

FISH SCREEN EFFICIENCY AND EFFECTS OF SCREENED
AND UNSCREENED IRRIGATION CANALS ON THE DOWNSTREAM
MOVEMENT OF WESTSLOPE CUTTHROAT TROUT JUVENILES
IN SKALKAHO CREEK, MONTANA

by

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ABSTRACT

Fish screens were installed in three of seven irrigation canals that divert water from Skalkaho Creek, a tributary of the Bitterroot River, in 2003 to prevent the loss of fluvial-adfluvial westslope cutthroat trout to irrigation canal entrainment. A study conducted in 2003 and 2004 established that fish screens were effective at reducing the loss of adult and age-0 westslope cutthroat trout. The efficiency of fish screens at preventing the loss of age 1-4 juveniles, the effect of screening on age-0 westslope cutthroat trout downstream movements, and the magnitude of entrainment at unscreened canals remained unclear after this initial study. The goal of my study was to address these information gaps. Fish screens prevented the loss of about 82% of entrained juvenile westslope cutthroat trout and bull trout. About 69% of entrained juveniles exited the screened canals through the headgates, 14% were bypassed, 12% remained in the canals, and the fate of 5% remained unknown. Entrained fish took about 7 days to exit the screened canals. Fish screen efficiency, the route used by fish to exit, and the amount of time taken by fish to exit varied by canal. Only about 1% of all age-0 westslope cutthroat trout that moved downstream into the irrigation-affected reach of Skalkaho Creek migrated beyond the Ward-Hughes diversion dam in 2005 and 2006. Downstream movement of age-0 westslope cutthroat trout beyond this point may have been selected against through predation by introduced brown trout, dewatering, increased water temperature, years of entrainment into unscreened canals, or other unknown causes. About 67 to 70% of downstream-migrating westslope cutthroat trout and bull trout that encountered the three largest unscreened irrigation canals were entrained as they attempted to emigrate to the Bitterroot River in 2006. Although fish screens were relatively efficient at returning entrained fish to Skalkaho Creek, additional entrainment-preventing measures (such as siphons) at unscreened canals and water management strategies that prevent dewatering are needed to enhance the fluvial-adfluvial population of westslope cutthroat trout in Skalkaho Creek. Fish screens, siphons, and creative water management strategies could be valuable tools in the recovery of fluvial-adfluvial fish populations in heavily-irrigated watersheds.

INTRODUCTION

Irrigation canals entrain salmonids of all life stages during annual migrations (Thoreson 1952; Clothier 1953; Spindler 1955; Der Hovanisian 1995; Reiland 1997; Megargle 1998; Megargle 1999; Gale 2005; Post et al. 2006).

Entrainment is the process by which aquatic organisms are diverted into irrigation canals at water diversion structures (Zydlewski and Johnson 2002).

Irrigation for agriculture has been present in western Montana since 1842 (Hakola 1951), and fish loss to irrigation canals has been a management issue since as early as 1893 (Clothier 1953). Large losses of salmonids to irrigation canals in Montana have been documented (Thoreson 1952; Clothier 1953; Good and Kronberg 1986; Clancy 1993; Reiland 1997). These losses are of concern because of the value of Montana's recreational fishing industry. Montana's overall net economic benefit from stream angling was calculated to be \$122 million in 1985, and the net economic value of the Bitterroot River fishery to be about \$4 million (Duffield et al. 1987). The total contribution of fishing to Montana's economy was about \$228 million in 2001 (Swanson 2004). Montana's streams may not be providing their full recreational potential where fish losses to irrigation withdrawals are large (Reiland 1997). Whereas fishing and tourism are principal sources of revenue in Montana, the agricultural industry has grown to a \$2.6 billion commodity market and is the state's largest source of revenue (Montana Agricultural Statistics Service 2003). As conflicting resource demands,

such as irrigation and recreation, continue to burden Montana's waterways, management strategies that incorporate methods to resolve these conflicts are needed (Reiland 1997).

One potential solution for fish entrainment prevention is to install physical barrier screens in irrigation canals where entrainment is a problem. Most fish screens are designed to block fish movement down an irrigation canal, diverting them back to the creek through a bypass pipe while still allowing water to be withdrawn from the stream. Fish screens may also prevent entrainment of larger salmonids by blocking their movement down a canal, allowing them to return to the creek by swimming upstream through the headgate opening(s) (Gale 2005).

The most important factors affecting fish guidance in front of fish screens are the allowable approach velocities, which are based on the swimming abilities of fish, the magnitude and direction of water velocity immediately upstream of the screen mesh, and the uniformity of the flow through the mesh, which optimizes screen performance (Pearce and Lee 1991). If the velocity of water immediately upstream of the screen mesh is too high, fish may become impinged (make physical contact with the screen) causing injury or death (Zydlewski and Johnson 2002). If water velocity is too low, fish will not be diverted to the bypass pipe and may become trapped in the canal between the headgate and the fish screen, where the risk of predation may be great (Nordlund 1996). Therefore, proper design and regular maintenance are critical to ensure proper operation. Lack of

attention to operational maintenance can increase the occurrence of impingement (Nordlund 1996).

Fish screens have been installed in many irrigation canals of the Pacific Northwest since the early 1900s to prevent entrainment of juvenile anadromous salmonids such as salmon and steelhead *Oncorhynchus mykiss* (Campbell 1959; Corley 1962 in Schill 1984; Neitzel et al. 1991; McMichael et al. 2001). The Mitchell Act of 1938 provided funding to protect fish through screening irrigation diversions and to evaluate fish screen effectiveness. Recently, the “Fisheries Restoration and Irrigation Mitigation Act (FRIMA) of 2000” was enacted

“to establish a program to plan, design, and construct fish screens, fish passage devices, and related features to mitigate impacts on fisheries associated with irrigation system water diversions by local governmental entities in the Pacific Ocean drainage of the states of Oregon, Washington, Montana, and Idaho” (PL 106-502).

This Act was created with the goals of decreasing entrainment and fish mortality associated with the withdrawal of water for irrigation and other purposes without impairing the continued withdrawal of water for those purposes (PL 106-502).

Few studies have been conducted to determine the benefits or efficiency of fish screens (Moyle and Israel 2005). However, screens that have been evaluated have shown the potential to reduce irrigation canal entrainment of anadromous salmonids (Campbell 1959; Corley 1962 in Schill 1984; Neitzel et al. 1990a; Neitzel et al. 1990b; Neitzel et al. 1991). Over a 5-year period, six fish screens prevented entrainment of more than 230,000 juvenile chinook salmon *Oncorhynchus tshawytscha* and steelhead in northeastern Oregon (Campbell

1959). More than 200 rotary fish screens installed in diversions of northeastern Oregon prevented the entrainment of an estimated 300,000 to 1,000,000 juvenile salmon and steelhead annually (Campbell 1959). Although considerable work has been done to prevent the loss of anadromous fish to irrigation canals (Campbell 1959; Hallock and Van Woert 1959; Corley 1962 in Schill 1984; Neitzel et al. 1991; Pearce and Lee 1991; Nordlund 1996; McMichael et al. 2001), relatively little is known about losses of non-anadromous fish to irrigation canals (Reiland 1997), and few canals have been screened to prevent such loss (Gale 2005).

The westslope cutthroat trout *Oncorhynchus clarkii lewisi* was the dominant trout over a vast historic range, which included the upper Columbia, Missouri, and South Saskatchewan river basins, as well as disjoint, isolated populations in the John Day drainage of Oregon, and several drainages of central and eastern Washington (Liknes and Graham 1988; Behnke 1992; McIntyre and Rieman 1995; Shepard et al. 1997). However, less than 100 years after the first European-American settlements of the West, westslope cutthroat trout disappeared from much of their historic range, and were replaced by nonnative trout (Behnke 1988). Westslope cutthroat trout currently occupy an estimated 59% of the 56,500 miles of habitat they historically occupied within the U.S., and an estimated 39% of the 33,000 miles of habitat they historically inhabited in Montana, with genetically pure populations remaining in just 9% of the historic range (23% of current distribution) (Shepard et al. 2003).

Factors identified as leading to the decline in distribution and abundance of westslope cutthroat trout include introductions of and hybridization with nonnative fishes, habitat degradation caused by land and water use practices, and overharvest (Hanzel 1959; Liknes and Graham 1988; McIntyre and Rieman 1995; Van Eimeren 1996). Human activities that have had detrimental effects on westslope cutthroat trout and their habitat include overgrazing by livestock, poor timber harvesting practices, oil and gas exploration, mining, subdivision construction and development of riparian zones, dam construction, and the diversion of water for irrigation.

The westslope cutthroat trout is classified by the Montana Department of Fish, Wildlife and Parks (MDFWP) as a level G4T3-S2 “species of special concern” in Montana, which means the subspecies is “potentially at risk globally and vulnerable to extirpation in the state of Montana because of limited and potentially declining numbers, extent and/or habitat, even though it may be abundant in some areas” (Montana Natural Heritage Program and MDFWP 2006). The U. S. Fish and Wildlife Service (USFWS) concluded in August 2003 that listing the westslope cutthroat trout as either a threatened or endangered species under the Endangered Species Act was not warranted (USFWS 2003). This conclusion was challenged in a legal suit, final briefs have been given, and a ruling by the court is forthcoming as of 26 September 2007 (Lynn Kaeding, USFWS, personal communication).

Westslope cutthroat trout exhibit one of four distinct life history strategies that are important for dispersal and maintenance of genetic diversity (Stearns 1976; Schmetterling 2001). Variation of life history strategies within a population is essential to its long-term sustainability (Stearns 1976). Non-migratory, fluvial stocks spend their entire lives within a single stream or river, fluvial-adfluvial populations migrate between mainstem rivers and tributaries, lacustrine-adfluvial stocks migrate between lakes and their inlet tributaries, and allacustrine stocks migrate between lakes and their outlet streams (Northcote 1997). Upon emergence from the gravel, migratory fish typically live in tributary streams for two to three years, but may emigrate shortly after emerging from gravel nests as age-0 fry or they may spend as many as four years in their natal stream before migrating to lakes or rivers (Liknes and Graham 1988).

Migratory populations of westslope cutthroat trout have suffered the greatest decline in distribution and abundance (Van Eimeren 1996) caused by habitat fragmentation and migration barriers such as dams, irrigation diversions, and culverts (McIntyre and Reiman 1995; Schmetterling 2001). Diversion dams and associated irrigation canals fragment streams and rivers disrupting life-history movements (Northcote 1997; Nelson et al. 2002; Schmetterling and McEvoy 2000; Morita and Yamamoto 2002; Schrank and Rahel 2004; Gale 2005), which can contribute to the decline of migratory fish populations (McIntyre and Reiman 1995; Schmetterling 2001; Gale 2005). Most remaining westslope cutthroat trout populations are now restricted to isolated headwater habitats

where small population sizes increase the risk of extinction (Shepard et al. 1997; Rieman et al. 1993; Van Eimeren 1996). However, some drainages still host populations that migrate considerable distances. These include spawning migrations, emigration of age 1-4 juveniles from nursery reaches to mainstem rivers, downstream dispersal of age-0 fish upon emergence from the gravel, movements to more favorable overwintering habitats, and movements within a stream or lake associated with food availability (Liknes and Graham 1988). Fish that migrate to higher order rivers or lakes typically experience greater growth potential (Behnke 1992). Because fecundity increases exponentially with size, large fish that spend most of their lives in mainstem rivers or nutrient-rich lakes potentially contribute more genetic material to the next generation than small fish that live in smaller tributaries (Schrank and Rahel 2004).

The migratory behavior of fluvial-adfluvial westslope cutthroat trout subjects them to the possibility of irrigation canal entrainment throughout their life history. Post-spawn adults returning to mainstem rivers, age 1-4 juveniles emigrating downstream from nursery reaches, and age-0 fish moving downstream upon emergence may become entrained, trapped, and die in the irrigation canal system resulting in a net loss to the population (Gale 2005).

Historical accounts of large-bodied trout in the Bitterroot River (Evermann 1891) and more recent documentation of abundant migratory westslope cutthroat trout populations in drainages that have not been fragmented by dams and irrigation diversions (Bjornn and Mallet 1964; Shepard et al. 1984; Zurstadt and

Stephan 2004) suggest that the Bitterroot drainage also supported large numbers of migratory westslope cutthroat trout prior to the construction of dams used to divert water from the mainstem and its tributaries. Historically, large numbers of fluvial-adfluvial adult westslope cutthroat trout probably ascended tributary streams from the Bitterroot River during annual spawning migrations and an even larger number of fluvial-adfluvial juveniles probably descended the tributaries as they emigrated to the Bitterroot River (Chris Clancy, MDFWP, personal communication).

Skalkaho Creek, a tributary to the Bitterroot River near Hamilton, Montana (Figure 1), supports a population of non-migratory, fluvial westslope cutthroat trout that spawn, rear, and remain in upper Skalkaho Creek (upstream of river kilometer (rkm) 8.24) (Nelson 1999; Gale 2005) and a presumably small population of fluvial-adfluvial westslope cutthroat trout that rear in upper Skalkaho Creek until they emigrate to the Bitterroot River where they reside until returning to upper Skalkaho Creek as adults to spawn (Clancy 2003; Gale 2005). Several low-head diversion dams, constructed between 1892 and 1942, on the lower 14 km of Skalkaho Creek have likely caused selection pressure against the fluvial-adfluvial life-history strategy (Nelson et al. 2002) and diminished numbers of migratory westslope cutthroat trout in Skalkaho Creek (Gale 2005). Since their construction, low-head dams have probably diverted downstream-migrating juveniles and post-spawn adults into irrigation canals and prevented or restricted upstream passage of adults migrating up Skalkaho Creek to spawn. Additionally,

dewatering and elevated water temperatures in lower Skalkaho Creek (downstream of rkm 8.24) may present seasonal barriers to westslope cutthroat trout movements (Nelson et al. 2002). Emigrating westslope cutthroat trout also face potential competition and predation from nonnative rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta*, which now dominate the Bitterroot River and lower Skalkaho Creek.

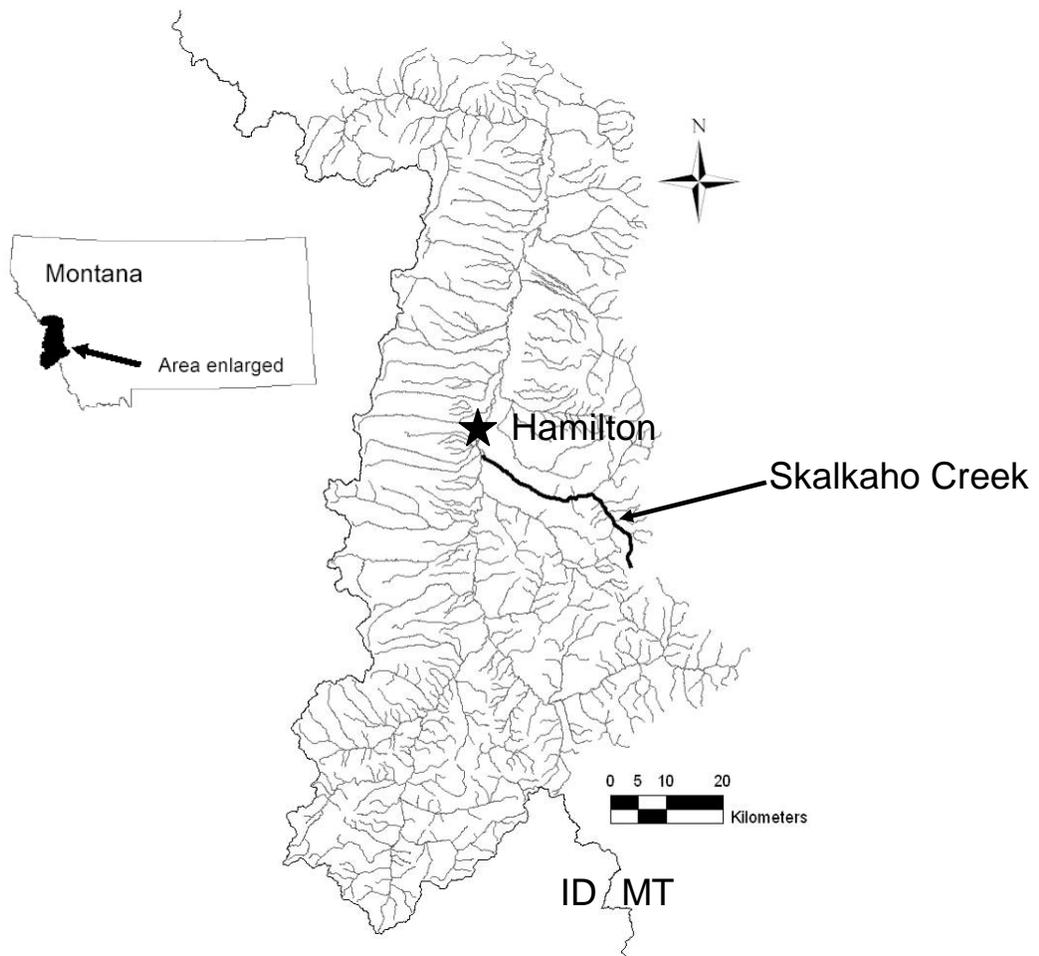


Figure 1. Map showing the Bitterroot River drainage, the location of Hamilton, Montana, and Skalkaho Creek.

The fluvial-adfluvial population of westslope cutthroat trout that spawns in Skalkaho Creek is likely a small remnant population. However, one adult westslope cutthroat trout that was captured and telemetered in the Bitterroot River ascended all seven diversion dams on Skalkaho Creek, presumably to spawn, in 2001 (Javorsky 2002; Clancy 2003), providing some evidence that Skalkaho Creek still supported a population of fluvial-adfluvial westslope cutthroat trout. Additionally, large numbers of westslope cutthroat trout were observed in the canals of Skalkaho Creek during the irrigation season (Clancy 2003). Therefore, Skalkaho Creek provided fisheries managers with the opportunity to restore a fluvial-adfluvial population of westslope cutthroat trout in the Bitterroot drainage by improving connectivity of Skalkaho Creek to the Bitterroot River. Improving connectivity within drainages may reverse the decline of migratory fish populations (Nelson 1999; Neraas and Spruell 2001; Hart et al. 2002; Schmetterling 2003).

The MDFWP obtained funding to install vertical fixed-plate fish screens in three irrigation canals of Skalkaho Creek in an effort to improve connectivity of Skalkaho Creek to the Bitterroot River for downstream migrants by reducing the loss of fluvial-adfluvial westslope cutthroat trout to irrigation canal entrainment. Because the majority of westslope cutthroat trout reside upstream of rkm 8.24, fish screens were installed in the three canals that divert water above this point. A research project was designed to quantify the efficiency of the fish screens at preventing the loss of entrained fish and to evaluate the loss of age-0, age-1, and

adult westslope cutthroat trout to irrigation canals before and after fish screen installation (Gale 2005).

Fish screen efficiency trials were conducted in 2004 to evaluate the effectiveness of the screens at preventing the loss of entrained fish (Gale 2005). A total of 301 juvenile westslope cutthroat trout, bull trout *Salvelinus confluentus*, and brown trout were implanted with Passive Integrated Transponder (PIT) tags and released into the screened canals. PIT tag detecting antennae and PIT tag readers were attached to the bypass pipes at all three screens to monitor when and how many PIT-tagged fish were returned to Skalkaho Creek through the bypass pipes. The area between the headgate and the fish screen was electrofished one to two weeks after PIT-tagged fish were released to recover any tagged fish that remained in the canals. Relatively few of the PIT-tagged fish were detected exiting the canals through the bypass pipes (15%), whereas 32% remained in the canals (Gale 2005). The efficiency of fish screens at preventing the loss of entrained fish was difficult to assess because many of the PIT-tagged fish (50%) were not detected by the antennae and were not recovered by electrofishing (Gale 2005). Fish never found may have swum out of the canals through the headgates, become entrained beyond the fish screens, evaded electrofishing efforts, died in the canals, or suffered predation. Therefore, a better understanding of the efficiency of the fish screens at preventing the loss of entrained juvenile fish was needed.

Entrainment losses of age-0 westslope cutthroat trout were estimated at the seven irrigation canals that divert water from or intersect Skalkaho Creek during the 2003 irrigation season, prior to fish screen installation, and during the 2004 irrigation season, after screen installation (Gale 2005). Large numbers of age-0 westslope cutthroat trout moved downstream into the irrigation-affected reach (below rkm 14.48) in 2003 and 2004. An estimated 12,709 moved downstream into the reach in 2003 and 14,216 moved into the reach in 2004 (Gale 2005). However, only 160 continued their downstream migration to rkm 8.24 in 2003 and just 623 migrated beyond this point in 2004 (Gale 2005). No age-0 westslope cutthroat trout were entrained into the irrigation canals of lower Skalkaho Creek and none were captured in a trap net located near the mouth of the creek in 2003 or 2004 (Gale 2005).

Several studies have documented large numbers of migratory salmonids emigrating to larger waterbodies as age-0 fry (Hayes 1988; Hennessey 1998; Dillon et al. 2004). Emigrating to a larger waterbody shortly after emergence may enable age-0 fish to avoid the pressures of competition imposed by the spatial restrictions of smaller tributary streams (Hayes 1988). These early emigrants may experience faster growth, higher survival, and higher fecundity later in life than fish that undergo a period of residence in parental spawning streams (Hayes 1988). Although fish screens installed in the three upstream-most canals reduced losses of age-0 westslope cutthroat trout to irrigation canal

entrainment by 96% from 2003 to 2004, screening did not result in any age-0 westslope cutthroat trout emigrating to the Bitterroot River in 2004 (Gale 2005).

Prior to this initial study, no data existed regarding the extent of age-0 westslope cutthroat trout downstream movement in Skalkaho Creek. Although this initial study provided this data, it remained unclear why these fish did not continue their migration into lower Skalkaho Creek. The downstream movement and mortality of age-0 westslope cutthroat trout between rkm 14.48 and rkm 8.24 may have been unnaturally altered through predation by introduced brown trout, dewatering, or other unknown causes (Gale 2005). Therefore, a better understanding of the distribution and mortality of age-0 westslope cutthroat trout in this segment of Skalkaho Creek was needed to determine why few age-0 fish migrated beyond rkm 8.24 to the Bitterroot River.

Entrainment of emigrating juvenile westslope cutthroat trout into unscreened irrigation canals and the effect of this entrainment on the number of juveniles that emigrated to the Bitterroot River was difficult to assess during this initial study because very few (8 of 117) telemetered juveniles displayed migratory behavior (moved downstream far enough to encounter a diversion dam) (Gale 2005). All eight telemetered fish that encountered a diversion dam in 2003 and 2004 were entrained into the upstream-most canal (rkm 14.48) (Gale 2005). No telemetered juveniles moved downstream far enough to encounter the next downstream diversion (rkm 8.24), or any of the unscreened canals located in lower Skalkaho Creek (Gale 2005). However, about 250,000 age-0 fish

(mostly longnose suckers *Catostomus catostomus*, longnose dace *Rhinichthys cataractae*, and brown trout) were entrained into the four unscreened canals of lower Skalkaho Creek in 2004 (Gale 2005), indicating that large numbers of fish are being entrained into the remaining unscreened canals.

About 64% (9 of 14) of post-spawn adult westslope cutthroat trout that encountered the unscreened irrigation canals of lower Skalkaho Creek were entrained in 2004 (Gale 2005). Most of this entrainment occurred at the two largest unscreened canals where the probability of entrainment was 80% (Gale 2005). Only one telemetered adult successfully migrated to the Bitterroot River in 2003 and 2004. This fish swam up a canal that diverts water from the Bitterroot River and intersects Skalkaho Creek to the point of diversion where it exited the canal through the headgate, thereby returning to the river (Gale 2005). No telemetered adults migrated past all the unscreened diversions by swimming down Skalkaho Creek to the Bitterroot River. Therefore, the probability of returning to the Bitterroot River was low (5%) for migratory adult westslope cutthroat trout (Gale 2005).

Although the fish screens bypassed all telemetered adult westslope cutthroat trout that were entrained into the screened canals in 2004 (Gale 2005), entrainment of emigrating westslope cutthroat trout may be shifted downstream to the remaining unscreened canals. Because large numbers of age-0 fish and a high percentage of downstream-migrating adults were entrained into the unscreened canals in 2004, it is likely that many fluvial-adfluvial juvenile

westslope cutthroat trout are also being entrained into the unscreened canals as they attempt to emigrate to the Bitterroot River. If the fluvial-adfluvial population of westslope cutthroat trout is to be recovered in Skalkaho Creek, downstream migrants must be able to emigrate to the Bitterroot River. Therefore, additional information was needed to determine the magnitude of entrainment of westslope cutthroat trout into the remaining unscreened canals and the effect this entrainment has on the number of westslope cutthroat trout that emigrate to the Bitterroot River. Such information could be used to determine whether or not entrainment-preventing measures at the remaining unscreened canals would enhance the population of fluvial-adfluvial westslope cutthroat trout in Skalkaho Creek.

The study conducted in 2003 and 2004 established that fish screens were an effective management tool for reducing the loss of adult and age-0 westslope cutthroat trout to entrainment into the screened irrigation canals (Gale 2005). However, the efficiency of fish screens at preventing the loss of age 1-4 juvenile fish and the effect of screening on the downstream movement of age-0 fish remained unclear after that study. Additionally, irrigation canal entrainment of emigrating juvenile westslope cutthroat trout may be shifted downstream to the remaining unscreened canals, as was observed for post-spawn adults (Gale 2005), resulting in little to no enhancement of the migratory component of the population.

My goals were to evaluate the efficiency of the Skalkaho Creek fish screens and to determine the magnitude of entrainment of emigrating westslope cutthroat trout into the remaining unscreened canals. My specific objectives were to i) quantify the efficiency of the fish screens at preventing the loss of entrained juvenile westslope cutthroat trout and bull trout, ii) evaluate the distribution and mortality of age-0 westslope cutthroat trout between rkm 14.48 and rkm 8.24, and iii) quantify the magnitude of westslope cutthroat trout entrainment into the remaining unscreened canals and the effect this entrainment has on the recruitment of fluvial-adfluvial westslope cutthroat trout to the Bitterroot River.

STUDY AREA

The Bitterroot River flows north from the confluence of the East and West Forks located near Conner, Montana, for 134 km through irrigated crop and pastureland to its confluence with the Clark Fork River near Missoula, Montana. The basin encompasses 7,288 km² of wilderness, national forest, and private lands. Headwaters of the Bitterroot River are located in three mountain ranges, the Bitterroots to the west, the Sapphires to the east, and the Anaconda-Pintlars to the southeast. Twenty-seven major tributaries originate in the Bitterroot Range and 12 originate in the Sapphire Range. Many of these tributaries support populations of westslope cutthroat trout and bull trout (Clancy 2001). Adult fluvial-adfluvial westslope cutthroat trout were documented ascending ten different tributaries of the Bitterroot River, including Skalkaho Creek, on spawning migrations in 2001 and 2002 (Javorsky 2002; Clancy 2003).

Five major diversions and numerous smaller diversions remove substantial quantities of water from the Bitterroot River during the irrigation season. Additionally, many tributaries of the Bitterroot River, including Skalkaho Creek, are diverted for irrigation during the summer months and contribute little water to the river during this time. Therefore, both the tributaries and mainstem of the Bitterroot River are chronically dewatered during the irrigation season (Clancy 2001).

Skalkaho Creek is a 40.1 km long fifth-order stream with a watershed area of 228 km². Its headwaters are located in the Sapphire Mountains. The

historical average peak flow is about 20 m³/s and the highest historical average monthly streamflow occurs in June (about 11 m³/s). The historical yearly average flow of Skalkaho Creek upstream of all diversions is about 2.6 m³/s.

Skalkaho Creek flows through a narrow valley and consists of fast-water habitats above rkm 19. The lower 19 rkm flows through a wide valley floor and contains mostly low-gradient riffles and runs. Several lowhead dams, used to divert water for irrigation, are located in the lower 14 rkm. The diversions from upstream to downstream are the Highline (rkm 14.48), BIG (rkm 8.78), Ward-Hughes (rkm 8.24), Thompson (rkm 5.71), Hedge (rkm 3.98), Republican (rkm 2.01), and C&C (rkm 0.11). The Highline Canal diverts about 1.0 to 1.4 m³/s of water during the irrigation season. A headgate allows about 1.4 m³/s of water to be diverted from Skalkaho Creek into the BIG Canal during spring runoff about once every five years, but the canal primarily carries water that originates from Lake Como and is siphoned under the creek (Gale 2005). No water was diverted from Skalkaho Creek into the BIG Canal in 2005 or 2006 and therefore entrainment was not assessed there during this study. The Ward-Hughes diversion dam diverts water into two irrigation canals. The Ward Canal flows in a northerly direction from Skalkaho Creek and diverts about 0.5 to 0.6 m³/s of water during the irrigation season. The Hughes Canal diverts about 0.15 to 0.2 m³/s of water from Skalkaho Creek and flows in a southerly direction. Vertical fixed-plate fish screens were installed in the Highline, Ward, and Hughes canals about 15 to 20 m downstream from the canal headgates during the autumn of

2003. The Thompson Canal diverts the least amount of water from Skalkaho Creek (about 0.08 to 0.1 m³/s). The Hedge and Republican canals each carry about 2.0 m³/s of water that originates in the Bitterroot River and intersect Skalkaho Creek. Water from the canals replaces Skalkaho Creek water where they intersect during much of the irrigation season (Figure 2). The Bitterroot River water in the canals empties into Skalkaho Creek and water from the creek is diverted out the other side into the canals (Figure 2). The C&C Canal diverts about 0.22 m³/s of water from a Skalkaho Creek sidechannel.

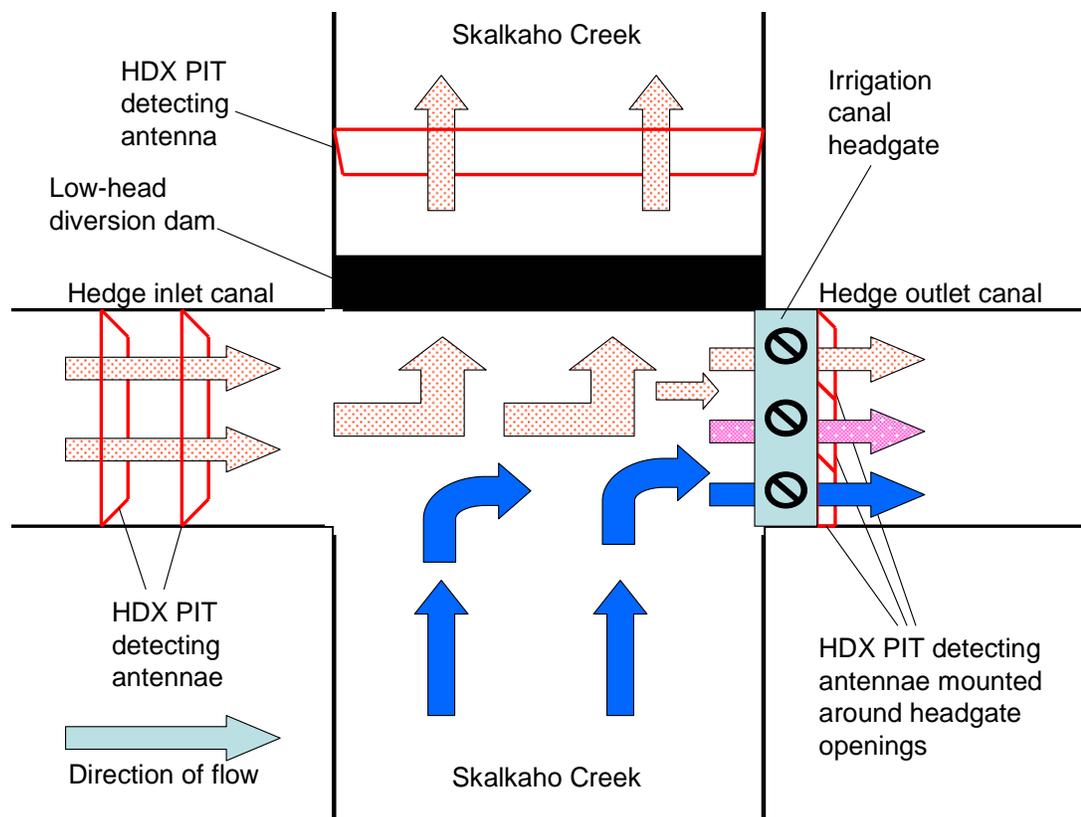


Figure 2. Diagram showing the movement of water during mid to late summer at the intersection of the Hedge Canal with Skalkaho Creek and the locations of PIT tag detecting antennae as described in the methods.

Skalkaho Creek is often severely dewatered downstream of the Ward-Hughes diversion dam (rkm 8.24) during mid to late summer (Figure 3). Dewatering increased the mean daily temperature of Skalkaho Creek downstream of Ward-Hughes by about 2.3°C during the 2006 irrigation season (Figure 4). Additionally, Bitterroot River water emptying into Skalkaho Creek from the Hedge Canal increased the temperature of Skalkaho Creek downstream of the Hedge diversion dam by about 2.2 °C during the 2006 irrigation season (Figure 4). The input of Bitterroot River water into Skalkaho Creek also lowers the conductivity (Gale 2005), and may alter the species composition of downstream reaches.

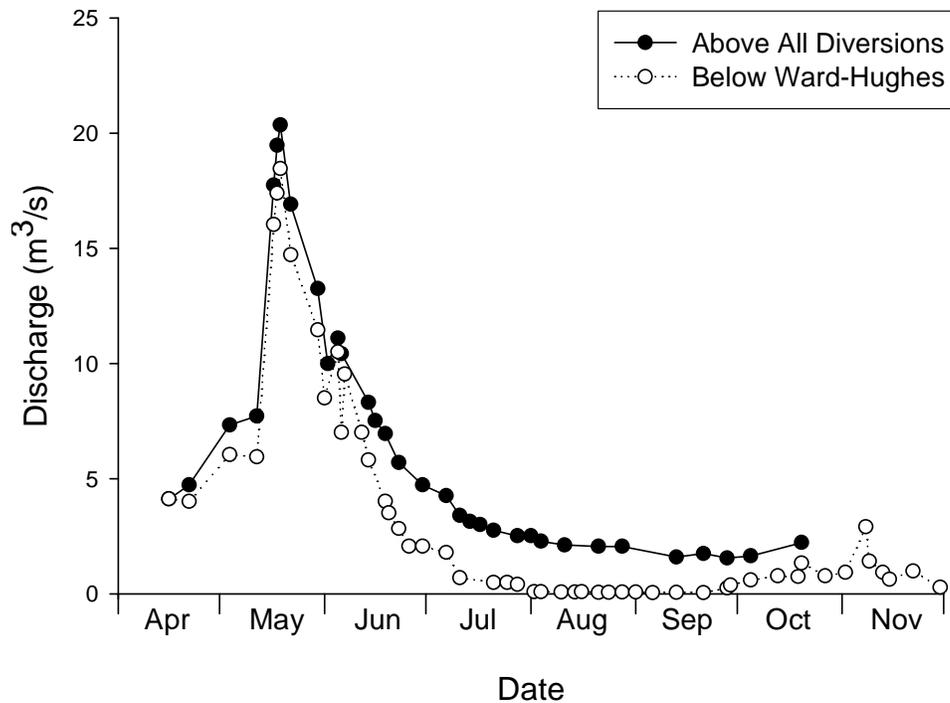


Figure 3. Discharge in Skalkaho Creek, Montana upstream of all diversions and downstream of the Ward-Hughes diversion dam, 2006.

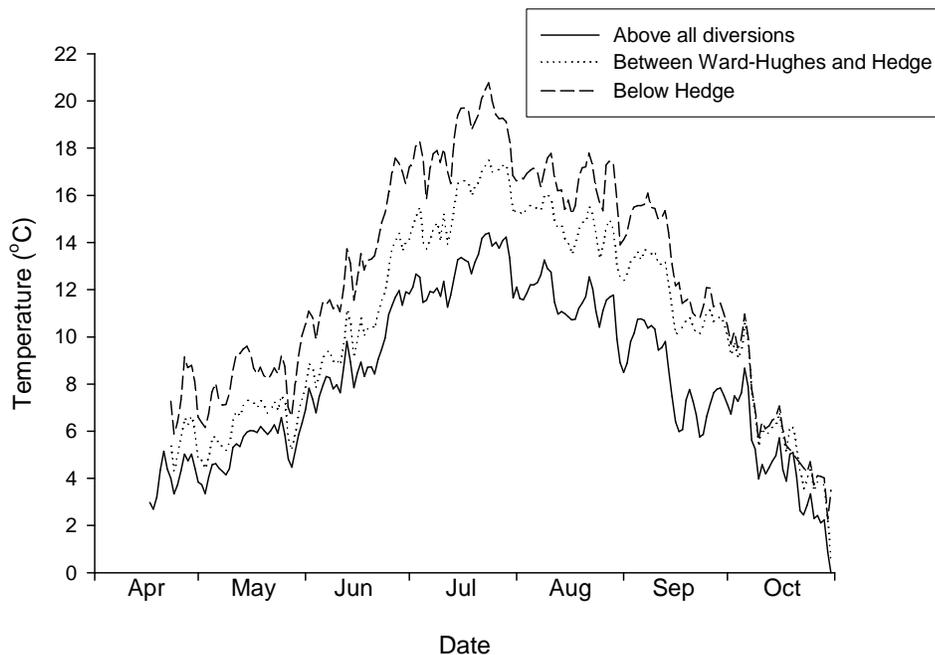


Figure 4. Mean daily temperatures above of all diversions, between Ward-Hughes and Hedge, and below the Hedge diversion dam in Skalkaho Creek, Montana, 2006.

Skalkaho Creek supports native populations of westslope cutthroat trout, bull trout, mountain whitefish *Prosopium williamsoni*, northern pikeminnow *Ptychocheilus oregonensis*, longnose sucker, longnose dace, redbelt shiner *Richardsonius balteatus*, and slimy sculpin *Cottus cognatus*. Non-native fish include rainbow trout, brook trout *Salvelinus fontinalis*, and brown trout. Westslope cutthroat trout exist in large numbers from the headwaters downstream to the Ward-Hughes diversion dam (rkm 8.24) (Nelson 1999). Non-migratory fluvial bull trout are present above rkm 10, but are rare below this point (Nelson 1999). Brown trout are the dominant trout species in the lower 10 rkm, but are rare above rkm 12 (Nelson 1999). Rainbow trout are common below the

Republican diversion dam, but are rare further upstream (Nelson 1999). Brook trout are present below the Republican diversion dam, but are rare above this point (Nelson 1999).

METHODS

Fish Screen Efficiency

Fish screen efficiency was quantified by conducting fish screen efficiency trials at the Highline, Ward, and Hughes (Figure 5) canals during the 2006 irrigation season (Table 1). Trials consisted of releasing juveniles implanted with half-duplex (HDX) PIT tags into each screened canal between the headgate and the fish screen (Figure 6). PIT tag detecting antennae were installed around the headgate openings, on the bypass pipes, and in the canals downstream of the fish screens (Figure 6) to determine the percentage of fish that were returned to the creek, the route used by fish to exit, and the exit time (amount of time taken by fish to exit the screened canals).

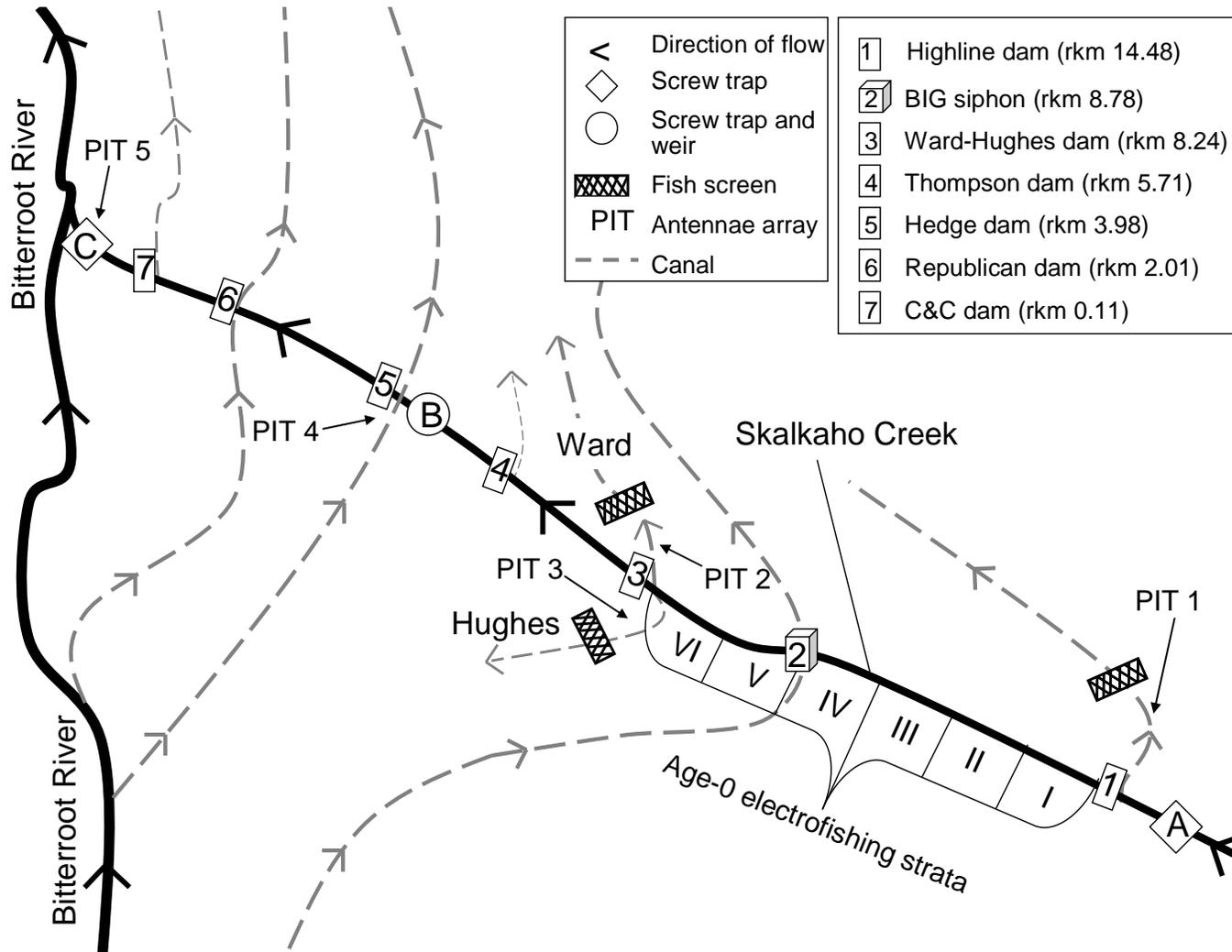


Figure 5. Schematic map of Skalkaho Creek, Montana, showing locations of diversion dams, irrigation canals, siphons, screw traps, picket weir, fish screens, and age-0 electrofishing strata as described in the study area and methods.

Table 1. Location, methods, objectives, and duration of sampling conducted on Skalkaho Creek in 2005 and 2006.

Figure 5 designation	Location description	Sampling method	Objective	Sampling period
1 (PIT 1)	Highline Canal (rkm 14.48)	PIT tag detecting antennae (Figure 6)	Fish screen efficiency	5/23 – 10/11, 2006
2	BIG Canal siphon (rkm 8.78)	None	None	None
3 (PIT 2 & 3)	Ward and Hughes canals (rkm 8.24)	PIT tag detecting antennae (Figure 6) in Ward and Hughes canals; Trap the outflow of the Ward and Hughes bypass pipes	Fish screen efficiency; Number of age-0 WCT that migrated beyond Ward-Hughes	Ward: 6/12 – 8/1, 2006 Hughes: 8/17 – 9/29, 2006; 7/8 – 9/28, 2005 7/14 – 9/29, 2006
4	Thompson Canal (rkm 5.71)	None	None	None
5 (PIT 4)	Hedge Canal (rkm 3.98)	PIT tag detecting antennae (Figure 3)	Entrainment rate of PIT-tagged fish into the Hedge Canal	Canal: 5/12 - 9/18, 2006 Creek: 5/12 – 11/30, 2006
6	Republican Canal (rkm 2.01)	None	None	None
7	C&C Canal (rkm 0.11)	None	None	None
A	Upper screw trap (rkm 15.48)	Screw trap located 1 km upstream from the Hedge diversion dam	Number of age-0 WCT that migrated downstream into the irrigation-affected reach	5/8 – 10/15, 2005 7/10 – 10/4, 2006
B	Hedge screw trap/weir (rkm 4.03)	Screw trap and picket-fence weir located 50 m upstream from the Hedge diversion dam	Number of emigrating WCT that encountered the unscreened Hedge, Republican, and C&C canals	Screw trap: 5/4 – 5/12, 5/31-7/10, 2006 Weir: 7/12 – 10/20, 2006
C (PIT 5)	Lower screw trap (rkm 0.10)	Screw trap and PIT detecting antenna located 0.1 rkm upstream from the mouth of Skalkaho Creek	Number of WCT that emigrated to the Bitterroot River	Screw trap: 5/12 – 10/15, 2005 and 5/4 – 11/1, 2006 PIT antenna: 3/7 – 5/7, 2007
I – VI	Age-0 WCT electrofishing stratum (rkm 8.24 to 14.48)	Electrofishing margins of 50-m reaches	Distribution and mortality of age-0 WCT between Highline and Ward-Hughes	7/26 – 10/19, 2006

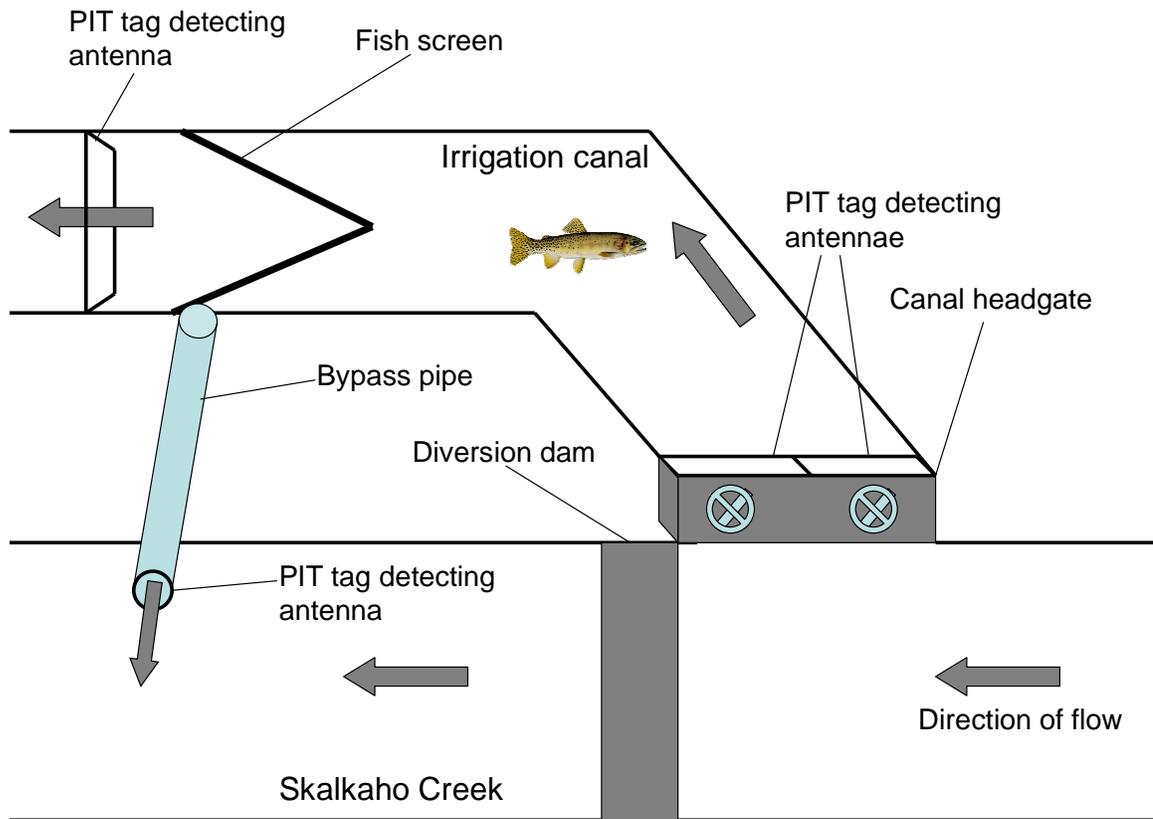


Figure 6. Diagram showing a screened irrigation canal and the locations of PIT tag detecting antennae used to determine the efficiency of fish screens.

Juvenile westslope cutthroat trout and bull trout were collected about once per month by electrofishing Skalkaho Creek above and below the Highline and Ward-Hughes diversion dams using a Smith-Root LR-24 battery-powered backpack electrofisher. Stream-dwelling salmonids may return to a particular area in a stream following displacement (Halvorsen and Stabell 1990; Armstrong and Herbert 1997; Starcevich 2005), which has been termed “homing.” PIT-tagged fish captured below the diversion dam would exit in a downstream direction, through the bypass pipe, and fish captured above the diversion dam would exit in an upstream direction, through the headgate, if displaying this

tendency. About half of the fish to be PIT-tagged were obtained from above the diversion dams, and about half from below to reduce the influence of homing on the results of fish screen efficiency trials. The capture location was recorded for most (219 of 239) PIT-tagged fish.

Juvenile westslope cutthroat trout and bull trout were anesthetized with tricaine methanesulfonate (Finquel), and total length (mm), weight (g), and PIT tag number were recorded for each fish. Model RI-TRP-REHP read-only HDX PIT tags (Texas Instruments, Oregon RFID), weighing 0.6 g in air and measuring 23 mm in length and 3.84 mm in diameter, were surgically implanted in the peritoneal cavity of the fish. Tag weight never exceeded 5% of tagged fish weights (Zale et al. 2005). A single suture was used to close the incision.

About 30 fish were captured and PIT-tagged on four separate occasions for fish screen efficiency trials conducted at the Highline Canal, on three occasions for trials at the Ward Canal, and on two occasions at the Hughes Canal (Table 2). A total of 221 westslope cutthroat trout and 18 bull trout was PIT tagged and released into the three screened canals in 2006 (Table 2).

Table 2. Mean, maximum, and minimum total lengths of PIT-tagged westslope cutthroat trout and bull trout released in 2006 into the Highline (HL), Ward (Wa), and Hughes (Hu) canals to determine fish screen efficiency.

Canal Trial	HL 1	HL 2	HL 3	HL 4	Wa 1	Wa 2	Wa 3	Hu 1	Hu 2
Date ^a	(5/23)	(6/27)	(8/4)	(9/8)	(6/12)	(7/6)	(7/19)	(8/17)	(9/15)
WCT ^b	n=26	n=29	n=25	n=24	n=27	n=17	n=14	n=29	n=30
BLT ^c	n=4	n=0	n=5	n=6	n=2	n=0	n=0	n=1	n=0
Total	n=30	n=29	n=30	n=30	n=29	n=17	n=14	n=30	n=30
Mean length (mm ± SD)	223 ± 62	239 ± 49	187 ± 45	172 ± 36	178 ± 72	251 ± 74	144 ± 36	160 ± 54	161 ± 64
Max length (mm)	350	360	284	250	368	430	209	287	314
Min length (mm)	116	160	112	111	110	111	110	110	109

^a Date of fish releases

^b Westslope cutthroat trout

^c Bull trout

The design of the Ward Canal headgate structure created an eddy directly adjacent to the headgate openings (Figure 7). Many PIT-tagged fish seemed to hold in these eddies, which were located next to the PIT tag detecting headgate antennae. Therefore, many PIT-tagged fish were detected repeatedly, which caused the memory card of the Personal Digital Assistant (PDA) that recorded PIT tag detections from the Ward Canal headgate antennae to fill on the evening of 1 August, well before the end of the irrigation season, which occurred at this site on 29 September. Because tags were still being detected by the Radio

Frequency Module (RFM), but were not being stored to the memory card, the problem was not identified until the end of the irrigation season. Therefore, fish screen efficiency trials ended at the Ward Canal (Figure 5, PIT array 2) on 1 August (Table 1, designation PIT 2). Additionally, problems encountered with radio frequency interference prevented RFM operations at the Hughes Canal (Figure 5, PIT array 3) until 17 August (Table 1, designation PIT 3).

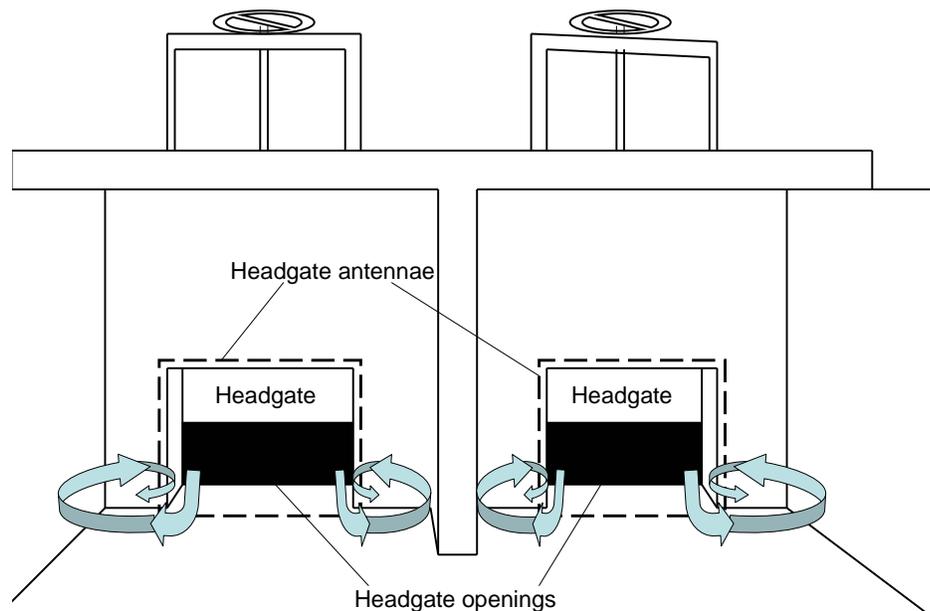


Figure 7. Diagram of the Ward Canal headgate structure, displaying the location of PIT tag-detecting antennae and eddies created by the headgate structure.

PIT-tagged fish were allowed as much time as needed to exit the canals. That is, PIT-tagged fish from previous trials were not removed before releasing additional PIT-tagged fish. Upon headgate closure at the end of the irrigation season, screened canals were electrofished to recover PIT-tagged fish that remained in the canals. Multiple-pass depletion electrofishing was employed,

starting 100 m downstream of the fish screen, moving in an upstream direction to the headgates. Electrofishing passes were made until the number of salmonids captured during a pass was less than or equal to 10% of the number of salmonids captured during the initial pass. All captured salmonids were counted, identified to species, measured (mm), and scanned for PIT tags. The location and tag number of all recovered PIT-tagged fish was recorded.

Half-duplex PIT tag detecting antennae, constructed of 8-gauge speaker cable with 665 strands of copper wire, were installed during March and April of 2006, prior to the irrigation season, at each screened canal (Figure 5, PIT arrays 1, 2, and 3). Antennae were installed around the headgate openings, on the bypass pipes, and in the canals downstream of the fish screens so that the entire flow volume was scanned for PIT tags at each location without obstructing the path of the fish (Figure 6).

Headgate antennae were constructed of two loops of 8-gauge speaker cable that encompassed each headgate opening (Figures 7). A length of cable extended from the antenna loops to the tuning box of each antenna. Headgate antennae were located about 0.25 to 0.30 m downstream from the actual headgate opening and were attached to the headgate concrete structure using construction adhesive, concrete sleeve anchors, and conduit clamps. The top of each antenna loop was held in place by a spreader bar that was secured to the concrete with construction adhesive.

The antennae located in the canals downstream of the fish screens (Figure 6), consisted of one to two loops of 8-gauge speaker cable. The top of each antenna was attached to a length of steel aircraft cable that was secured on both ditch banks. The bottom of each antenna was buried in the substrate.

Bypass pipes constructed of 30.5-cm diameter PVC returned water from the fish screens to Skalkaho Creek. A PIT tag detecting antenna was installed on each bypass pipe to sample the outflow for PIT-tagged fish (Figure 6).

Bypass antennae consisted of multiple loops of 8-gauge speaker cable wrapped around each bypass pipe, with a length of antenna connecting the bypass loops to the tuning box.

Antennae were constructed so that the inductance of each antenna was as close as possible to the ideal inductance (27 μ H) for standard low frequency RFMs (Scher 2004). Each antenna was connected to a tuning box that was used to tune each antenna so that it resonated at the carrier frequency of 134.2 kHz. Twinaxial cable connected up to four tuning boxes and associated antennae to a single multiplexing Series 2000 High Performance Remote Antenna RFM (Texas Instruments, Oregon RFID) housed in an environmental enclosure. PIT tag readers (RFMs) were powered by one or two 12-volt (V) deep-cycle marine batteries (130 Amp hour) that were also placed inside the enclosure. This configuration allowed a single reader to scan up to four antennae for PIT tags at distances of 50 to 100 cm from the antennae at a read rate of 8 to 10 energize/receive cycles/second. Tag number, antenna number, date, and time

were recorded as a PIT-tagged fish passed through an antenna on a datalogging PDA that was connected to the PIT tag reader.

To ensure that antennae were functioning properly, detection efficiency of each antenna was quantified weekly by passing a PIT tag attached to the end of a meter-long stick through each antenna in a grid-configuration at one to three different depths at as many as eight locations across the width of the antenna. Detection efficiency of bypass antennae was quantified by passing a 150-mm long stick with a PIT tag attached to it through the bypass pipe. The smaller stick was dropped into the bypass pipe from the fish screen, and recovered in the creek after it passed through the pipe. Detection efficiency was calculated as the number of PIT tag detections divided by the number of times the PIT tag was passed through the antenna multiplied by 100.

The mean detection efficiency of each antenna was calculated for each fish screen efficiency trial. Detection efficiency of headgate antennae varied temporally, but remained relatively high, ranging from 86 to 100% at the Highline Canal, 92 to 100% at the Ward Canal, and 78 to 88% at the Hughes Canal. The efficiency of antennae located in the canals downstream of the fish screens also varied temporally from 98 to 100% at Highline, 63 to 77% at Ward, and 81 to 100% at Hughes. Bypass pipe antennae typically had lower detection efficiencies, ranging from 37 to 54% at Highline and 30 to 88% at Ward. No water (and therefore no fish) was bypassed at the Hughes Canal during fish screen efficiency trials because all water diverted into the Hughes Canal during

the trials was needed for irrigation. Consequently, detection efficiency was not quantified for the Hughes bypass pipe antenna.

The percentages of PIT-tagged fish that were bypassed back to Skalkaho Creek, became entrained down the canal beyond the fish screen, exited the canal through the headgate, remained in the canal, or went undetected at each screened diversion were calculated. Fish screen efficiency was defined as the percentage of PIT-tagged fish that exited the screened canals, either through the bypass pipe or through the headgate.

The exit time (amount of time taken by PIT-tagged fish to exit the screened canals) was calculated for each fish detected exiting by subtracting the date and time of release from the date and time of exit. Because the times were not normally distributed (Highline Canal: Shapiro-Wilk normality test: $\alpha = 0.05$; $P < 0.001$), (Ward Canal: Shapiro-Wilk normality test: $\alpha = 0.05$; $P < 0.001$), (Hughes Canal: Shapiro-Wilk normality test: $\alpha = 0.05$; $P < 0.001$) (Figure 8), the median amount of time taken by fish to exit was determined for each canal. The Kruskal-Wallis one-way analysis of variance by ranks test (SAS 9.1, $\alpha = 0.05$) was used to determine if the median amount of time taken by fish to exit differed between at least two of the canals. If a significant difference was detected, pairwise comparisons for each pair of canals were made using the Mann-Whitney U test (SAS 9.1, $\alpha = 0.05$) to determine which two canals differed significantly. The Mann-Whitney U test was also used to determine if the median

amount of time taken by fish to exit the screened canals varied by route (bypass or headgate) or by species (westslope cutthroat trout versus bull trout).

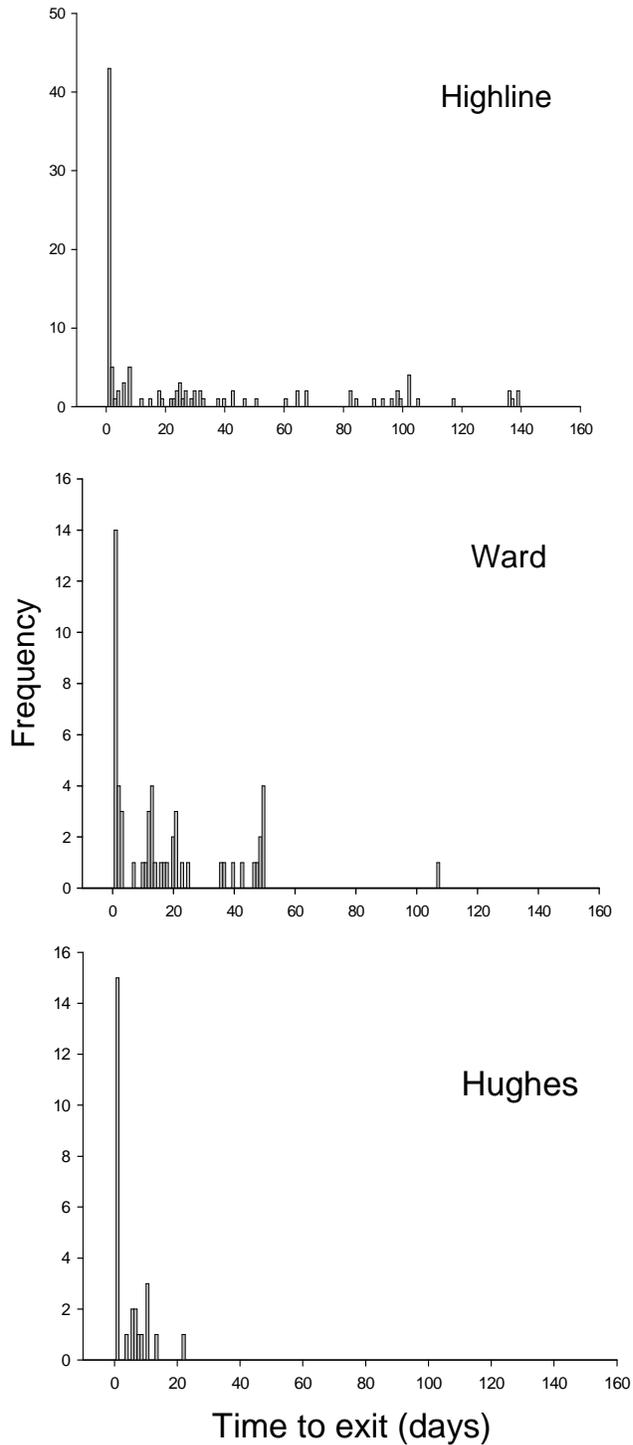


Figure 8. Number of days taken by PIT-tagged fish to exit the screened canals.

Age-0 Westslope Cutthroat Trout Distribution

I estimated the number of age-0 westslope cutthroat trout that moved downstream into the irrigation-affected reach and the number that moved downstream of the Ward-Hughes diversion dam. Additionally, I evaluated the spatial distribution of age-0 westslope cutthroat trout between the Highline (Figure 5, location 1) and Ward-Hughes diversions (Figure 5, location 3). These data were used to evaluate the downstream movement and mortality of age-0 westslope cutthroat trout in Skalkaho Creek.

A screw trap (EG Solutions) with a 1.5-m diameter cone entrance was placed in Skalkaho Creek about 1 rkm upstream from the Highline diversion dam (Figure 5, location A) prior to the emergence of age-0 westslope cutthroat trout in 2005 and 2006 to determine the number of age-0 westslope cutthroat trout that moved downstream into the irrigation-affected reach. The trap was operated about 5 d per week from 8 May to 15 October in 2005 and from 10 July to 4 October in 2006 (Table 1, designation A). Fish were counted, identified to species, and total lengths (mm) of all captured fish were recorded. Trap efficiencies were used to expand daily catches to estimate the total number of age-0 westslope cutthroat trout that moved downstream at the trap location each day the trap was operated. Trap efficiency was estimated about once per week by mark-recapture trials. If ten or more fish were captured during a 24-h period, they were marked with Bismarck Brown Y dye, transported upstream 50 m, and released. The trap was reset, and checked 24 h later when the number of dyed

fish was counted. Trap efficiency was calculated by dividing the number of recaptured dyed fish by the total number of dyed fish released. Data were pooled if efficiencies of consecutive mark-recapture trials were similar (chi-square test, $P > 0.05$). Pooled trap efficiencies varied significantly from 1.71% to 29.73% (Table 3). Confidence intervals for trap efficiencies were calculated using the relationship between the F and the binomial distributions (Zar 1984). The number of fish moving downstream during a 24-h deployment period was estimated by dividing the total number of captured fish by the efficiency of the trap during that period. The Area-Under-the-Curve (AUC) method (Sigma Plot 9.0, English et al. 1992) was used to estimate the annual number of age-0 westslope cutthroat trout that moved past the trap location and presumably into the irrigation-affected reach.

Table 3. Pooled capture efficiency results and 95% confidence limits for the screw trap located about 1 rkm upstream from the Highline diversion dam (Figure 5, location A), Skalkaho Creek, Montana, 2005 and 2006.

Date	Number Marked	Number Recaptured	Pooled efficiency (%)	95% LCL (%)	95% UCL (%)
5/8/05 – 10/15/05	278	39	12.23	8.62	16.67
7/10/06 – 8/14/06	175	3	1.71	0.35	4.93
8/15/06 – 8/27/06	258	25	9.69	6.37	13.97
8/28/06 – 9/5/06	138	32	23.19	15.78	30.59
9/6/06 – 9/10/06	70	7	10.0	4.12	19.52
9/11/06 – 9/17/06	37	11	29.73	13.65	45.81
9/18/06 – 9/24/06	120	12	10.0	5.27	16.82
9/25/06 – 10/4/06	83	17	20.48	11.2	29.77

Because little to no water flowed over the Ward-Hughes diversion dam (Figure 5, location 3) from July through September in 2005 or 2006, the only routes available to fish attempting to pass downstream of this site during this time were the Ward and Hughes bypass pipes (Figure 6). Therefore, the number of age-0 westslope cutthroat trout that moved downstream of the Ward-Hughes diversion dam was estimated by trapping the outflow of the Ward and Hughes bypass pipes (Table 1, designation 3). A modified trap net (Research Nets, Inc.), consisting of a 305-cm long net (1.6-mm mesh) leading to a 61 x 61 x 61 cm live box (impermeable vinyl and 1.6-mm mesh), was attached to the bypass pipe by wrapping the mouth of the net completely around the pipe and securing it with rubber tarp straps to ensure that 100% of the outflow was sampled. Because age-0 westslope cutthroat trout in Skalkaho Creek primarily move downstream during periods of low light (Gale 2005) the bypass trap was set overnight for about 12 h once per week until the canal was shut down at the end of the irrigation season. All captured fish were counted, identified to species, and total lengths (mm) were recorded. Annual numbers of fish bypassed by the Ward and Hughes fish screens were estimated using the AUC method.

Water once again flowed over the Ward-Hughes diversion dam on 27 September in 2005 and on 29 September in 2006, after the irrigation canals had been shut down at the end of the irrigation season. Sampling for downstream-migrating age-0 westslope cutthroat trout ended at the bypass pipes upon

headgate closure. However, a screw trap located about 7.1 rkm downstream of the Ward-Hughes diversion dam near the mouth of Skalkaho Creek (Figure 5, location C) sampled for downstream migrants from 11 May until 15 October in 2005 (Table 1, designation C). In 2006, a picket weir located about 4.2 rkm downstream of the Ward-Hughes diversion (Figure 5, location B) sampled for downstream migrants from 12 July until 20 October (Table 1, designation B) and a screw trap located near the mouth of Skalkaho Creek (Figure 5, location C) sampled for downstream migrants from 3 May until 1 November (Table 1, designation C).

The distribution and mortality of age-0 westslope cutthroat trout in the 6.3 rkm reach located between the Highline and Ward-Hughes diversion dams (Figure 5, locations I-VI) was determined by single-pass electrofishing randomly selected 50-m reaches (Table 1, designation I-VI). The segment was divided into six strata of about equal lengths (1.05 km). Each stratum was divided into 21 50-m reaches. Following age-0 westslope cutthroat trout emergence, two 50-m reaches were randomly selected each month from each stratum. Because newly emergent salmonids frequently occupy slow water at the edge of stream channels (Keenleyside 1962; Chapman 1966; Lister and Genoe 1970; Moore and Gregory 1988) the margins of each selected reach were electrofished to obtain estimates of age-0 westslope cutthroat trout density (Opitz 1999; Mitro

and Zale 2000; Mitro and Zale 2002). Reaches were electrofished about once per month from July through October 2006 (Table 1, designation I-VI).

Because age-0 fish could not swim over the Highline diversion dam in an upstream direction and the number of age-0 fish that moved downstream and out of this segment was estimated, the mortality rate of age-0 westslope cutthroat trout between Highline and Ward-Hughes was calculated from the electrofishing data. The density of age-0 fish in all six strata combined during the final week was divided by the density of age-0 fish during the first week. This quotient was subtracted from one then multiplied by 100 to obtain the rate of mortality.

Unscreened Canal Entrainment

The number of migratory westslope cutthroat trout that became entrained into the unscreened Hedge, Republican, and C&C canals (Figure 5, locations 5, 6, and 7) and the rate of entrainment into the Hedge Canal were estimated in 2006. Non-migratory, fluvial westslope cutthroat trout and bull trout are rare downstream of the Ward-Hughes diversion dam (Nelson 1999; Chris Clancy, MDFWP, personal communication) possibly because daily high water temperatures in this reach of Skalkaho Creek frequently exceed levels tolerated by these species during the summer. Therefore, I assumed westslope cutthroat trout and bull trout captured downstream of the Ward-Hughes diversion dam were attempting to emigrate to the Bitterroot River.

Prior to spring 2006 runoff, a screw trap (EG Solutions) with a 1.5-m diameter cone entrance was placed in Skalkaho Creek about 50 m upstream from the Hedge diversion (Figure 5, location B) to estimate the number of westslope cutthroat trout and bull trout that encountered the Hedge, Republican, and C&C diversions as they emigrated to the Bitterroot River (Table 1, designation B). The trap was checked about 5 d per week from 3 May to 10 July except when high discharge prevented trap operation from 13 May to 30 May (Table 1, designation B). Fish were counted, identified to species, and total lengths (mm) of all captured fish were recorded. Captured fish weighing 12 g or more were PIT-tagged. Trap efficiency and estimates were determined as per the methods used for the screw trap located upstream of all diversions. Trap efficiencies were similar enough throughout the sampling period to be pooled (chi-square test, $P > 0.05$), resulting in an overall trap efficiency of 8.82% (95% CI; 3.31 – 18.22%).

The screw trap remained in this location until the second week of July when discharge was reduced and the trap no longer operated efficiently. At this time, a vertical “picket-fence” weir (Schroeder 1996; Reiland 1999), covered with 1.6 mm hardware cloth was installed in place of the screw trap (Figure 5, location B) to continue estimation of the number of emigrating juveniles that encountered the Hedge, Republican, and C&C diversions (Table 1, designation B). The weir was checked about 5 d per week until 20 October (Table 1, designation B). Fish

captured in the weir were counted, identified to species, and total lengths (mm) of all captured fish were recorded. Captured fish weighing 12 g or more were PIT-tagged. Large quantities of leaves clogged the weir on several occasions from 29 September to 20 October allowing water to flow around or over the weir. Therefore, less than 100% of the flow and presumably less than 100% of the fish were sampled on these occasions. The number of fish passing the weir was calculated using the AUC method from days in which 100% of the flow, and presumably 100% of the fish was sampled. A staff gauge and temperature logger were placed in Skalkaho Creek upstream of the screw trap and weir location to determine the effect of stream discharge and water temperature on the timing of juvenile westslope cutthroat trout and bull trout downstream movements.

The number of juvenile westslope cutthroat trout and bull trout that successfully emigrated to the Bitterroot River was quantified by placing a screw trap in the creek, downstream of all irrigation diversions, about 0.1 rkm upstream from the mouth of Skalkaho Creek (Figure 5, location C). The trap was checked about 5 d per week from 3 May until 15 October 2005 and from 11 May to 1 November 2006 (Table 1, designation C). Captured fish were counted, identified to species, and total lengths of all salmonids were recorded. Trap efficiency, which varied significantly from 1.4 to 45% (chi-square test, $P > 0.05$) (Table 4), and estimates were determined as per the methods used for the other screw trap

locations. To ensure that the screw trap sampled during the time when the majority of westslope cutthroat trout emigrated to the Bitterroot River, a PIT tag detecting antenna was operated near the mouth of Skalkaho Creek (Figure 5, PIT array 5) from 7 March to 7 May 2007 to detect PIT-tagged fish that emigrated during late winter or early spring (Table 1, designation C (PIT5)). A staff gauge and temperature logger were placed in Skalkaho Creek directly downstream of the screw trap location to determine the effect of discharge and water temperature on the timing of westslope cutthroat trout and bull trout downstream movements to the Bitterroot River.

Table 4. Pooled capture efficiency results and 95% confidence limits for the screw trap located about 0.1 rkm upstream from the mouth of Skalkaho Creek, Montana, 2005 and 2006.

Date	Number marked	Number recaptured	Pooled Efficiency (%)	95% LCL (%)	95% UCL (%)
5/11/05 – 8/29/05	357	19	5.32	3.23	8.19
8/30/05 – 9/27/05	116	30	25.86	17.46	34.82
9/28/05 – 10/15/05	141	9	6.38	2.96	11.77
5/3/06 – 8/7/06	337	19	5.64	3.43	8.66
8/8/06 – 8/13/06	571	8	1.4	0.61	2.74
8/14/06 – 8/20/06	100	28	28.0	18.7	37.3
8/21/06 – 8/27/06	113	5	4.42	1.45	10.02
8/28/06 – 9/12/06	54	11	20.37	8.7	32.04
9/13/06 – 10/8/06	115	2	1.74	0.21	6.14
10/9/06 – 10/25/06	46	8	17.39	7.82	31.42
10/26/06 – 11/1/06	20	9	45.0	20.7	69.3

The entrainment rate of emigrating westslope cutthroat trout and bull trout into the Hedge Canal was estimated by determining the percentage of PIT-tagged fish encountering the Hedge diversion that became entrained into the Hedge Canal in 2006. A total of 496 westslope cutthroat trout and 49 bull trout was PIT-tagged and released at several sites located from 50 m upstream of the Hedge diversion dam up to about 1 rkm upstream of the Highline diversion dam in 2005 and 2006. Thirty-three PIT-tagged fish were released about 1 rkm upstream of the Highline diversion dam, 190 were released into or directly downstream of the Highline Canal, 257 were released into the Ward and Hughes canals, 20 were released directly downstream of the Ward-Hughes diversion dam, and 40 were released upstream of the Hedge diversion, within 100 m of the dam. Although many of the PIT-tagged fish were released directly into the Highline, Ward, and Hughes irrigation canals for fish screen efficiency trials, information about the Hedge Canal entrainment rate was obtained from PIT-tagged fish that moved downstream far enough to encounter the Hedge diversion (Figure 5, location 5).

Only 16 of the 545 PIT-tagged fish were detected encountering the Hedge diversion dam by PIT tag detecting antennae (Figure 5, PIT array 4). The percentage of these 16 fish that became entrained into the Hedge Canal was multiplied by the estimated number of westslope cutthroat trout and bull trout that encountered the Hedge diversion, which was obtained from the screw trap and weir at location B (Figure 5). This product provided an estimate of the number of

westslope cutthroat trout and bull trout that were entrained into the Hedge Canal during the 2006 irrigation season.

PIT tag-detecting antennae were installed around each headgate opening, in the Hedge Canal directly upstream from its intersection with Skalkaho Creek, and in Skalkaho Creek about 50 m downstream from the Hedge diversion dam (Figure 3) at PIT array 4 (Figure 5) to determine the fate of PIT-tagged fish. The entire flow volume was scanned for PIT tags at each site without obstructing the path of the fish. To determine the percentage of PIT-tagged fish that was drawn through the headgates into the Hedge outlet canal (Figure 3), headgate antennae were constructed of two loops of eight gauge speaker cable and attached to the concrete headgate structure as described for other headgate antennae as near to each headgate opening as possible (0.80 m to 0.96 m). All headgate antennae remained operational throughout the irrigation season, which ended at this location on 18 September, except for a two-week period from 29 June to 13 July when the right headgate antenna did not detect PIT tags after it had been accidentally severed by ditch operators. Two antennae were installed in the Hedge inlet canal about 15 m upstream from the Hedge Canal-Skalkaho Creek intersection (Figure 3) to determine the percentage of PIT-tagged fish that were entrained by swimming upstream into the Hedge inlet canal. Antennae were spaced about 10 m apart to determine the direction of movement of entrained fish. Inlet canal antennae remained operational throughout the irrigation season. An antenna installed on 4 May in Skalkaho Creek about 50 m downstream from

the Hedge diversion dam (Figure 3) was used to determine the percentage and timing of downstream-migrating PIT-tagged fish that migrated beyond the Hedge diversion dam. However, high discharge experienced during spring runoff dislodged the antenna on 19 May. The antenna was reinstalled on 23 June and remained operational until 30 November, when it was removed from the creek.

To ensure that antennae were functioning properly, the detection efficiency of each antenna was quantified weekly as per the methods described for other PIT tag detecting antennae. Detection efficiency was about 75 to 92% for the headgate antennae, 66% for each antenna located in the inlet canal, and 95% for the antenna located in Skalkaho Creek downstream of the Hedge diversion dam. A staff gauge and temperature logger were installed in the Hedge inlet canal, outlet canal, and in Skalkaho Creek upstream and downstream of the Hedge diversion dam to determine the effect of stream discharge, canal discharge, and water temperature on the timing of downstream movements and entrainment.

RESULTS

Fish Screen Efficiency

The efficiency of the Highline, Ward, and Hughes fish screens was 82% during 2006 (Table 5). Most fish (69%) exited through the headgates; only 14% exited through the bypass pipes (Table 5). Twenty-nine fish (12%) never exited the canals (Table 5). No fish were entrained beyond the fish screens and 13 (5%) were never detected by the antennae or recovered (Table 5).

Table 5. Percentages of PIT-tagged fish that exited the screened canals through the headgate, exited through the bypass pipe, remained in the canal, were not detected or recovered, and the efficiency of fish screens during fish screen efficiency trials conducted in 2006.

Canal	Headgate exit	Bypass exit	Remained	Not detected or recovered	Efficiency
Highline	75% (89 of 119)	19% (22 of 119)	3% (3 of 119)	4% (5 of 119)	93% (111 of 119)
Ward	73% (44 of 60)	18% (11 of 60)	5% (3 of 60)	3% (2 of 60)	92% (55 of 60)
Hughes	52% (31 of 60)	0% (0 of 60)	26% (23 of 60)	10% (6 of 60)	52% (31 of 60)
Total	69% (164 of 239)	14% (33 of 239)	12% (29 of 239)	5% (13 of 239)	82% (197 of 239)

The Highline and Ward canals were similarly efficient with near equal percentages of fish that exited through the bypass pipes and headgates (Table 5). The Hughes Canal was only about 52% efficient (Table 5). All fish that exited

the Hughes Canal swam through the headgate (Table 5). No water flowed through the Hughes bypass pipe during efficiency trials because all water diverted into the canal was used for irrigation (Figure 9).

The small size of the Hughes Canal headgate opening (Figure 9) prevented many fish from exiting through the headgates during the final two weeks of the irrigation season. Because no water was bypassed during this time (Figure 9), many fish became trapped in the canal between the headgate and the fish screen. The mean total length of fish that exited during the final two weeks (144.2 mm) was smaller than the length of fish that remained in the canal (168.5 mm), although the difference was not statistically significant (t-test: $\alpha = 0.05$; $P = 0.237$).

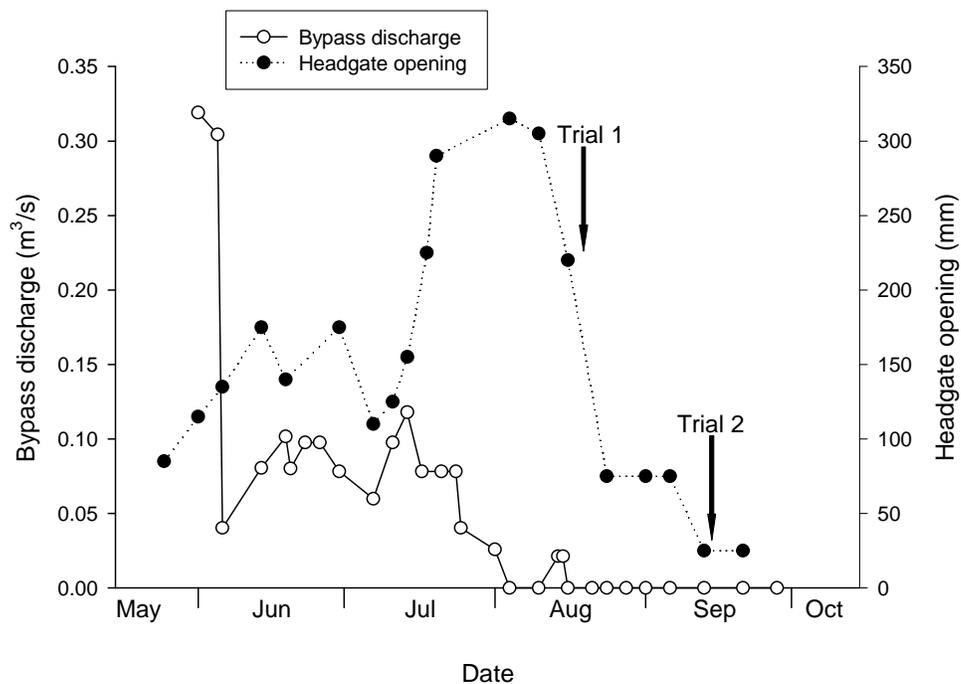


Figure 9. Amount of water flowing through the Hughes Canal bypass pipe and the size of the headgate opening during the 2006 irrigation season. Arrows indicate dates of screen efficiency trial fish releases.

The location of capture (above or below the dams) did not affect the route used by fish to exit. Excluding Hughes (because fish were not able to exit through the bypass pipe), a greater percentage of fish captured above the dams was bypassed (20%) than the percentage of fish captured below the dams (15%). If fish exited the canals to return to their location of capture, a greater percentage of fish captured from below the dams would have exited in a downstream direction, through the bypass pipe, than the percentage of fish captured from above the dams.

Exit time ranged from 0.03 h (2 minutes) to 3358.3 h (140 d). The median exit time was 168.35 h (7 d) (Table 6). About 37% of fish detected exiting the canals exited within 24 h of being released and 50% exited within one week (Table 6). Exit time was significantly higher at the Highline and Ward canals than at the Hughes Canal (Mann-Whitney U test; both $P < 0.011$) (Table 6). Exit time was higher for bypass exits (536.22 h) than for headgate exits (150.25 h) and for bull trout (183.28 h) than westslope cutthroat trout (167.47 h), but the differences were not statistically significant (Mann-Whitney U tests; both $P > 0.150$).

Table 6. Median time to exit and percentages of PIT-tagged fish exiting the screened canals within 24 h and one week after being released for fish screen efficiency trials conducted during the 2006 irrigation season.

Canal	Median time to exit (h)	Exiting within 24 h	Exiting within 1 week
Highline	168.62	39% (43 of 111)	49% (54 of 111)
Ward	292.48	25% (14 of 55)	40% (22 of 55)
Hughes	16.79	56% (15 of 27)	74% (20 of 27)
Total	168.35	37% (72 of 193)	50% (96 of 193)

About 90% (28 of 31) of PIT-tagged fish that remained in the Highline Canal on 20 September exited the canal during the final three weeks of the irrigation season, coinciding with the staged flow reduction (Figure 10). This staged drawdown was conducted from 21 September to 11 October by reducing the amount of water that was diverted into the canal from 0.70 m³/s on 21 September to 0.31 m³/s on 28 September, and again to 0.13 m³/s on 5 October before closing the headgate on 11 October. These reductions were conducted to prompt fish to exit the canal by swimming upstream through the headgate openings. Nineteen of the 31 fish (61%) were detected exiting through the headgate during this time, nine (29%) were detected exiting through the bypass pipe, and three fish (10%) remained in the canal after headgate closure.

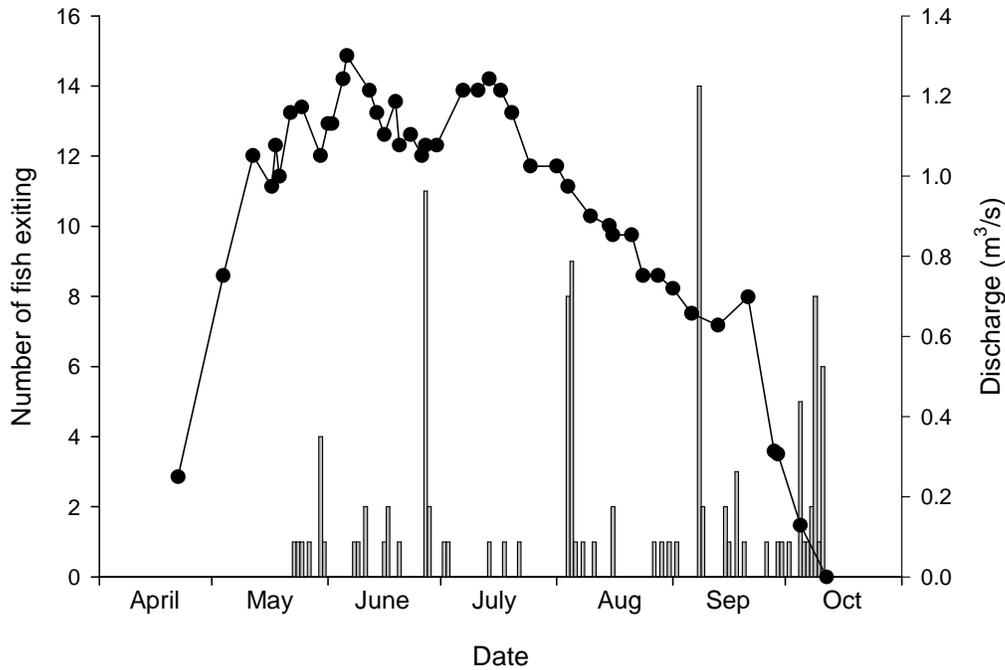


Figure 10. Number of PIT-tagged fish exiting the Highline Canal during each day of the 2006 irrigation season plotted with the Highline Canal discharge. Spikes in late June, early August, and early September correspond to introductions of tagged fish. The spike in early October coincided with the staged flow reduction.

Age-0 Westslope Cutthroat Trout Distribution

The total number of age-0 westslope cutthroat trout that moved downstream into the irrigation-affected reach was estimated to be 19,978 (95% CI; 14,664–28,355) in 2005 and 25,991 (95% CI; 11,822–99,077) in 2006. Downstream movement peaked above the Highline diversion dam (Figure 5, location A) in mid to late September in 2005 and in late July in 2006 (Figure 11).

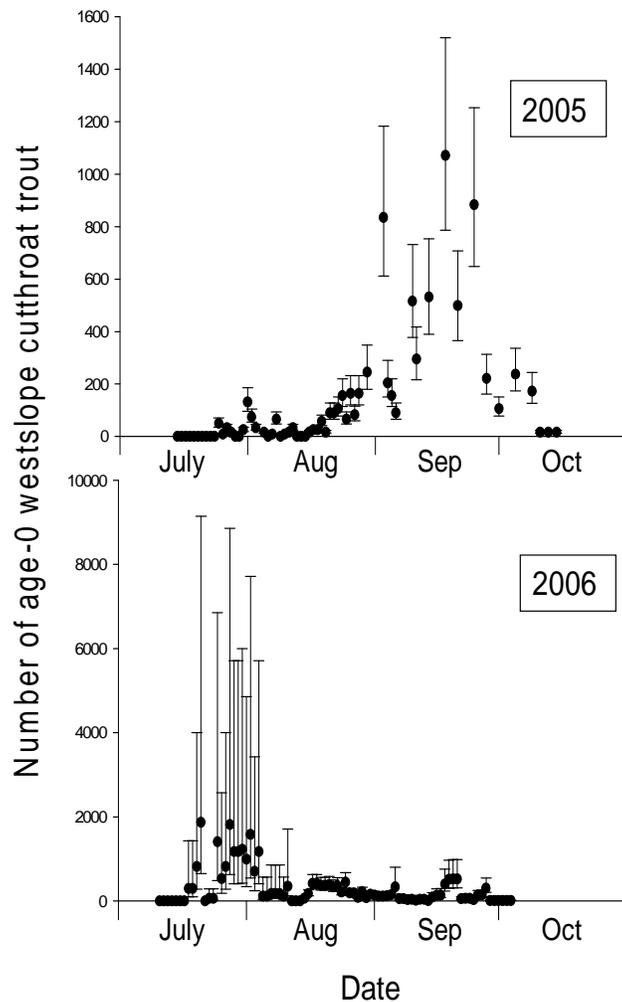


Figure 11. Estimated number of age-0 westslope cutthroat trout that moved downstream into the irrigation-affected reach of Skalkaho Creek in 2005 and 2006.

Although large numbers of age-0 westslope cutthroat trout moved downstream into the irrigation-affected reach, only an estimated 264 continued their migration beyond the Ward-Hughes diversion dam (Figure 5, location 3) in 2005 and only 291 moved downstream of this point in 2006. Because no age-0 westslope cutthroat trout were captured near the mouth of Skalkaho Creek (Figure 5, location C) after the end of the irrigation season in 2005 or 2006, and

none were captured upstream of the Hedge diversion (Figure 5, location B) in 2006, the bypass estimates likely represent the majority of age-0 westslope cutthroat trout that migrated beyond the Ward-Hughes diversion dam in 2006.

Peak downstream movement of age-0 westslope cutthroat trout through the Ward and Hughes bypass pipes (Figure 5, location 3) occurred in late July, coinciding with emergence, as judged by length (about 20 mm) and the presence of yolk sacs, and again in late September (Figure 12), coinciding with increased stream discharge (Figure 12). No water flowed through the bypass pipes during all of August and much of September in 2005. Similarly, no water flowed through the Hughes bypass pipe during much of August in 2006. All water diverted into the canals during these times was used for irrigation. Therefore, no fish were bypassed during these times (Figure 12).

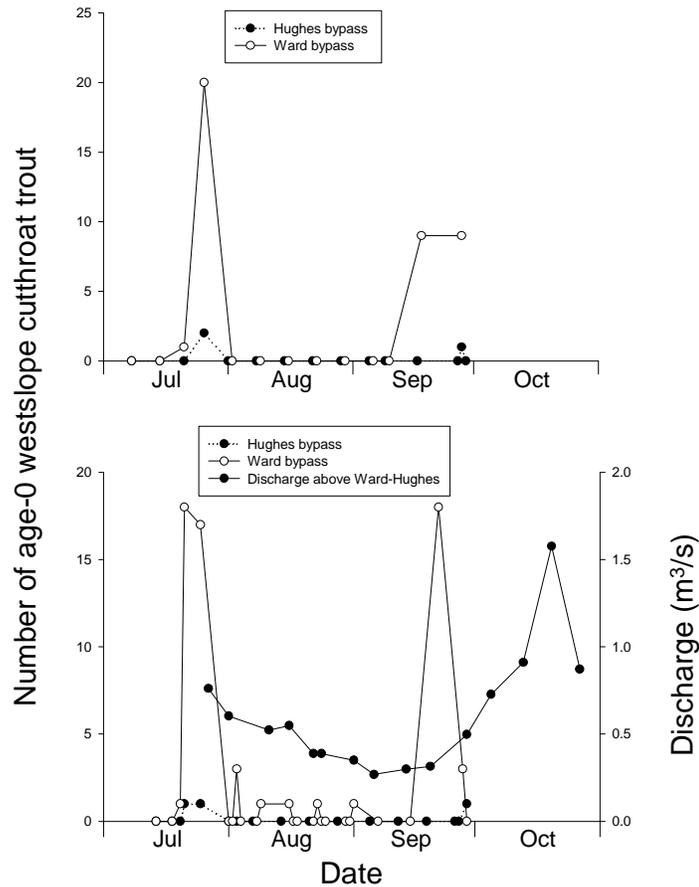


Figure 12. Number of age-0 westslope cutthroat trout that moved downstream of the Ward-Hughes diversion dam in 2005 and 2006.

Although relatively few age-0 westslope cutthroat trout migrated downstream of the Ward-Hughes diversion dam, they were distributed throughout Skalkaho Creek from Highline to Ward-Hughes. Higher densities of age-0 fish were observed near Highline (Stratum 1) shortly after their emergence, with lower densities in downstream strata (Figure 13). By autumn, they were dispersed throughout this segment, becoming more evenly distributed during each successive electrofishing event (Figure 13).

The density of age-0 fish declined from 1.39 fish/m in all six strata combined during late July to 0.65 fish/m during mid-October (Figure 13).

Because so few age-0 fish migrated out of this reach during this time the mortality rate was obtained from the electrofishing data. About 53% of age-0 westslope cutthroat trout died between Highline and Ward-Hughes during the first 2.5 months following their emergence.

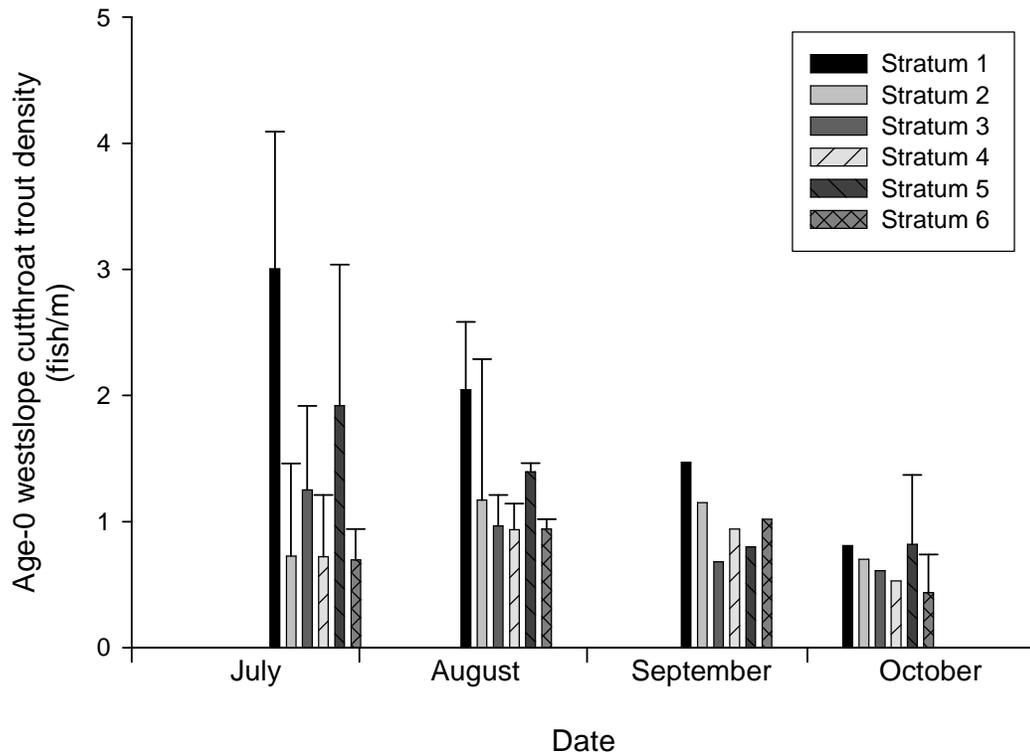


Figure 13. Spatial and temporal trend of age-0 westslope cutthroat trout distribution between the Highline (Stratum 1) and Ward-Hughes (Stratum 6) diversion dams, Skalkaho Creek, 2006.

Unscreened Canal Entrainment

Based on screw trap and weir catches (Figure 5, location B), an estimated 290 (95% CI; 114–662) age-1 and older westslope cutthroat trout and 162 (95% CI; 73–435) age-1 and older bull trout encountered the Hedge diversion from 3

May to 20 October 2006. Peak downstream movements above the Hedge diversion dam (Figure 5, location B) occurred in mid to late June and again during the first week of October (Figure 14). The October peak coincided closely with the closure of the Ward and Hughes irrigation canals on 29 September, which allowed more water to flow down Skalkaho Creek to the Hedge diversion dam (Figure 14).

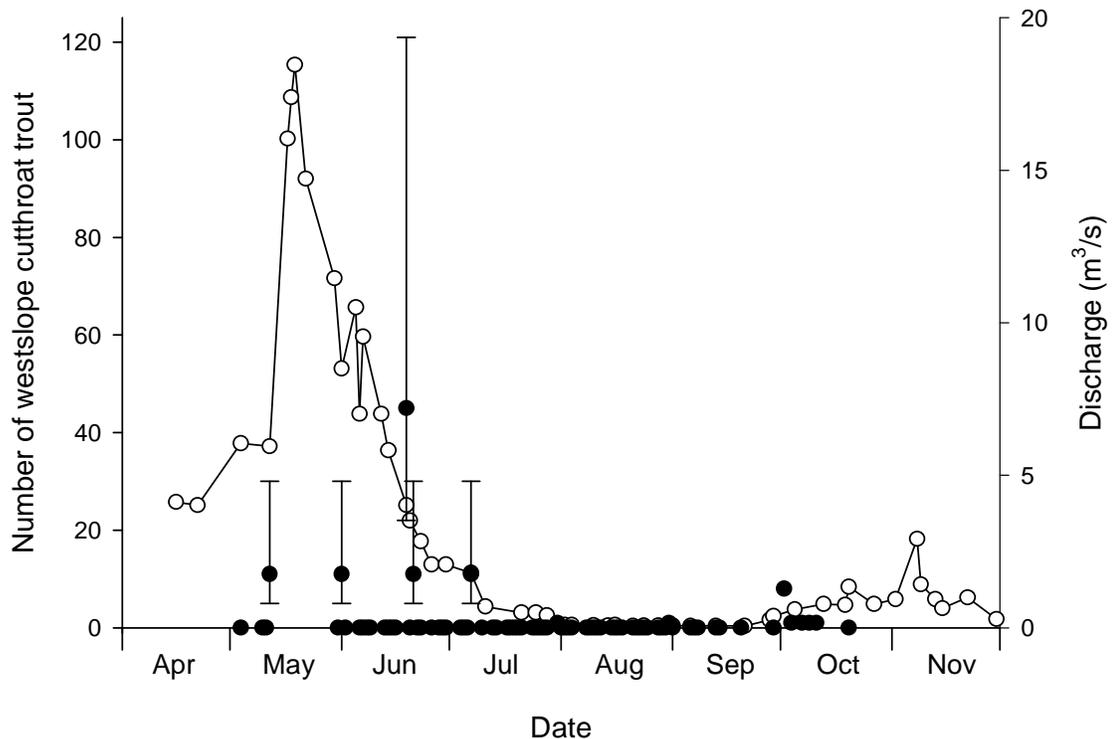


Figure 14. Estimated number of westslope cutthroat trout (closed circles) that encountered the Hedge diversion dam from 3 May to 20 October 2006. Error bars represent the upper and lower 95% confidence intervals for screw trap estimates. Discharge (open circles) was measured 100 m upstream from the Hedge diversion dam.

All westslope cutthroat trout captured above the Hedge diversion from May to July were age-1 fish with a mean total length of about 82 mm. Bull trout

captured during this time had a mean total length of about 126 mm, indicating that they were probably age-1 or age-2 fish. Westslope cutthroat trout captured in the autumn were considerably larger (mean total length of about 185 mm) and older than fish captured during the spring.

An estimated 283 westslope cutthroat trout successfully emigrated from Skalkaho Creek to the Bitterroot River from 11 May to 15 October with no distinct peak in 2005 (Figure 15) and 86 emigrated from 3 May to 1 November with no distinct peak in 2006 (Figure 15). Emigrating westslope cutthroat trout had a mean total length of about 211 mm (95% CI; 170 – 252 mm) during the two years combined. Westslope cutthroat trout emigrated to the Bitterroot River over a wide range of discharges and water temperatures in 2005 and 2006 (Figure 15). An estimated 76 bull trout emigrated in 2005 and 54 emigrated in 2006. The mean total length of emigrating bull trout was about 190 mm (95% CI; 143 – 236 mm). Only one out of 545 (0.18%) PIT-tagged fish was detected by PIT array 5 (Figure 5) emigrating to the Bitterroot River during late winter and early spring 2007.

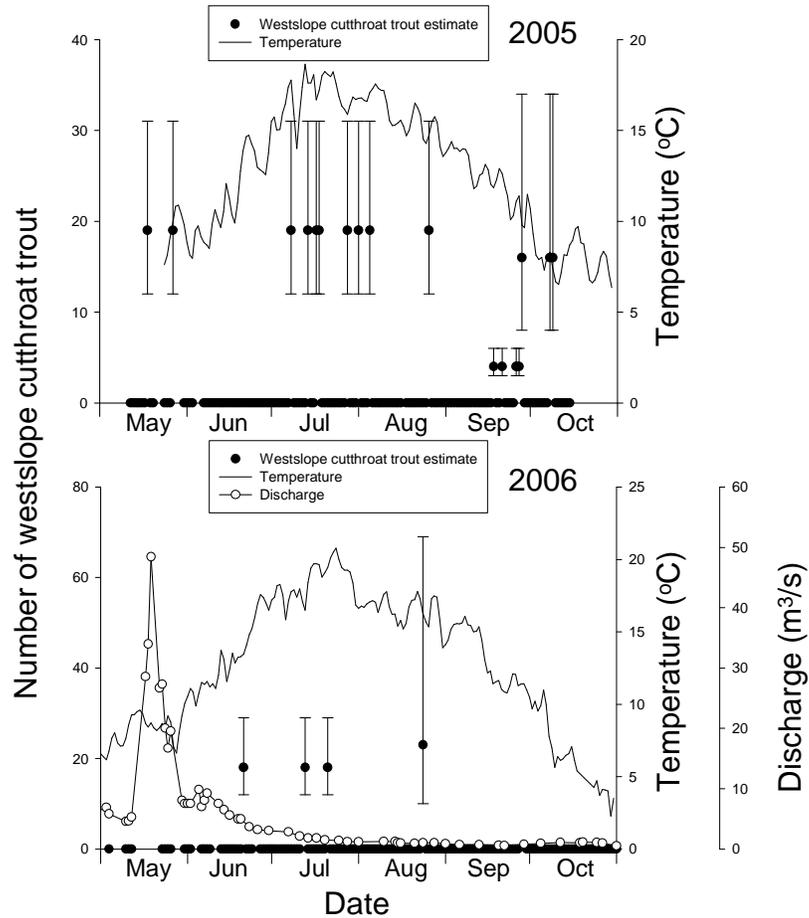


Figure 15. Estimated numbers of westslope cutthroat trout that emigrated to the Bitterroot River from 11 May to 15 October 2005 and from 3 May to 1 November 2006. Error bars represent the upper and lower 95% confidence intervals. Mean daily temperatures recorded about 0.1 rkm upstream from the mouth of Skalkaho Creek in 2005 and about 4 rkm upstream from the mouth in 2006. Discharge measured about 0.1 rkm upstream from the mouth of Skalkaho Creek in 2006. Discharge was similar in 2005 but was not measured.

An estimated 204 westslope cutthroat trout and 108 bull trout were entrained into the Hedge, Republican, and C&C canals in 2006. These numbers represent about 70% of all westslope cutthroat trout and 67% of all bull trout that encountered these diversions.

Thirteen PIT-tagged westslope cutthroat trout and three PIT-tagged bull trout encountered the Hedge diversion in 2006 (Table 7). Five of the 16 fish (31%) were detected only by the antenna located in Skalkaho Creek downstream of the Hedge diversion dam (Figure 3) from 28 September to 25 October after the Hedge Canal had been shut down on 18 September (Figure 16), which allowed water to flow over the dam. The downstream movement of these fish coincided closely with increased stream discharge (Figure 16) that resulted from the closure of the Ward and Hughes headgates on 29 September.

Table 7. Fish number, species, total length, number of times PIT-tagged fish were entrained into the Hedge inlet canal, outlet canal, and the final location of PIT-tagged fish that encountered the Hedge diversion in 2006.

Fish #	Species	Total length (mm)	Number of times entrained into inlet canal	Number of times entrained into outlet canal	Final location
979	WCT ^a	183	2	1	Below Hedge
699	WCT	247	0	0	Below Hedge
681	WCT	207	1	0	Below Hedge
414	WCT	138	0	0	Below Hedge
333	WCT	117	0	0	Below Hedge
135	WCT	287	0	0	Below Hedge
007	WCT	215	0	0	Below Hedge
719	BLT ^b	111	1	0	Inlet canal
692	BLT	122	1	0	Inlet canal
631	WCT	189	2	1	Inlet canal
129	WCT	220	1	0	Inlet canal
098	WCT	227	2	1	Inlet canal
669	WCT	368	0	1	Outlet canal
655	WCT	367	1	1	Outlet canal
149	WCT	240	1	1	Outlet canal
069	BLT	158	2	2	Outlet canal

^a WCT = westslope cutthroat trout

^b BLT = bull trout

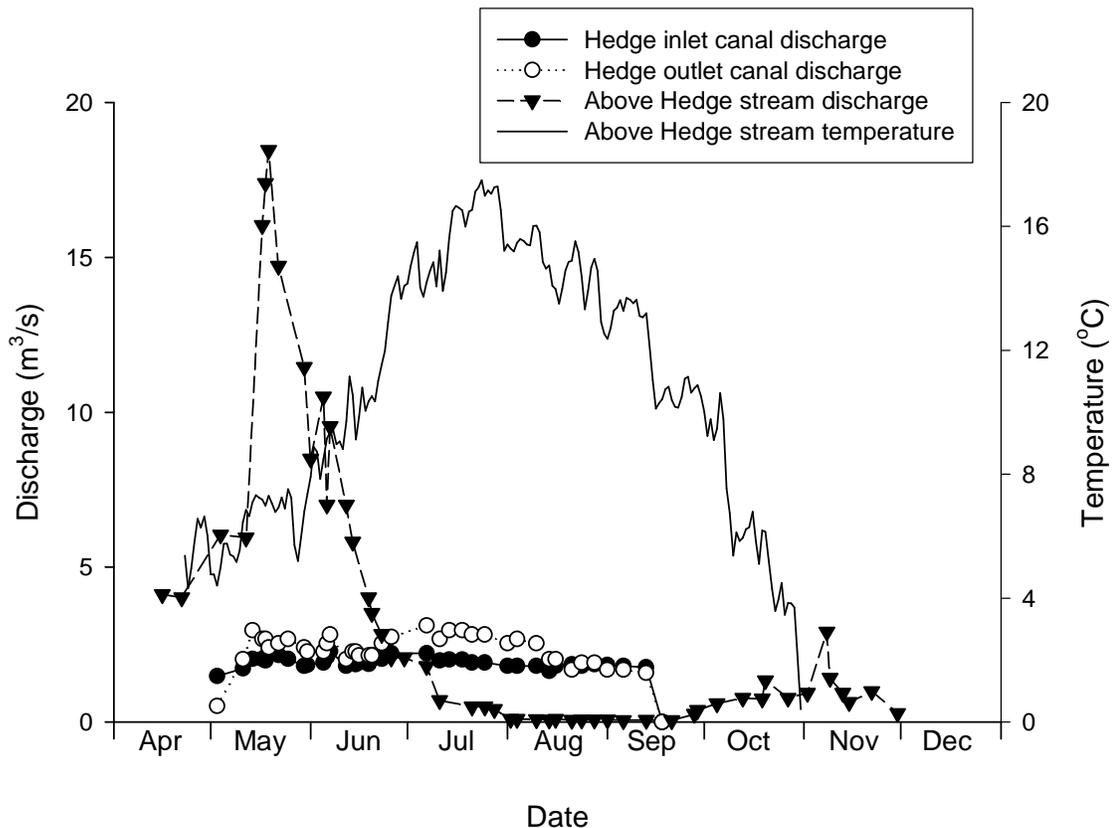


Figure 16. Discharge and mean daily temperature of Skalkaho Creek about 100 m upstream from the Hedge diversion dam, and discharge measured in the Hedge inlet canal, and Hedge outlet canal, Montana, 2006.

Eleven of the 16 PIT-tagged fish (69%) that encountered the Hedge diversion dam were entrained into the Hedge Canal from 17 May to 2 August, coinciding with decreasing stream discharge and increasing stream temperature (Figure 16). Five PIT-tagged fish were entrained by swimming upstream into the Hedge inlet canal and were either lost to the population upon canal dewatering or they may have continued to swim up the canal about 12 km to the point of diversion where they could have exited through the headgate, thereby entering the Bitterroot River (Figure 5). Four PIT-tagged fish were entrained through the headgate of the Hedge outlet canal, which does not reconnect to the Bitterroot

River. Therefore, these fish likely died upon canal dewatering at the end of the irrigation season.

Two fish that were entrained into the Hedge Canal (Table 7, #'s 979 and 681) returned to Skalkaho Creek and eventually passed over the Hedge diversion dam after the Hedge Canal was shut down. Overall, seven of the 16 PIT-tagged fish (44%) that were detected encountering the Hedge diversion dam migrated beyond the dam and nine fish (56%) likely remained in the Hedge Canal upon dewatering and were lost to the population. Applying these percentages to the estimated number of westslope cutthroat trout and bull trout that encountered the Hedge diversion dam an estimated 163 westslope cutthroat trout and 91 bull trout were entrained into the Hedge Canal in 2006 without returning to Skalkaho Creek.

The downstream migration of PIT-tagged fish that encountered the Hedge diversion dam during the irrigation season was delayed because little or no water flowed over the dam. Therefore, no route was available for fish to migrate downstream past the dam until the Hedge Canal was shut down. Fish # 681, which was first entrained into the Hedge inlet canal on 24 June, did not migrate beyond the Hedge diversion dam until 29 October, 127 d after first being detected. Similarly, fish # 979, which was first entrained into the Hedge inlet canal on 17 May, did not migrate beyond the Hedge diversion dam until 26 September, 132 d after first being detected.

Fish that encountered the Hedge diversion after the irrigation season took much less time to migrate beyond the dam. Two westslope cutthroat trout (#'s 007 and 414) that were captured, PIT tagged, and released about 50 m upstream of the Hedge diversion dam on 4 October and 9 October migrated past the dam in two to 12 d.

DISCUSSION

Fish Screen Efficiency

I found that fish screens are an efficient tool for reducing the loss of potamodromous fish species to irrigation canal entrainment and may be an important tool in the recovery of migratory fish populations. However, many streams that support diminished fluvial-adfluvial fish populations continue to be dewatered by irrigation canals that remain unscreened. Therefore, entrainment prevention measures at remaining unscreened canals and creative water management strategies that prevent dewatering are needed to recover fluvial-adfluvial fish populations in heavily-irrigated watersheds.

Most fish screen studies to date have focused on the direction and magnitude of approach and sweeping velocities directly in front of the screen mesh (Pearce and Lee 1991; McMichael et al. 2001; McMichael et al. 2004) and the frequency of impingement of entrained fish (Zydlewski and Johnson 2002; Swanson et al. 2004; Swanson et al. 2005). Several other studies estimated the numbers or percentages of emigrating fish whose entrainment was prevented by fish screens (Corley 1962 *in* Schill 1984; Schill 1984; Der Hovanisian and Megargle 1998; Megargle 1998). However, few studies quantified the efficiency of fish screens at preventing the loss of entrained fish or the time taken by fish to exit screened canals and most of these addressed age-0 anadromous fish. Several rotary drum fish screens prevented the loss of between 75 and 99% of

hatchery-reared chinook salmon smolts and fingerlings to irrigation canals of the Yakima and Umatilla basins; most screens achieved efficiencies greater than 95% (Neitzel et al. 1990a; Neitzel et al. 1990b; Knapp 1995). The efficiency of rotary drum fish screens at preventing the loss of hatchery-reared rainbow trout fry varied from 94 to 99% (Neitzel et al. 1990a; Neitzel et al. 1990b). Prior to Gale's (2005) and my studies at Skalkaho Creek, no studies had been conducted to quantify the efficiency of vertical fixed-plate fish screens at preventing the loss of naturally-produced, age-1 and older potamodromous fish.

Fish screens installed in the Highline, Ward, and Hughes irrigation canals of Skalkaho Creek were 82% efficient at preventing the loss of entrained juvenile westslope cutthroat trout. However, screen efficiency varied by canal from 52 to 93%. Between-canal variation was attributed to differences in the temporal scale of screen efficiency trials, which were exacerbated by alterations to canal operations that occurred during the final two weeks of the irrigation season. These alterations included closing the bypass pipe and nearly closing the headgate at one of the screened canals. It is likely that efficiency would not have varied so greatly had efficiency trials been conducted at all three screened canals throughout the irrigation season, prior to these alterations.

Fish screens were about 93% efficient when water flowed through the bypass pipes and headgate openings were large enough for fish to swim through. Screens were about 90% efficient when no water flowed through the bypass pipes and headgates were open enough to allow fish to exit. Although

fish screens that do not bypass water may be useless to migratory fish (Campbell 1959) they may still be efficient at reducing the loss of non-migratory fluvial fish. Screen efficiency declined to 30% when no water flowed through the bypass pipes and headgates were almost closed, which made exiting through the headgates difficult for larger fish. To maximize efficiency, irrigators, in coordination with fishery managers, should ensure that there is at least one exit route available to entrained fish during all times of the irrigation season.

Only 14% of PIT-tagged fish were returned to Skalkaho Creek through the bypass pipes, which compares closely to the 15% that were bypassed during screen efficiency trials conducted in 2004 (Gale 2005). Although relatively few fish were bypassed, the screens may nevertheless have enabled the return of fish to Skalkaho Creek by preventing their movement further down the canals. Fish screens increased the proximity of entrained fish to the headgates, which may have increased the probability that fish would exit the canals by swimming upstream back through the headgate openings (Gale 2005). The downstream movement of fish entrained in unscreened canals would not be similarly limited (Gale 2005).

The high percentage (69%) of PIT-tagged fish that exited the canals through the headgates suggests that perhaps the flow pattern (both magnitude and direction of velocity) immediately upstream of the screen mesh was insufficient to guide larger fish towards the bypass pipes. However, the current flow patterns at the Highline, Ward, and Hughes canals have successfully guided

about 95% of entrained age-0 westslope cutthroat trout to bypass pipes during the three years following screen installation. Therefore, effects of any alterations of flow patterns on impingement of age-0 fish, which are poor swimmers, should be investigated before such changes are made.

The high percentage of fish exiting through the headgates may also be the result of a behavioral avoidance of the bypass pipe by larger fish. Fish are often reluctant to enter bypass pipes at low-head dams (Kynard and O'Leary 1993; Kynard and Buerkett 1997; Haro et al. 1998), presumably because of unnatural transition conditions of accelerating water velocity, increasing darkness, or decreasing area (Haro et al. 1998).

Insufficient motivation of PIT-tagged fish to move downstream may also be a potential cause of the high percentage of fish that exited through the headgates. Fish screens bypass large numbers of downstream-migrating anadromous juvenile chinook salmon and steelhead, which are highly motivated to migrate downstream, at screened irrigation canals in the Pacific Northwest (Campbell 1959; Corley 1962 *in* Schill 1984). Many of the PIT-tagged fish released during fish screen efficiency trials may have been fluvial, non-migratory fish with little motivation to migrate downstream. Additionally, homing instinct did not provide sufficient motivation for PIT-tagged fish to exit the screened canals of Skalkaho Creek in a downstream direction, through the bypass pipes, during fish screen efficiency trials conducted in 2006.

The headgate structures, particularly at the Ward and Hughes canals, provide considerable overhead cover to entrained fish. The large number of PIT tag detections/fish recorded at the Ward Canal headgate antennae suggests that entrained fish spent a considerable amount of time holding near the headgates. This may also help to explain why more fish exited the screened canals through the headgate because fish that used the headgate structures for cover were in close proximity to the headgate openings.

Staged flow reductions conducted at the end of irrigation seasons prompt fish to swim upstream and exit unscreened irrigation canals through canal headgates (Clothier 1954; Finnegan 1978; Shepard 1990). The staged drawdown conducted over the final three weeks of the 2006 irrigation season at the Highline Canal prompted 90% of the remaining PIT-tagged fish to exit the canal. Staged drawdowns appear to be an effective tool for further reducing the loss of entrained fish at screened canals. The close proximity of entrained fish to the headgates of screened canals may improve the effectiveness of staged drawdowns.

Large percentages of fish exiting through the headgates may delay the timing of downstream-migrating westslope cutthroat trout in Skalkaho Creek. Because little or no water flows over the diversion dams of Skalkaho Creek during much of the irrigation season, the only route available for fish to pass downstream of the dams during these times is through the bypass pipes. If downstream-migrating fish avoid the bypass pipes, instead exiting through the

headgates, as the majority of PIT-tagged fish did, they will remain upstream of the diversion dams until the end of the irrigation season when water once again flows over the dams. This could result in migration delays of up to three to four months. The amount of time taken by fish to exit screened canals may also cause delays in the downstream migration of fluvial-adfluvial westslope cutthroat trout in Skalkaho Creek. In this study, fish took substantially more time to exit the screened canals than was observed in previous studies. PIT-tagged fish took a median of about 7 d to exit the screened canals of Skalkaho Creek. However, some fish remained in the canals for as many as 140 d before exiting, which would delay downstream migrations considerably. The distance a fish must travel from the canal headgates to the terminus of the bypass pipe varies by canal and may affect exit time (Neitzel et al. 1990a). Although fish entrained in screened irrigation canals of the Yakima and Umatilla river basins had to travel 20 to 2,400 m farther than fish entrained in screened canals of Skalkaho Creek, they took less time to exit. The median exit time of entrained chinook salmon fry and fingerlings was 1 to 8 h at screened canals of the Yakima and Umatilla (Neitzel et al. 1990a; Neitzel et al. 1990b; Knapp 1995). The median exit time of rainbow trout fry was reported as 4 to 9 h at screened canals of the Yakima River basin; steelhead smolts took 28 to 39 h to exit the screened canals (Neitzel et al. 1990a; Neitzel 1990b). Again, insufficient motivation of non-migratory, fluvial fish may have prolonged the exit time of fish entrained in screened canals of Skalkaho Creek. However, migratory fish may also be delayed. Migratory fish

that are delayed at diversion dams or screened irrigation canals may migrate during periods of, or be exposed longer to, reduced flows, elevated water temperatures, and increased predation risk. Therefore, delayed migrants may experience lower survival, which has been well documented for other salmonid species (Park 1969; Bentley and Raymond 1976; Blackwell et al. 1998; Venditti et al. 2000).

About 5% of the PIT-tagged fish released into the screened canals were not detected by the antennae or recovered by electrofishing. Although these fish may have exited or become entrained down the canal beyond the fish screen passing through an antenna that did not detect them, it is also possible that they were preyed upon (Moyle and Israel 2005), ejected their tag, or died while in the canals. Fish screens may attract predators because of the abundance of small fish (Moyle and Israel 2005). Tag retention rates of juvenile salmonids surgically implanted with 23-mm PIT tags typically exceed 90% (Roussel et al. 2000; Zydlewski et al. 2001; Zydlewski et al. 2003; Hill et al. 2006) and survival rates frequently exceed 95% in laboratory studies (Zydlewski et al. 2001; Zydlewski et al. 2003; Hill et al. 2006). However, tag retention rates of wild coastal cutthroat trout *Oncorhynchus clarkii clarkii* tagged with 23-mm PIT tags were as low as 62 to 84% in a field study (Bateman, unpublished data). However, several factors that may have contributed to these low retention rates did not affect tag retention during my study. First, coastal cutthroat trout had to retain their tag for a minimum of 274 d to be included in the results (Bateman, unpublished data).

Fish tagged for my fish screen efficiency trials only had to retain tags for the duration of the irrigation season (a maximum of 140 d). Second, many coastal cutthroat trout tagged during that study were spawners (Bateman, unpublished data). Salmonids eject tags at a higher rate during spawning activities (Prentice et al. 1990). I tagged juveniles that did not spawn during my study. Finally, sutures were not used to close incisions on wild coastal cutthroat trout. I closed all incisions with a suture to reduce tag loss. Survival rates for PIT-tagged juvenile steelhead were as low as 86% (Bateman and Gresswell 2006). However, fish that were tagged during that study were substantially smaller (73-97 mm fork length) than the fish I tagged (≥ 109 mm). Because the percentage of PIT-tagged fish that went undetected was similar to the percentages of tag loss and mortality reported in most studies, it may not be unreasonable to suspect that undetected fish expelled their tags or died while in the canals.

Age-0 Westslope Cutthroat Trout Distribution

Although large numbers of age-0 westslope cutthroat trout moved downstream into the irrigation-affected reach, only about 1% of these fish continued their migration beyond the Ward-Hughes diversion dam in 2005 and 2006. Additionally, extensive trapping efforts downstream of Ward-Hughes produced a total of only two age-0 westslope cutthroat trout in 2005 and 2006.

Age-0 westslope cutthroat trout were distributed throughout the segment of Skalkaho Creek located between the Highline and Ward-Hughes diversion

dams. The mortality rate of age-0 westslope cutthroat trout in this segment was about 53% over a 2.5 month period. Although relatively little information exists regarding the mortality rate of age-0 westslope cutthroat trout in streams, this rate appears to be comparable to rates reported for other salmonid species in small streams (Mortensen 1977; Einum and Fleming 2000).

Some of the variability observed in density estimates of age-0 westslope cutthroat trout between the Highline and Ward-Hughes diversions can be explained by the habitat variability of sampled reaches. Although no differences of age-0 fish habitat were apparent among strata, much variability was observed among reaches within strata. Some reaches had abundant age-0 fish habitat on stream margins that provided shallow, slow-moving water and substrate cover whereas other reaches lacked suitable habitat for age-0 fish. The precision of monthly density estimates for each stratum may have been low because estimates were made by sampling only one or two 50-m reaches. Precision increases when age-0 fish sampling effort is allocated to sampling more bank units of smaller length versus fewer bank units of longer length (Mitro and Zale 2000). Available habitat should be considered when selecting areas to sample (Opitz 1999) or many small bank units should be sampled (Mitro and Zale 2000) to reduce bias in estimates that occur by randomly selecting only a few long habitat reaches that may contain abundant or poor age-0 fish habitat.

Because age-0 westslope cutthroat trout were distributed between Highline and Ward-Hughes and their mortality rate was not abnormally high, it

seems that the majority of age-0 westslope cutthroat trout emerging from spawning grounds located upstream of the Ward-Hughes diversion dam rear upstream of this point as non-migratory, fluvial fish, or until the following year when they may migrate downstream as age-1 fish. Only two age-0 westslope cutthroat trout were estimated to have moved downstream far enough to encounter the Hedge diversion dam in 2006. However, an estimated 147 age-1 westslope cutthroat trout migrated downstream to this point during the spring and early summer of 2006.

Emigration of age-0 fish to larger waterbodies is likely genetically controlled (Raleigh and Chapman 1971; Bowler 1975; Knight et al. 1999). Conditions downstream of the Ward-Hughes diversion dam from mid-summer to autumn have not favored the survival of emigrating age-0 westslope cutthroat trout since the construction of low-head diversion dams because of predation by introduced brown trout, dewatering, increased water temperature, and irrigation canal entrainment. Predation could be an important factor contributing to high mortality rates of salmonid fry (Knight et al. 1999). Low summer flows and resulting high water temperatures may be a primary limiting factor for some salmonids (Kraft 1972; Binns 1994). Additionally, the density of small fish has been shown to decrease in unstable shallow-water habitats (Bain et al. 1988) and stream sections where lateral habitat is reduced (Moore and Gregory 1988). Reductions in discharge have also been shown to reduce the rate of downstream emigration of age-0 rainbow trout (Rimmer 1985). Therefore, the downstream

movement of age-0 westslope cutthroat trout beyond the Ward-Hughes diversion dam may have been selected against since the onset of these conditions, which occurred over 100 years ago.

The genetic control of emigration of age-0 salmonids can be selected for or against depending on the conditions of downstream habitat. For example, lacustrine-adfluvial Bonneville cutthroat trout *Oncorhynchus clarkii utah* stocked in Strawberry Reservoir, Utah, were the direct progeny of Bear Lake Bonneville cutthroat trout (Knight et al. 1999). Many of these fish emigrated from spawning tributaries to Strawberry Reservoir, which is eutrophic, as age-0 fry (Knight et al. 1999). Abundant food (zooplankton and macroinvertebrates), warmer water temperatures, and reduced competitive interactions among fry promoted higher growth rates and may have selected for fish that emigrated to the reservoir as age-0 fry (Knight et al. 1999). However, the Bonneville cutthroat trout of Bear Lake do not emigrate from spawning tributaries to the lake, which is oligotrophic, as age-0 fry because food is scarce and young fish must compete with several planktivorous fish species that inhabit the lake (Nielson and Lentsch 1988; Knight et al. 1999). Scarce food in Bear Lake causes low growth rates and prolonged exposure to predators (Knight et al. 1999), which may have selected against emigration to Bear Lake at age-0.

The MDFWP is working on a project that would divert water from the BIG Canal into the Ward and Hughes canals, which would prevent the need to divert water from Skalkaho Creek into these canals, allowing cold water from Skalkaho

Creek to flow over the Ward-Hughes diversion dam during the irrigation season (Chris Clancy, MDFWP, personal communication). This would prevent dewatering downstream of Ward-Hughes, keeping water temperatures at a level tolerated by westslope cutthroat trout throughout the year, thereby improving habitat and connectivity for downstream migrants. Emigration of age-0 westslope cutthroat trout to the Bitterroot River may once again be selected for once conditions improve in lower Skalkaho Creek. Stocking Bear Lake Bonneville cutthroat trout into Strawberry Reservoir released the selection pressure against age-0 emigration because downstream conditions were more favorable for age-0 fish in the reservoir than they were in the lake. Bonneville cutthroat trout emigrated to Strawberry Reservoir as age-0 fry just five years after they were initially stocked from Bear Lake (Knight et al. 1999). Therefore, assuming that sufficient numbers of fluvial-adfluvial adults spawn in Skalkaho Creek, as little as five years may be required after improving connectivity for migrants to see increased numbers of age-0 westslope cutthroat trout emigrating from Skalkaho Creek to the Bitterroot River.

Unscreened Canal Entrainment

Although few age-0 westslope cutthroat trout migrated past the Ward-Hughes diversion dam in 2005 or 2006, an estimated 290 age-1 and older juvenile westslope cutthroat trout and 162 age-1 and older juvenile bull trout migrated downstream far enough to encounter the Hedge diversion from 3 May

to 20 October 2006. The majority of fish encountered Hedge from 3 May to 10 July when water flowed over all seven diversion dams, which aided their downstream movement.

A low water year coupled with upstream irrigation withdrawals left Skalkaho Creek severely dewatered upstream of the Hedge diversion dam by mid-July (Figure 16). Little to no water flowed over the diversion dams from mid-July to late September, thereby fragmenting Skalkaho Creek and making movements difficult for downstream migrants. Additionally, daytime high water temperatures exceeded the optimal growth temperature for westslope cutthroat trout (13.6°C) (Bear et al. 2007) directly upstream of the Hedge diversion dam nearly every day during this time. In tributaries of the Madison River, Montana, westslope cutthroat trout were associated with habitats that had maximum daily stream temperatures below 16°C from July to September (Sloat et al. 2005). The maximum daily stream temperature directly upstream of the Hedge diversion dam exceeded 16°C on 55 out of 62 days from 1 July to 1 September in 2006. Only three westslope cutthroat trout and two bull trout were estimated to have moved downstream to the Hedge diversion from 13 July to 29 September (Figure 14). High water temperatures and fragmentation may have contributed to the lack of movement directly upstream of the Hedge diversion dam during this time.

About 70% of all westslope cutthroat trout and 67% of all bull trout that encountered the Hedge, Republican, and C&C canals were estimated to have become entrained into these canals in 2006. These estimates are contingent

upon the assumption that emigrating westslope cutthroat trout did not take up residence or die in Skalkaho Creek between the Hedge diversion dam and the Bitterroot River. However, these estimates compare closely with entrainment rates of downstream-migrating adult westslope cutthroat trout that were entrained into the unscreened canals of lower Skalkaho Creek in 2003 and 2004. Of the 15 encounters telemetered adults had with unscreened canals, nine (60%) resulted in entrainment (Gale 2005). Four of the six (66%) encounters at the Hedge Canal resulted in entrainment (Gale 2005). During my study, 56% of PIT-tagged fish that encountered the Hedge Canal were entrained.

Emigrating juvenile westslope cutthroat trout and bull trout that are not lost to entrainment into the Hedge Canal may nevertheless be delayed there by the Hedge diversion dam. Dams delay emigrating salmonids (Raymond 1968; Park 1969; Raymond 1969; Bentley and Raymond 1976; Zabel and Anderson 1997; Venditti et al. 2000). Migration delays of the extent I observed at the Hedge Canal (127 to 132 d) may negatively affect the survival of downstream-migrating westslope cutthroat trout and bull trout. Prolonged exposure to elevated water temperatures and an increased risk of predation caused by stream dewatering may affect both the condition and survival of delayed migrants (Park 1969; Bentley and Raymond 1976; Blackwell et al. 1998; Venditti et al. 2000).

It appears that conditions (dewatering, increased water temperatures, predation by non-natives, and entrainment into unscreened irrigation canals) in lower Skalkaho have negatively affected the survival of emigrating westslope

cutthroat trout. An estimated 283 westslope cutthroat trout emigrated from Skalkaho Creek to the Bitterroot River in 2005 and just 86 emigrated in 2006. These numbers are quite low when compared with numbers of emigrants from other migratory cutthroat trout populations. About 40,000 age-0 Yellowstone cutthroat trout were captured as they emigrated from Cedar Creek to the Yellowstone River in 1996 and 1997 (Hennessey 1998). From 1950 to 1957 over 34,500 Yellowstone cutthroat trout juveniles (mostly age-0 fish) were captured as they emigrated from Arnica Creek to Yellowstone Lake (Benson 1960). Each year, about 1,400 to 2,600 juvenile westslope cutthroat trout (mostly age 1-3) were captured as they emigrated from Hungry Horse Creek to Hungry Horse Reservoir from 1968 to 1972 (Huston 1969, 1971, 1972, 1974). The estimated number of westslope cutthroat trout that emigrate from Young Creek to Lake Koocanusa ranges from 500 to over 3,000 per year (Lukens 1978). These comparisons indicate that the fluvial-adfluvial westslope cutthroat trout population in Skalkaho Creek is a small, remnant population whose numbers have likely declined from historic levels.

Estimates of emigrating westslope cutthroat trout were obtained from May through October during this study. Age 1-4 juvenile cutthroat trout typically emigrate from nursery reaches to larger waterbodies during spring and early summer (Lukens 1978; Shepard et al. 1984; Liknes and Graham 1988; Nelson 1999) or autumn (Bjornn and Mallet 1964; Chapman and Bjornn 1969; Thurow 1976; Nelson 1999). Therefore, the estimates I obtained likely represent the

majority of westslope cutthroat trout juveniles that migrated down Skalkaho Creek in 2005 and 2006. Although several studies have shown that inland trout move very little during winter (Needham and Cramer 1943; Muhlfeld et al. 2001; Annear et al. 2002; Lindstrom and Hubert 2004) it is however possible that fish emigrated during late autumn or winter, when no sampling for downstream migrants occurred.

Unscreened irrigation diversions entrained a large percentage of westslope cutthroat trout emigrants and delayed their downstream migration. Therefore, additional entrainment prevention measures at the remaining unscreened irrigation canals, and water management strategies that prevent dewatering and fragmentation, are needed to enhance the fluvial-adfluvial population of westslope cutthroat trout in Skalkaho Creek. The MDFWP is working on a project to siphon both the Hedge and Republican canals under Skalkaho Creek (Chris Clancy, MDFWP, personal communication). Siphoning the canals (projected for autumn 2008) would allow water from Skalkaho Creek to flow over the Hedge and Republican diversion dams throughout the irrigation season, keeping the warmer canal water in the canals, while also preventing entrainment of fish from Skalkaho Creek into the canals and thus improving connectivity to the Bitterroot River. By eliminating entrainment of downstream migrants into the Hedge and Republican canals, increasing stream discharge over the diversion dams during the irrigation season, and reducing mid-summer water temperatures, siphoning should improve the survival of downstream-

migrating westslope cutthroat trout, thereby increasing the fluvial-adfluvial population in Skalkaho Creek.

The diversion dams on Skalkaho Creek act as selective barriers that segregate westslope cutthroat trout and rainbow trout, which has prevented introgression and maintained the genetic integrity of the westslope cutthroat trout population (Gale 2005). Low flows prior to spring peak discharge may inhibit the ability of rainbow trout to ascend the diversion dams during spawning migrations (Gale 2005). However, fluvial-adfluvial westslope cutthroat trout ascend Skalkaho Creek during spawning migrations from May to June when considerably more water is flowing down the creek, which aids fish passage over the dams (Gale 2005). In the absence of diversion dams, and the associated drop structures, rainbow trout and westslope cutthroat trout would likely spawn in the same locations on Skalkaho Creek, which could increase the risk of introgression during periods of spawning overlap (Gale 2005). Therefore, MDFWP plans to retain all drop structures on Skalkaho Creek after the completion of projects (siphons, diversion of water from BIG into Ward and Hughes) that are designed to improve habitat and connectivity for downstream migrants (Chris Clancy, MDFWP, personal communication). Maintaining these structures should ensure the preservation of the genetic integrity of westslope cutthroat trout in Skalkaho Creek.

Siphoning the Hedge and Republican canals may also improve conditions for non-migratory, fluvial westslope cutthroat trout and bull trout in Skalkaho

Creek downstream of the Hedge diversion dam. Siphoning will reduce the water temperature, sediment load, and nutrient content of Skalkaho Creek downstream of the Hedge diversion dam. These reductions may cause a shift of the fish species composition in this reach. Very few, if any, non-migratory fluvial westslope cutthroat trout and bull trout reside in Skalkaho Creek downstream of the Hedge diversion dam. The majority (85%) of fish captured near the mouth of Skalkaho Creek were longnose dace and longnose suckers. Brown trout were the most abundant salmonid species, making up about 8% of the total catch. Longnose suckers, longnose dace, and brown trout can tolerate much warmer water temperatures than westslope cutthroat trout and bull trout (Hillman et al. 1999; Selong et al. 2001; Bear 2005; Davis et al. 2006). A reduction in water temperature will make Skalkaho Creek downstream of the Hedge diversion dam more habitable to non-migratory, fluvial westslope cutthroat trout and bull trout.

Maintaining connectivity of habitats necessary for all life-histories is essential to the conservation of inland salmonid populations (Rieman and Dunham 2000; Schrank and Rahel 2004). Therefore, it is important to pursue restoration efforts that connect tributary streams with mainstem rivers to enhance fluvial-adfluvial populations. However, caution should be exercised to prevent invasion of native fish populations in headwater reaches with non-natives from lower stream reaches. Future restoration efforts aimed at restoring fluvial-adfluvial populations in heavily-irrigated watersheds such as the Bitterroot should be directed towards identifying tributaries used by adults for spawning. Limiting

factors, such as entrainment and dewatering, and spatial and temporal variations in movement patterns (Schrank and Rahel 2004) and entrainment rates should be determined for each spawning tributary before restoration efforts (e.g., fish screens and irrigation siphons) are initiated. Only then should restoration efforts, such as canal screening and siphoning, proceed. Fish screens and irrigation siphons could be a valuable management tool in the recovery of fluvial-adfluvial westslope cutthroat trout populations in heavily-irrigated watersheds. However, water management strategies that prevent fragmentation of irrigated tributaries may also be necessary to improve connectivity. Post-installation monitoring is needed to determine the biological success of management actions (Moyle and Israel 2005).

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