic char (Nordeng 1983), brown trout (Jonsson 1985; Hindar et al. 1991), sockeye salmon (Ricker 1938), and kokanee salmon (Rieman et al. 1994). In these populations, the expression of each life-history may be determined by environmental factors (Dingle 1996) or density which affect access to resources. For example, Nordeng (1983) found Arctic char may manifest both resident and anadromous forms from the same gene pool, and individuals could display each type within their lifetime. Furthermore, he found expression of a life-form could be dependent on availability of food, where increased food resulted in an increase in number of individuals adopting the resident life-history. Nordeng's study suggests that a decreased food availability resulting from high fish densities, may lead to increases in individuals adapting the migratory life-history. It is likely that bull trout across their range exist within a continuum of life-history variability, where adaptation to historic habitat conditions (e.g., the "openness" of the system to migration), and periodic success of each life-history form may dictate the degree of life-history flexibility now present in populations. My study indicates both migratory and resident life-forms can coexist in one population, although it is unknown whether life-forms are producing each other.

It is possible the low dispersal rates observed during my study were partially influenced by lower bull trout densities resulting from high flow rates during the two

years of the study. Discharge in the Bitterroot River was 31% above the 50 year average during both years of the study (U.S. Geological Survey 1999), and was presumably as high in the study streams. One indication that flow may have influenced downstream movement was at the upper Skalkaho Creek site. In 1997, flow over the trapping period was 65% greater than in 1996 (Figure 12); correspondingly, there was a 76% reduction in downstream movement by bull trout. However, because a large downstream movement was observed in Sleeping Child Creek in 1997, the indication is that flow or fish density is not a "controlling" factor for downstream movement in this low density migratory population. It is also noteworthy that Sweathouse and Skalkaho creeks have bull trout densities among the highest in the Bitterroot River basin, and Sleeping Child Creek densities are less than half the other streams (MFWP, data files, Hamilton). Possibly, within population movement was higher during 1996 in Skalkaho Creek because of increased densities resulting from decreased flow, or a strong cohort. However, because the downstream moving bull trout were not recaptured at the lower trap, they likely remained residents of the upper reach. Because I trapped in two above average water years, however, it cannot be discounted that high densities due to drought may promote dispersal or outmigration.

My results suggest that if phenotypic plasticity for multiple life-forms historically occurred, it has now been selected against on Sweathouse and Skalkaho creeks and may no longer be present. Consequently, biological or environmental conditions which promote movement in other populations may not produce a significant outmigration or downstream dispersal in either stream. Bull trout populations in Sweathouse and

Skalkaho creeks are not unlike salmonid populations isolated by impassable waterfalls where downstream dispersal or outmigration is selected against (Northcote 1969; Jonsson 1982; Elliot 1987; Northcote and Hartman 1988; Deleray and Kaya 1992). Downstream habitat changes and predation may produce a similar strong selective effect against the migratory life-history.

In the streams I studied, selection pressure against downstream movement probably began with human alterations of tributaries and the mainstem in the late 1800's; these included introductions of exotic salmonids throughout the basin, habitat changes which increased water temperatures, and the construction of lowhead dams on Skalkaho Creek. More recently the high gradient barrier on Sweathouse Creek (built in the 1960's) and the lowhead dam on Sleeping Child Creek (built prior to the 1950's) would have acted as selective factors against migration.

The amount of time needed to completely select for or against a migratory life-form is uncertain. For example, Berg (1985) found that a population of fluvial Atlantic salmon isolated above a waterfall for 9,500 years still produced smolts. Incomplete adaptation has also been suggested in Arctic grayling (*Thymallus arcticus*), where downstream movement over waterfalls was observed 60— 90 years after introduction (Deleray and Kaya 1989). In contrast, Nordeng (1983) found migratory Arctic char placed above a waterfall shifted to a nonmigratory life-history within 61 years of introduction. Nordeng (1983) also found that in a population of Arctic char, in which individuals produced both migratory and nonmigratory offspring, second generation crosses between migratory individuals produced significantly fewer (34.9%) nonmigrants

than their parents. These studies suggest complete selection for or against a life-form may take relatively few generations, or alternatively, selection may not be complete after 1000's of generations.

In summary, the results of this study suggest outmigration and dispersal are rare or absent in Sweathouse and Skalkaho creek bull trout populations, and is likely a result of 40 or more years of strong selective pressure against migration. In contrast, a small number of fluvial bull trout are able to negotiate the lowhead dam in Sleeping Child Creek, indicating selection against downstream or upstream movement is not complete. These fish likely represent a remnant migratory population, and their presence suggests that the genetics or habitat conditions which produce the migratory life-form on this stream are intact, although in a much reduced state.

The main goal of this study was to determine the potential for reestablishing a migratory life-form from resident bull trout populations by assessing the magnitude of downstream dispersal or outmigration from isolated headwater populations. Dispersal between local populations has been suggested to be very important in the persistence of metapopulations (Hanski and Gilpin 1991; Rieman and McIntyre 1993) and small populations in variable habitats (Stacey and Taper 1992), however, it is notoriously difficult to measure. In this research, I believe trapping efficiency and sampling periods were sufficient to describe downstream movement and life-history of bull trout on Sweathouse, Skalkaho, and Sleeping Child creeks. Trapping data suggest residents are the only life-history form on Sweathouse and Skalkaho creeks, and both migratory and resident bull trout coexist on Sleeping Child Creek. Furthermore, dispersal from

Sweathouse Creek and Skalkaho Creek is nearly nonexistent, while downstream movement on Sleeping Child Creek is much less than other migratory populations.

Conclusions and Management Implications

This research indicates bull trout populations which have undergone selective pressure against downstream movement may now produce few individuals capable of reestablishing a migratory life-form. As such, remaining resident bull trout populations will continue to be prone to stochastic and deterministic extinction risk of small populations in variable environments (Rieman and McIntyre 1993).

The expression of multiple life-forms is likely a strategy to persist through habitat uncertainties. Historically, most, if not all, bull trout populations probably maintained both resident and migratory life-forms. Currently, the resident life-form probably exists in most populations, although in numbers that may be difficult to detect without intensive sampling of headwaters. I suggest where habitat changes have reduced the survival of migratory adults or juveniles (e.g., Flathead River basin, MT), the resident form in these populations will become more prominent, and may eventually dominate the systems. In tributary populations now dominated by migratory juveniles, replacement by the resident life-form may be rapid if selection pressure against migration becomes strong.

Restoration plans for bull trout in the Bitterroot River basin are based on the reestablishment of self-reproducing migratory populations which spawn in all core tributaries to the mainstem (MBTSG 1995). A necessary first step to achieve this

objective is to identify and remove barriers which reduce the survival of upstream and downstream migrants. In this study, it was noteworthy that migratory bull trout are still present in Sleeping Child Creek, a stream with a large low-head dam, while in Sweathouse Creek, a stream with no barriers in its lower reach, only resident bull trout exist. One possibility is that temperature increases in lower Sweathouse Creek and the Bitterroot River have acted as physiological barriers to upstream and downstream movement of bull trout. Increased temperatures may also favor exotic salmonids; particularly the brown trout which now has replaced the bull trout as the top salmonid predator in the drainage. This research, however, indicates that even if those conditions which have selected against the migratory life-forms are alleviated, the reestablishment of the life-form may take an evolutionary adaptation, or the introduction of migratory fish.

It may be possible to establish a migratory life-form through the introduction of fluvial stock from remaining populations in the Bitterroot River basin. With this course of action, managers could rear and imprint fertilized eggs from fluvial life-forms in streams with extinct bull trout populations, or could be introduced by hybridization with native residents, thereby producing a population with localized adaptation and migratory tendencies.

Migratory bull trout are assumed to be extinct, or nearly so, from most tributaries in the lower Bitterroot River basin; however, this study identified one stream which still maintains a small fluvial bull trout population. Several management and research opportunities exist on Sleeping Child Creek where the migratory life-form appears to coexist with resident bull trout. Certainly, one goal should be to determine if a larger

number of adult bull trout are attempting to negotiate the low-head dam, but are failing to do so. This could simply be accomplished by snorkeling below the structure during the periods when adults would be expected to move upstream. Radio telemetry could also be used to determine under what conditions these fish are able to negotiate the dam, and what habitats they utilize in the mainstem. If migratory bull trout are concentrating below the dam, a fish-ladder or actively placing fish above the structure may allow rapid recolonization of the life-form. Placement of a fish ladder could also serve to test the possibility that low-head dams also serve to limit upstream movement by nonnative salmonids. Finally, genetic testing of known resident and migratory fish may lead to a better understanding of differences between the migratory and resident life-history forms in bull trout. Specifically, it is important to determine if each life-form in this stream belongs to unique lineages, or if they belong to the same gene-pool and simply represent phenotypic variation.

While the density of the Sleeping Child Creek population is relatively low compared to the other study streams, it may be more likely to persist through stochastic events threatening all resident populations. Further research should try to identify and protect as core areas those streams which support similar migratory populations. If the migratory life-form is lost in these drainages, evidence from this study suggest reestablishing them may be difficult.

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APPENDICES

APPENDIX A

SALMONID POPULATION ESTIMATE TABLE

Table 4. Mark-recapture electrofishing estimates (MFWP, data files, Hamilton) for salmonids > 127 mm total length for sites on Sweathouse, Skalkaho, and Sleeping Child creeks. Parentheses indicate proportion of total bull trout captured < 178 mm. Sampling sections were 123 to 305-m in length.

Stream	Section (km from mouth)	Year of estimate	Salmonid density (fish/100 m) Bull	Cutthroat	Brook	Brown	Rainbow
Sweathouse	4.2	1996	—	1[a]	28	48	—
	6.0	1996	—	4	28	52	—
	7.7	1996	7[a] (0.57)	39	13	—	—
	10.3	1991	25 (0.34)	27	—	—	—
Skalkaho	0.6	1990	—	—	44[b]	101[b]	9[b]
	6.0	1991	—	10	1[a]	65	1[a]
	9.3	1996	2[a] (0.50)	33	1[a]	72	—
	12.4	1989	12[a] (0.83)	95	1[a]	4[a]	—
	21.1	1994	14[c] (0.47)	79	—	2[a]	—
	27.0	1997	23 (0.65)	38	—	—	—
	33.2	1994	30 (0.81)	35	—	—	—
Sleeping Child	3.1	1993	2[a] (0)	13	26	4[a]	8[a]
	7.2	1997	6[a] (0.17)	40	7	2[a]	—
	12.7	1986	5[a] (0.40)	127	12[a]	—	—
	16.4	1997	16[a] (0.63)	45	1[a]	1[a]	—
	23.3	1996	12 (0.93)	23	—	—	—
	27.2	1991	3 (0.76)	51	—	—	—

[a] Total individuals captured in mark and recapture runs. Recaptures were insufficient to calculate estimate.

[b] Total individuals captured in one 305-m pass.

[c] Estimate for fish > 178 mm total length only.

APPENDIX B

PERIODS OF TRAPPING TABLE

Table 5. Periods of weir and fry trapping on Skalkaho, Sweathouse and Sleeping Child creeks, 1996 - 1997. Underlined dates indicate periods when full stream width weir was operated.

Stream	Trap site	Periods of weir trapping, 1996 (month/day)	Periods of weir trapping, 1997 (month/day)	Total days of weir trapping	Periods of fry trapping, 1996 (month/day)	Periods of fry trapping, 1997 (month/day)	Total days of fry trapping
Sweathouse	Lower	7/10-10/20, 25-27; 11/1-3, 9-11, 15-17	3/22-24, 29-31; 4/6, 7, 13, 14, 21-23; 5/26-31; 6/7-11, 17-19, 24-29; 7/4-15, 16-30	176	7/13-7/26		14
	Mid	7/9-10/20, 25-27; 11/1-3, 9-11, 15-17	3/18-24, 29-31; 4/6, 7, 12-14, 22, 23; 5/19-21, 24-31; 6/1, 8-11, 15-19, 23-29; 7/4-10/31	281	7/17-9/20	5/25-30; 6/15-19, 23-29; 7/4-9/15	158
	Upper	7/29-10/20, 25-27; 11/1-3, 9-11, 15-17		96	8/15-9/20		37
Skalkaho	Lower	8/8-10/4, 11-13, 25, 26; 11/2, 3	3/21-24, 29-31; 4/6, 7, 12-14, 21-23; 5/28-30; 6/27-29; 7/3-14, 7/15-9/26, 30-10/2, 7, 10, 11, 14, 16, 20	179		one trap: 7/5-17: two traps 7/17-9/15	73
	Upper	8/15-10/5	8/1-9/15	97			
Sleeping Child	Lower		7/9-10/22; 10/25-27	109		7/17-9/15	61
	Upper		7/17-10/31	107			