Interactions between Fluctuating Reservoir Water Levels and Bull Trout (*Salvelinus confluentus*) Ecology

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Anthony F. Prisciandaro

Major Professor: Dennis L. Scarnecchia, Ph.D.

Committee Members: Christopher Caudill, Ph.D.; James Nagler, Ph.D.

Department Administrator: Lisette Waits, Ph.D.

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Anthony Prisciandaro, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Interactions between Fluctuating Reservoir Water Levels and Bull Trout (*Salvelinus confluentus*) Ecology," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ______________________ Date __________
Dennis Scarnecchia, Ph.D.

Committee Members: ______________________ Date __________
Christopher Caudill, Ph.D.

______________________ Date __________
James Nagler, Ph.D.

Department Administrator: ______________________ Date __________
Lisette Waits, Ph.D.

ABSTRACT

Fluctuating reservoir water levels create varial zones that tributaries flow through before reaching the reservoir pool during low water levels. Aquatic habitat in eight tributaries of six northwestern reservoirs was distinctly different between varial and un-impacted reference zones. Bull trout migration speeds varied greatly between the two tributaries monitored using radio telemetry (Trail Creek and the Middle Fork Boise River) as well as within Trail Creek. Documentations of predator species were concentrated in the downstream end of the varial zone of Trail Creek where a shallow delta formed annually. Thirty three to 50% of the annual tag loss (mortality or expulsion) occurred in the varial zone. Raising reservoir water levels between the end of irrigation season and the start of bull trout downstream migration could limit the impacts of predators when bull trout are most vulnerable in the shallow deltas after expending the majority of their energy reserves during spawning.

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CHAPTER 1: INTRODUCTION

The bull trout *Salvelinus confluentus*, is a species of charr (Family Salmonidae) native to the cooler regions of Western North America. Its range extends from northern Nevada, north to the Yukon and from coastal Washington and Oregon east to Glacier National Park in Montana (Cavender 1978; Bond et al. 1992; USFWS 2010a). In the Continental United States, this cold-tolerant, glacial relict species is near the southern geographical edge of its habitat suitability (Haas and McPhail 1991).

The species has declined in numbers at an increasing rate in the last 150 years (USFWS 1999). Many factors have contributed to this decline, including habitat degradation and fragmentation, introduction of exotic species, overfishing, global climate change, and anthropogenic migration barriers (Fraley and Shepard 1989; Rieman and McIntyre 1993; Lohr et al. 2000; Rieman et al. 2007; Johnston and Post 2009). In 1999, the bull trout was listed as threatened under the Endangered Species Act (ESA) in the entire coterminous United States (USFWS 1998; USFWS 1999).

The bull trout displays a wide diversity of life histories, including resident, fluvial, adfluvial and anadromous strategies and forms. Whereas resident forms remain in tributaries throughout their lives, the other forms typically rear for some period in tributaries and then migrate downstream into: larger flowing waters (fluvial form; Hogen and Scarnecchia 2006), lakes or reservoirs (adfluvial form; Watry and Scarnecchia 2008), or the ocean (anadromous form; Brenkman and Corbett 2005) to grow and mature before migrating back into tributaries to spawn in fall. The lake and reservoir habitats that adfluvial bull trout, a common form, rear and overwinter in have abundant food resources that allow adults to reach larger sizes than resident bull trout (McPhail and Baxter 1996). The larger body size of adfluvial adults enables them to have a higher fecundity and produce more offspring than resident forms. Migratory adults can also re-establish populations after local extirpation (Rieman and McIntyre 1993). The depth available in lentic environments also provides cover from predators (Power and Kerfoot 1987; Randle and Chapman 2004).

It is extremely important that the limiting habitat factors (Al-Chokhachy et al. 2010) be identified for cost-effective bull trout recovery efforts. Critical habitat for bull trout Under the ESA has been listed in 126 lentic water bodies throughout their range (USFWS 2010a). This habitat includes 31 reservoirs inundating 552 km^2, 16 raised and regulated lakes covering 1,163 km^2, as well as 76 natural lakes covering 338 km^2 (USFWS 2010a). The majority (84% of total surface area) of the lentic habitat available for adfluvial bull trout in the coterminous United States is in water regulated by dams.

Some ecological impacts of dams on bull trout are well documented, including entrainment of the fish, blockage of upstream migrations (Rieman and McIntyre 1993; McPhail and Baxter 1996; USFWS 2002; Underwood and Cramer 2007), and effects of altered flows and temperatures below the dams (Annear et al. 2002). Other ecological impacts of impoundments on the species are much less well described. For example, although the physical aspects of geomorphological change and delta formation where tributaries run through the dewatered portion of reservoirs (hereafter called varial zones) have been documented since the 1950's (Harrison 1952; Mahmood 1987; Graf 1988; Fan and Morris 1992a, 1992b; BOR 2006), the ecological effects of these varial zones are still not well understood (Kline 2006; Salow and Hostettler 2004; IDFG 2007; Prisciandaro and Harbison 2007; Teuscher 2009).

The role of the varial zone in bull trout life history and survival can be complex. The length of the varial zone in each reservoir changes with fluctuating reservoir water levels both within and between years. Sedimentation combined with frequently changing water levels affect physical characteristics associated with aquatic habitat in these zones. Habitat within the reservoir pool at the mouths of tributaries where bull trout stage to spawn is also affected by altered temperature regimes, sedimentation and water level fluctuations. With numerous altered habitat features caused by fluctuating water levels, it is necessary to identify the specific habitat alterations leading to effects on bull trout in particular situations. A range of possibilities exists. Migration impediments can be caused by conditions such as high velocities in channelized sections or shallow depths in delta areas. The shallow, unstable channels with little to no cover in varial zones may also increase mortality of bull trout as a result of predation, or being buried by bank sloughing (Salow and Hostettler 2004; Prisciandaro and Schmasow 2008; Teuscher and Scully 2008; Teuscher 2009). Habitat degradation (wider, shallower channels with no riparian vegetation) within the varial zone may lead to water temperatures increasing at an unnatural rate, impacting not only migrating fish but fish staging in the reservoir. Indirect impacts could include pre-spawn mortality or re-absorption of gametes from increased energy expenditure, delayed migration, increased stress, and restricted access to upstream cold water refugia or downstream food resources (Macdonald et al. 2000; Schreck et al. 2001; Budy et al. 2002; Clabough et al. 2008; Hinch et al. 2006; Keefer et al. 2008). With the high cost of implementing habitat modification projects and the substantial number of reservoirs with possible issues, studies are needed to determine which degraded habitat characteristics are most commonly detrimental to bull trout.

In the area encompassing Washington, Oregon, Idaho and Montana, the Bureau of Reclamation (BOR) operates nine reservoirs and five raised natural lakes within critical habitat for bull trout. Small bull trout populations as well as strict handling and tagging restrictions at a majority of these reservoirs do not allow for direct bull trout studies. The BOR has conducted studies on the movement of bull trout using radio telemetry at two of these reservoirs; Deadwood and Arrowrock. Issues with bull trout migrating through varial zones have been noted at a number of BOR sites and facilities (Kline 2006; Prisciandaro and Harbison 2007; Underwood and Cramer 2007; D. Kenney, Sawtooth National Forest, and S. Willey, BOR, personal communications). Past BOR studies have documented complete migration barriers or partial barriers (Kline 2006), some resulting in high mortality rates (Salow and Hostettler 2004; Prisciandaro and Harbison 2007). Habitat improvement efforts have in some cases been implemented without knowing or addressing the underlying habitat characteristics associated with impacts to fish in varial zones (Kline 2006; Vidergar and Butts 2014). This study is designed to identify the specific habitat characteristics impacting the migration of bull trout through varial zones in six regional reservoirs (Idaho, eastern Oregon, and western Montana). The specific objectives are to: (1) Characterize and compare the physical characteristics associated with aquatic habitat in varial and upstream reference zones of six reservoirs as they are affected by fluctuating reservoir water levels. (Chapter 2); (2) Identify habitat characteristics associated with migration barriers and differences in bull trout travel speed within the varial zone and between the varial zone and reference zone of two Idaho tributaries (Chapter 3); and (3) Investigate how fluctuating reservoir water levels influence predator presence and bull trout mortality in the varial zone of Trail Creek in Deadwood Reservoir (Chapter 4).

Results of this study will have applicability to not only the surveyed reservoirs, but for other reservoirs with similar operations range-wide, for identifying potential impacts to bull trout in situations where populations are too low for direct monitoring. Results will also be useful in identifying the most critical habitat variables where research on, or implementation of, mitigation measures should be focused.

Review of bull trout ecology and status

Increased research efforts since the early 1980's have greatly augmented our knowledge of bull trout biology, life history, ecology and habitat requirements (Dare 2006; Rieman et al. 2007; Al-Chokhachy et al. 2010). Charr in general are a cold-water tolerant group of fish that evolved on the boundaries of ice sheets as they advanced and receded during past glacial and interglacial periods; in its southern range, the species can be characterized as a glacial relict of colder habitats that were formerly more common than at present (Haas and McPhail 1991; Power 2002). Habitats that remain occupied are typically in headwater areas; migratory life history strategies of some of these populations no longer exist (Nelson et al. 2002).

Field and laboratory studies confirm that bull trout have low thermal tolerances compared to most other salmonids and prefer the colder waters of northwest river basins (Bonneau and Scarnecchia 1996; Dunham et al. 2003). Spawning and resident/juvenile rearing areas rarely exceed a 7-day average daily maximum of 15°C; the highest documented juvenile bull trout growth rates occur at 13.2°C (Fraley and Shepard 1989; Rieman and McIntyre 1993, 1995; Selong et al. 2001; Howell et al. 2010). In Deadwood Reservoir, Idaho bull trout have a wide range of available temperatures during the summer stratification period, but are most often found at about 12°C. They have, however, been documented in temperatures up to 19.6°C (Table 1.1; Prisciandaro and Schmasow 2008). Some adults in other systems have been documented occurring at temperatures up to 20°C during spawning migrations (Selong et al. 2001; Howell et al. 2010). In these warmer waters, bull trout may persist, especially as adults, but be at a disadvantage against other salmonids and fish taxa. Maximum growth rates for most other salmonids occur at higher temperatures than for bull trout. For example brook trout (*Salvelinus fontinalis*) exhibited maximum growth between 14.4 and 16°C and rainbow trout (*Onchorhynchus mykiss*) between 16 and 18.1°C (Dwyer et al. 1983; Eaton et al. 1995). With the bull trout's low temperature preferences, available and accessible cold water refugia are important components of high quality habitat (Nelson et al. 2002).

The three different life history forms, fluvial, adfluvial (including a few anadromous populations), and resident, occupy distinctly different habitats and show distinct differences in growth as well as in age and size at sexual maturity (Fraley and

Shepard 1989; McPhail and Baxter 1996; USFWS 2002). Bull trout in most systems mature between 5 and 7 years of age (Fraley and Shepard 1989; McPhail and Baxter 1996). Adult resident fish can range from 150 to 300 mm whereas adfluvial adults usually attain lengths exceeding 600 mm. The world record is just over 1 m and 14.5 kg (Fraley and Shepard 1989; USFWS 2002). For long-term persistence of their diverse life histories, bull trout require areas with complex interconnected habitats and open migratory corridors (Rieman and McIntyre 1995; Neraas and Spruell 2001).

It is estimated that bull trout now occur in only 21% of their historic range in the coterminous United States (USFWS 2010b). Although populations remain stable in some systems such as the Middle Fork Salmon River in Idaho and the Skagit River in Washington, many other populations south of Canada are under more duress, such as the North Fork Payette River in Idaho and Lake McDonald in Montana (Haas and McPhail 1991; USFWS 2005).

Concerns over bull trout declines have led to efforts, beginning in the 1980s, to afford protection to the species. In 1985, the bull trout was listed as a species of concern by the U.S. Fish and Wildlife Service (USFWS 1985). The USFWS also indicated that “proposing to list as endangered or threatened is possibly appropriate, but … conclusive data on biological vulnerability and threat are not currently available to support proposed rules” (USFWS 1985, p. 37958). In 1992, the first petition to list bull trout under the ESA was submitted to the USFWS. In 1998, the bull trout was listed as threatened under the ESA in the Colombia and Klamath Basins, and subsequently (1999) in the entire coterminous United States (USFWS 1998; USFWS

1999). Critical habitat for bull trout has been listed in 126 lentic water bodies throughout their range (USFWS 2010a).

Since ESA listing, numerous other efforts have been undertaken to assist in the recovery of the species, including habitat and passage improvements and exotic species control efforts. The Boise National Forest Aquatic Organism Passage Program in Idaho has identified over 700 culvert barriers since 2003 and has so far replaced 30 of them with open bottom arches or bridges that now permit reconnection of 165 miles of stream habitat (M. Faurot, Boise National Forest, personal communication). The state of Washington replaced or refitted more than 3,500 fish passage barriers over the period 1999 to 2010 (Price et al. 2010). The Burns Paiute Tribe in Eastern Oregon has implemented a brook trout suppression project in the Upper Malheur River (Burns-Paiute Tribe 2010). Their project includes gill netting brook trout from a headwater lake that is thought to be a continual source population for the rest of the drainage as well as removing brook trout using backpack electroshockers in the rest of the drainage (Burns-Paiute Tribe 2010). An unsuccessful brook trout eradication effort was also attempted on the Pikes Fork tributary to the North Fork Boise River in central Idaho (Meyer and Lamansky 2005).

In addition to these habitat and exotic species actions, more restrictive fishing regulations have been implemented range-wide (USFWS 2008). Even before the species was listed under the ESA, some states began restricting or eliminating angling methods and harvest. In Idaho, the Department of Fish and Game (IDFG) initiated a No-Harvest regulation in 1994 (High et al. 2008). Since then, bull trout have been documented in 35% of surveyed sites and populations in general have been increasing or stable (High et al. 2008; Meyer at al. 2014). In the Jarbridge River drainage in Nevada, where prior to 1998 bull trout had been lumped into the aggregate 10 trout per day bag limit, bull trout harvest was prohibited in 1998 after ESA listing (USFWS 2004). The history of fishing regulations for bull trout is more complicated in Washington and Oregon. In the Yakima River Drainage a one-fish bag limit was implemented in 1984 and a barbless-only restriction was enacted in 1990 to limit harvest and reduce hooking mortality of spawning adults in small tributaries (USFWS 2002). The 2002 Draft Recovery Plan states that harvest was still allowed in some other Washington drainages where populations were healthy (USFWS 2002). The bull trout population in Lake Billy Chinook, Oregon is doing sufficiently well that harvest is allowed in an attempt to reduce their predation on juvenile anadromous salmonids (ODFW 2011; USFWS 2002).

Bull trout misidentification and subsequent harvest by anglers, as well as incidental mortality from catch and release fishing remain documented threats as identified in the Bull Trout Draft Recovery Plan (Schmetterling and Long 1999; USFWS 2002). Only 44% of anglers in Montana were able to correctly identify bull trout and some were being harvested illegally (Schmetterling and Long 1999). Although 77 to 91% of anglers on the Middle and South Forks of the Boise River, Idaho knew not to harvest bull trout, only 30 to 57% anglers were able to correctly identify bull trout (Lamansky et al. 2001). Catch and release angling not only can cause direct injury or mortality from wounds, but fatigued fish are more susceptible to predation and increased stress levels can effect immune responses, reproduction and progeny survival (Schreck et al. 2001; Bartholomew and Bohnsack 2005). To reduce angling incidental mortality, angling is prohibited year-round in bull trout staging areas near the mouth of Trapper Creek (Odell Lake, Oregon; ODFW 2011). Although Lake Billy Chinook, Oregon is one of the few remaining areas where bull trout harvest is permitted, fisheries managers believe the fish are so susceptible to angling in their staging areas at the mouth of the Metolius River that the entire Metolius arm of the reservoir is closed to fishing (ODFW 2011).

As a result of numerous habitat improvements and harvest restrictions, some populations have rebounded (Schmetterling 2003; Dare 2006; Johnston et al. 2007; Johnston and Post 2009). Johnston and Post (2009) documented a 28-fold increase in bull trout spawner abundance after mitigating for a major source of mortality in Lower Kananaskis Lake in Alberta, Canada. A No-Harvest regulation in the Clearwater Drainage of Northern Idaho has resulted in an increase in the bull trout population above Dworshak Dam and an accumulation of larger migratory adults (Erhardt and Scarnecchia 2014). Although stricter harvest regulations may result in recovery in areas with good remaining habitat, in many areas, habitat is degraded, and more than harvest restrictions are needed for recovery.

Potential impacts of varial zones on adfluvial fish

In the introduction to the 2002 Draft Bull trout Recovery Plan, the USFWS recognized specifically that reservoir water level manipulations can create migration barriers at the confluence of tributaries entering a reservoir. However, no reference was made to any particular reservoir or any specific documented evidence (USFWS 2002).

Effects of varial zones on migration and reproduction are important to understand because the entire process of reproduction, including gamete production, protracted pre-spawning staging, migrating to spawning grounds, competing for mates, constructing redds, and the act of spawning, are costly (Meffe et al. 1988; Lambert and Dutil 2000), all requiring substantial amounts of energy (Mommsen et al. 1980; Guderley et al. 1986; Hendry et al. 2000; Hendry and Beall 2004). Even though bull trout are iteroparous, some die during the natural stresses of spawning (Stelfox 1997; Salow and Hostettler 2004; Johnston et al. 2007; Prisciandaro and Harbison 2007). Published bull trout mortality rates during spawning migrations have ranged from a low of 5% (Stelfox 1997), to intermediate levels of 26-28% (Johnston et al. 2007), to as high as 49% (Salow and Hostettler 2004).

Any additional stressors to the already high costs of natural reproduction caused by the modified habitat of varial zones could increase mortality rates even more. Adfluvial bull trout often stage at the mouth of tributaries in lakes and reservoirs well prior to spawning, benefitting from the relative safety of the habitat and the abundant food resources and stable temperatures there. Staging in colder water, such as in or at the mouth of a tributary, has also been shown to result in decreased metabolism, allowing fish to conserve energy (Berman and Quinn 1991; Goniea et al. 2006). The concentration of large fish staging in these areas with little cover is often noticeable and enticing to fishermen. In lakes these areas typically provide a complex environment with riparian vegetation and often large woody debris. In reservoirs this may be true at higher reservoir elevations; however this important staging area moves increasingly further away from “natural” conditions as reservoir water levels decrease. Ultimately, adfluvial bull trout need to migrate upstream to spawn in the fall and sometimes to obtain shelter from water temperatures in summer (Fraley and Shepard 1989; McPhail and Baxter 1996; Swanberg 1997). Conditions where preferred temperatures are not available in the reservoir and where migration barriers in the varial zones block fish from moving to upstream cold water refugia would cause fish to use more energy for base metabolism in the warmer reservoir water. If the varial zones increase water temperatures entering the reservoir, fish metabolism may increase or fish may migrate earlier. After using most of their energy stores during upstream migration and spawning, migration impediments that block or slow bull trout returning downstream through varial zones to the lentic environment would also be detrimental. Because of the seasonal changes in the benefits of both lotic and lentic environments, safe and unobstructed migratory corridors to and from spawning areas are important for the health of adfluvial bull trout populations.

Whereas some bull trout embark on extended spawning migrations involving long distances (exceeding 250 km) and extended periods of time (exceeding 8 months) (Fraley and Shepard 1989; McPhail and Baxter 1996; Salow and Hostettler 2004; Paragamian and Walters 2011), other populations in higher elevation reservoirs can undertake much shorter migrations, spawning within a km of the high water line and spending only a few weeks out of the reservoir (Stelfox 1997; Knight and Hebdon 2006; Prisciandaro 2006). Species such as rainbow trout and westslope cutthroat trout (*O. clarkii lewisi*), spawn in the spring when reservoirs are typically full or near full. In the spring, reservoirs generally have shorter varial zones resulting in fewer migration issues. Bull trout, in contrast, spawn in the fall when many reservoirs are usually at or near their lowest annual level and varial zones are their longest. In addition, most reservoirs also have a wide range of inter-annual variability in water levels, resulting in highly variable inter-annual varial zones (Figure 1.1).

Shallow water and a lack of cover in varial zones are not typically direct causes of mortality but may lead to increased predation rates and stress (Swales 1982; Power and Kerfoot 1987; Teuscher and Scully 2008). Scars from predation attempts were found on 70% of Yellowstone cutthroat trout (*O. clarkii bouvieri*) captured at a weir above the varial zone of Blackfoot Reservoir in spring of 2004 and 21% of radio tagged Yellowstone cutthroat were preyed upon by American white pelicans (*Pelecanus erythrorhynchos)* in the first 50 m of the varial zone (Teuscher and Scully 2008). In Pyramid Lake, Nevada, 90% of annual mortality of Cui-ui (*Chasmistes cujus)* was attributed to predation by pelicans in a delta formation at the mouth of the Truckee River, similar to conditions found in varial zones (Scoppettone et al. 2014). Increased predation by pinnipeds (California sea lions (*Zalophus californianus*) and Pacific harbor seals (*Phoca vitulina*) has been identified as a threat for salmon and steelhead (*O. mykiss*) when migration is slowed at the fish passage structures of many dams and locks on the Pacific Coast (NMFS 1997).

Increased stress levels, such as might be associated with blocked or impeded movement through varial zones, have been shown to effect growth, reproduction and immune function in fish (Wendelaar Bonga 1997). Literature on assumed stressful conditions (high temperatures; Clabough et al. 2008), increased velocities (Hinch and Bratty 2000) and physical obstacles (Caudill et al. 2007)) is available in the literature on migratory fish. Direct study of the impacts of these likely stressful events on fish stress (cortisol) levels and sub-lethal effects has been limited to laboratory studies and would be difficult to obtain in a field study due to the handling stress of obtaining the samples themselves. However, stress levels of other vertebrate taxa affected by degraded habitats during migration have been studied. Spotted salamanders (*Ambystoma maculatum*) showed more elevated stress levels while migrating through degraded habitat than through natural forest (Newcomb Homan et al. 2003). Howler monkeys (*Alouatta caraya*) showed higher stress levels in populations that had to travel between fragmented forest patches than those that were in continuous forest (Martínez-Mota et al. 2007). Wolves (*Canis lupus)* and elk *(Cervus canadensis)* have also been shown to have higher stress levels when migrating through areas with higher snowmobile use (Creel et al. 2002). Frid and Dill (2002) show that organisms respond to human disturbances in the same manner as predators. These examples suggest how degraded varial zone habitat and additional stressors such as boating/angling in staging areas, may result in elevated levels of stress. This additional stress in turn has the potential to lead to increased pre or post-spawn mortality, decreased fecundity, altered timing of maturation of gametes, or decreased growth in bull trout (Schreck et al. 2001; Budy et al. 2002; Leatherland et al. 2010).

Federal and state agencies have implemented some mitigation measures in varial zones to reduce impacts to fish (Kline 2006; Teuscher and Scully 2008). Most measures have met with temporary success, little success or unknown success (Vidergar and Butts 2014). Temporary fish passage channels were installed by BOR in multiple years within the varial zone of Box Canyon Creek in Kachess Reservoir, Washington (Figure 1.2) (Kline 2006). Passage was improved in some years, but in one drought year bull trout encountered a natural shallow water migration barrier above the reservoir high water line and suffered predation by North American river otters (*Lutra canadensis*) (S. Willey, BOR, personal communication). The BOR also installed log structures in an attempt to create cover and resting areas in varial zones at Deadwood and Arrowrock Reservoirs in 2008 (Vidergar and Butts 2014). Channel movement the following year left the structures out of water (Vidergar and Butts 2014). IDFG used cracker shells and an air boat to actively harass pelicans in the varial zone of Blackfoot Reservoir and installed multiple rows of flagging as a passive deterrent (Teuscher and Scully 2008). This effort had to be implemented annually and continuously maintained with the varying water levels of the reservoir. Its effectiveness was never quantified but the flagging was said to be the most effective method to reduce predation by pelicans (Teuscher and Scully 2008). None of these studies linked specific habitat variables to impacts on fish migration or susceptibility of fish to predation.

Study area

Of the fourteen BOR project facilities (and associated reservoirs) designated as critical habitat for bull trout (Deadwood, Arrowrock and Anderson Ranch in southwestern Idaho, Beulah and Phillips in Eastern Oregon, Rimrock, Bumping, Cle Elum, Kachess, Keechelus, Easton and Clear in the Yakima Drainage of Washington, and Sherburne and Hungry Horse in northern Montana; USFWS 2010a), most have extremely low populations and/or strict scientific permitting regulations that limit handling and or tagging bull trout for research purposes. Habitat studies (Chapter 2) were conducted at six of these projects: Beulah, Phillips, Sherburne, Anderson Ranch, Arrowrock, and Deadwood reservoirs. The fish movement study (Chapter 3) focused on Arrowrock and Deadwood reservoirs, since these two reservoirs have sufficient bull trout numbers to support a more robust investigation. Predation monitoring (Chapter 4) was limited to Deadwood Reservoir due to the limited number of game cameras available.

Habitat Study Areas—Beulah Reservoir is formed on the North Fork Malheur River by Agency Valley Dam (constructed 1935), 30 river kilometers (rkm) upriver of the confluence with the mainstem Malheur River, a tributary to the Snake River. The North Fork Malheur River is approximately 95 km long from headwaters (2,444 m asl) to mouth (890 m asl; Figure 1.3). Agency Valley Dam is the only dam on the North Fork Malheur River. The reservoir has a capacity of 73 X 10^6 m^3 with a maximum pool elevation of 1,019 m and a drainage area of 1,150 km^2. The reservoir typically experiences extreme drawdowns and has been drawn down to run of river 4 out of the last 15 years. Water elevations in Beulah Reservoir fluctuate up to 24m during a single year creating a maximum varial zone length estimated at up to 5,750 m. The geology of the North Fork Malheur River Basin predominantly consists of fine-grained igneous rock (USGS 1995). The sediments within the reservoir itself consist mainly of dark-colored silt (October 2012).

Phillips Reservoir is formed by Mason Dam (constructed 1968), 156 rkm upriver of the confluence with the Snake River, a tributary to the Colombia River. The Powder River is approximately 189 km long from headwaters (2,444 m asl) to mouth (635 m asl; Figure 1.3). The reservoir typically experiences extreme drawdowns and has been drawn down below 6 X 10^6 m^3 (6.8% capacity) in three of the last 15 years. Water elevations in Phillips Reservoir fluctuate up to 23m during a single year creating a maximum varial zone length on the Powder River estimated at up to 4,450 m and to 3,400 on Deer Creek. The geology of the Powder River Basin above Mason Dam consists predominantly of fine-grained sedimentary rock (USGS 1995). The sediment within the reservoir itself consists mainly of dark-colored silt (October 2012).

Lake Sherburne was raised by Lake Sherburne Dam (constructed 1921), 9 rkm upriver of St Mary's Lake. St Mary's Lake drains into the St Mary's River, a tributary of the Saskatchewan River, itself a tributary of the Nelson River, which drains into Hudson Bay. Swiftcurrent Creek is approximately 189 km long from headwaters (2,904 m asl) to mouth (1,365 m asl; Figure 1.3). Lake Sherburne Dam is the only dam on Swiftcurrent Creek. Lake Sherburne has a capacity of 80 X 10^6 m^3 with a maximum pool elevation of 1,459 m and a drainage area of 166 km^2. Water elevations in Lake Sherburne fluctuate up to 30m during a single year creating a maximum varial zone length estimated at up to 3,950 m in Canyon Creek. The geology of the Canyon Creek Basin above Lake Sherburne Dam predominantly consists of fine-grained sedimentary rock (USGS 1995). The sediment within the reservoir itself consists of mainly light-colored sand (August 2013).

Anderson Ranch Reservoir is formed on the South Fork Boise River by Anderson Ranch Dam (constructed 1950), 45 rkm upriver of Arrowrock Reservoir. The South Fork Boise River above Anderson Ranch Reservoir is approximately 70 km long from headwaters (3,170 m asl) to the reservoir (1,279 m asl; Figure 1.3).

Anderson Ranch Reservoir has a capacity of 585 X 10^6 m^3 with a maximum pool elevation of 1,279 m and a drainage area of 1,664 km^2. The location of the outlet works on the dam creates a dead pool in the reservoir, limiting the extent of drawdowns. Water elevations in Anderson Ranch Reservoir fluctuate up to 36m creating a maximum varial zone length estimated at up to 7,550 m in the South Fork Boise River. The geology of the South Fork Boise River Basin above Anderson Ranch Dam consists predominantly of coarse-grained igneous rock (USGS 1995). The sediments within the reservoir itself are mainly light-colored sand (September 2011).

Habitat and Fish Study Area—Arrowrock Reservoir, a site used to address the first two objectives of this study, is located upstream of the city of Boise, Idaho at rkm 67 of the Boise River, which drains into the Snake River at rkm 636 near Parma, Idaho. Three dams are present on the upper Boise River system; Lucky Peak, Arrowrock, and Anderson Ranch (Figure 1.4) and these reservoirs are operated collectively as one system for irrigation, flood control, and recreation. Lucky Peak Dam, a U.S. Army Corps of Engineers facility, is the most downstream of the three located on the Boise River at rkm 103 with a full pool elevation of 931 m asl. Arrowrock Dam was completed in 1915 and is 19 rkms upstream from Lucky Peak Dam. It has a full pool elevation of 980 m asl. Anderson Ranch Dam, the most upstream of the three, is located at rkm 81 of the South Fork of the Boise River. It has a full pool elevation of 1,279 m asl.

Arrowrock Reservoir has a maximum storage capacity of 335 X10^6 m^3. The reservoir was emptied in 2003 for maintenance and typically experiences extreme drawdowns. For Arrowrock Reservoir to be at or above 945 m in elevation by September 15th, when the first bull trout are known to return to the reservoir, was also a recommendation of the 2005 Biological Opinion (USFWS 2005). A water elevation of 945 m in Arrowrock Reservoir allows for 38 m of water level fluctuation and creates a maximum varial zone length on the Middle Fork Boise River (MFBR) estimated at up to 9,850 m.

The Boise River basin upstream from Arrowrock Dam covers 5,700 km² of the Atlanta section of the Idaho Batholith (coarse-grained, calc-alkaline intrusive) with elevations ranging from 931 m to 3,231 m above sea level (USGS 1995). The geology of the basin leads to naturally high erosion rates and sediment levels in the streams (Quigley and Arbelbide 1997; Servheen et al. 2004). The sediments within the reservoir itself are mainly sand and are light in color (September 2013). The upper Boise River includes three sub-basins: the North, Middle, and South forks. The Boise River system is fed primarily by snowmelt run-off with highest flows typically occurring in May or June and lowest in September or October. Land uses in the Boise River watershed include mining, grazing, recreation, and both commercial and individual timber harvest. The majority of the Boise River basin lies within National Forest or Wilderness area boundaries.

Sediment grain size plays a large role in the dynamics of sedimentation in these reservoirs (BOR 2006). The various surficial geological types in the drainage basins of study sites can be grouped into two categories, fine-grained and coarse-grained. The volcanic geology of the North Fork Malheur River is dominated by fine-grained sediment. Phillips and Sherburne reservoirs are dominated by fine-grained sedimentary rock. In contrast, the Idaho study sites (Deadwood, Arrowrock and Anderson Ranch reservoirs) are dominated by the coarse-grained sediment of the Idaho Batholith.

Boise Diversion Dam on the Boise River near Boise Idaho blocked all upstream migrating anadromous steelhead and Chinook salmon (*Oncorhynchus tshawytscha*) from the areas that now drain into Arrowrock Reservoir in 1906 (Servheen et al. 2004).

The fish assemblage in Arrowrock Reservoir includes rainbow trout, bull trout, redside shiner (*Richardsonius balteatus*), mountain whitefish (*Prosopium williamsoni*), kokanee (*O. nerka)*, largescale sucker (*Catostomus macrocheilus),* bridgelip sucker (*Catostomus colombianus),* northern pikeminnow (*Ptychocheilus oregonensis),* yellow perch (*Perca flavescens),* chiselmouth (*Acrocheilus alutaceus), and* smallmouth bass (*Micropterus dolomieu)* (Flatter 1999). The major spawning areas for bull trout from Arrowrock Reservoir are accessed via the MFBR which covers a drainage area of 2,174 km^2 and has flows ranging from 4.3 m^3/s to 339.8 m^3/s.

Deadwood Reservoir, a site used to address all three objectives of this study, is formed by Deadwood Dam (constructed 1929), 36 rkm upriver of the mouth of the Deadwood River, a major tributary to the South Fork of the Payette River, itself a tributary of the Snake River. The Deadwood River is approximately 70 km long from headwaters (2,124 meters above sea level (m asl)) to mouth (1,135 m asl; Figure 1.5). Deadwood Dam is the only dam on the Deadwood River. The reservoir has a capacity of 190 X 10^6 m^3 with a maximum pool elevation of 1,628 m and a drainage area of 282 km^2. The reservoir has a voluntary 62 X 10^6 m^3 conservation pool that limits extensive drawdowns. Water elevations in Deadwood Reservoir fluctuate up to 14 m during a single year creating a maximum varial zone length on the Deadwood River estimated at up to 2,300 m and 1,225 on Trail Creek. The geology of the entire South Fork Payette Watershed leads to naturally high erosion rates and high sediment inputs to streams and in turn the reservoir (Quigley and Arbelbide 1997; Servheen et al. 2004; IDEQ 2005). The geology of the Deadwood River Basin predominantly consists of coarse-grained igneous rock (USGS 1995). The sediment within the reservoir itself is mainly light-colored sand, but fires in the basin (2006 and 2007) have caused very fine, dark sediment to settle in some areas (October, 2006-2013). This fine, dark-colored sediment is only observed in the reservoir pool. It is re-suspended as the transition between tributary and reservoir migrates downslope, leaving light colored sandy substrate to dominate the varial zone.

Grimes Pass Dam on the South Fork Payette River near Crouch, Idaho blocked all upstream migrating anadromous steelhead and Chinook from the Deadwood drainage in 1907 (IDEQ 2005). Native fish species currently found in Deadwood Reservoir include: rainbow trout, bull trout, longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinichthys osculus*), redside shiner, mountain whitefish, and sculpin (*Cottus spp.*) (Allen 1998; Prisciandaro 2010). Kokanee, Chinook salmon, and westslope cutthroat trout have been introduced to the reservoir (IDFG 2012).

Bull trout are the only ESA-listed fish species in the drainage. Deadwood Reservoir has four direct tributaries with documented adfluvial bull trout spawning and an additional two with documented juvenile downstream migration. These tributaries range in drainage area from 8 to 164 km^2. As a high-elevation reservoir, some years provide suitable temperatures in the reservoir for bull trout year-round, with the date of initiation of migration from the reservoir to the spawning grounds varying depending on available temperatures (Prisciandaro and Schmasow 2008).

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Figures

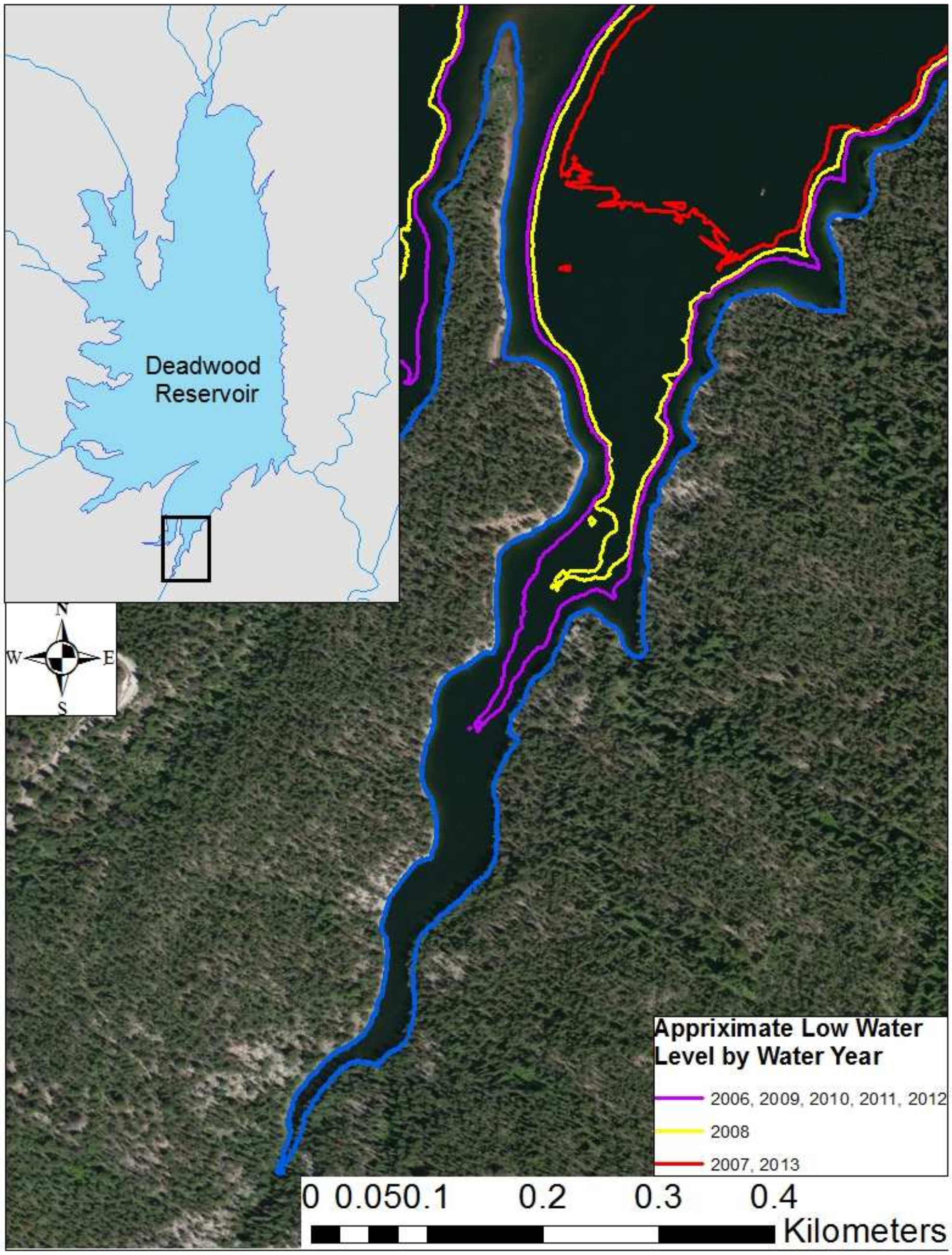

Figure 1.1. The Trail Creek arm of Deadwood Reservoir, Idaho, as an example of inter-annual variability in fall water levels.

Figure 1.2. Passage channel created in the varial zone of Kachees Reservoir, Washington.

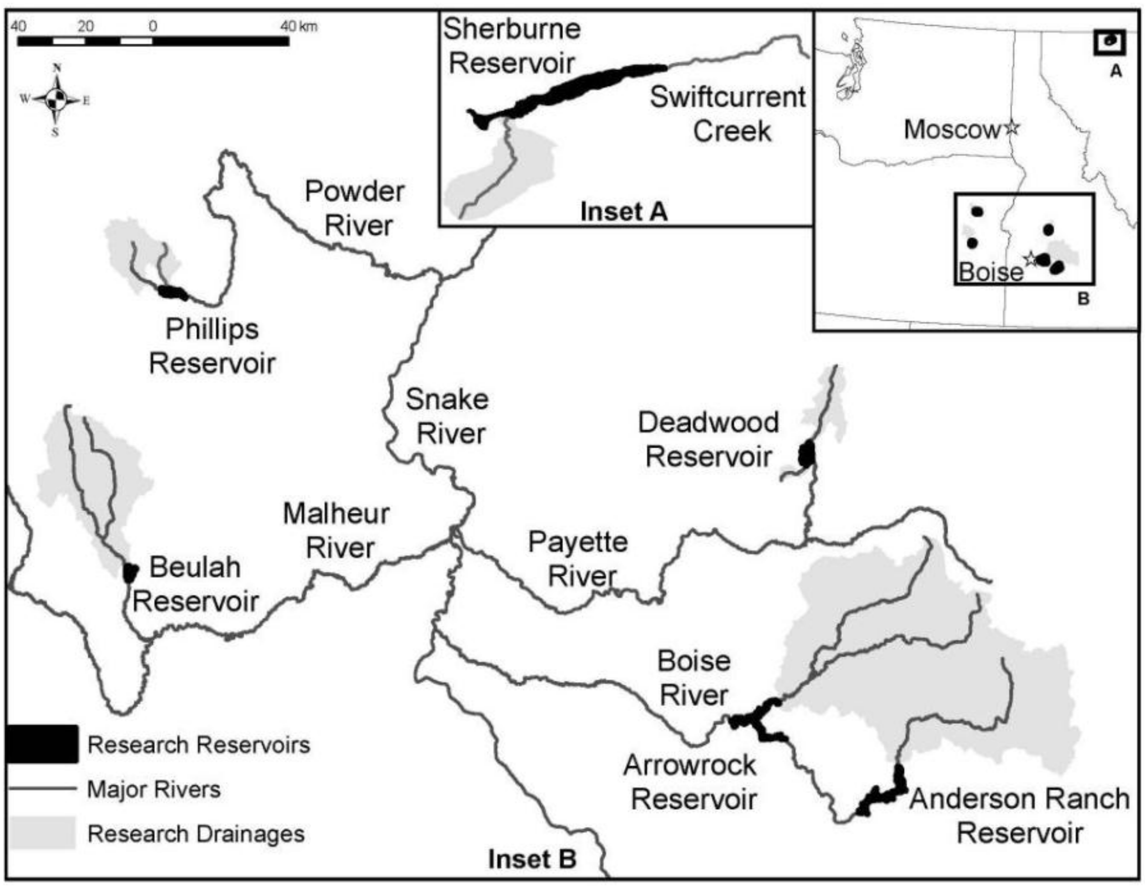

Figure 1.3. Varial zone habitat survey study areas.

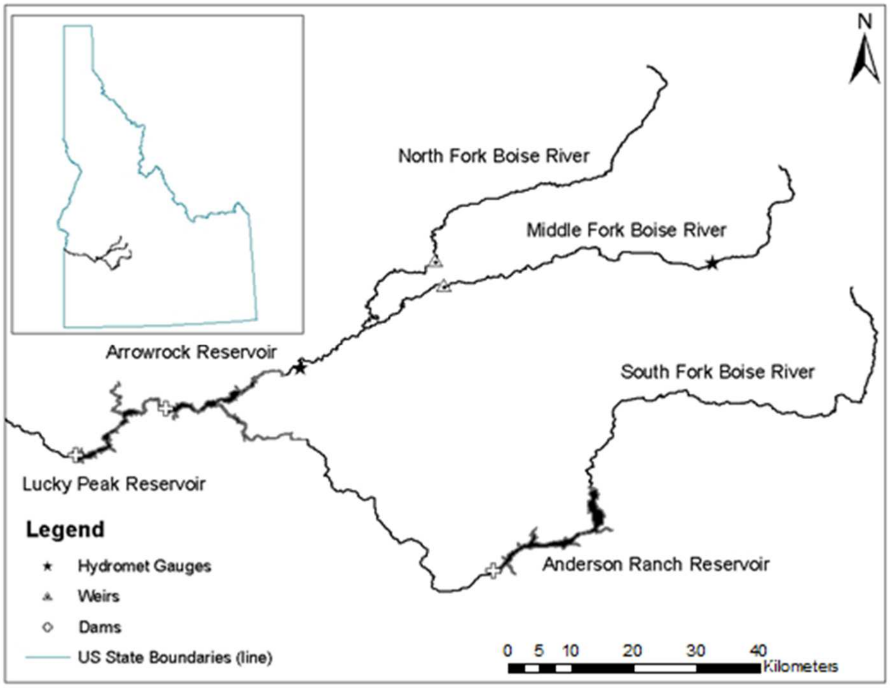

Figure 1.4. Boise River watershed with Arrowrock, Anderson Ranch and Lucky Peak reservoirs and dams, Idaho.

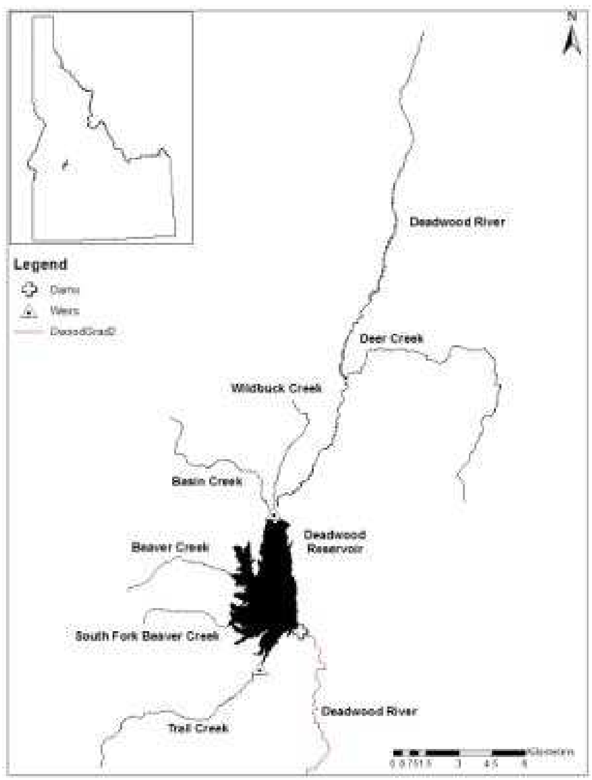

Figure 1.5. Deadwood River drainage, Idaho study area showing main tributaries.

Tables

Table 1.1: Temperatures (mean, maximum, minimum, median and standard deviation from the mean; degrees Celsius) from sensor on internal radio tags in bull trout at Deadwood Reservoir. During the reservoir's stratified period (July-September) 2006-2008.

Year	Temperature ˚C				Standard Deviation
	Mean	Maximum	Minimum	Median	
2006	12.6	18.0	8.4	12	2.04
2007	12.5	19.6	8.0	12	2.13
2008	12.1	17.2	7.6	12	3.25

CHAPTER 2: CHARACTERIZATION AND COMPARISON OF THE HABITAT CONDITIONS IN VARIAL AND UPRIVER REFERENCE ZONES OF RESERVOIRS.

Abstract

Varial zones at the interface of reservoirs and inflowing tributaries are associated with fluctuating reservoir water levels. Eight tributaries of six northwestern regional (Oregon, Idaho and Montana) reservoirs were surveyed to characterize and compare the physical characteristics associated with aquatic habitat in varial and upstream reference zones as affected by fluctuating reservoir water levels. Overall, physical conditions associated with aquatic habitat in varial zones were distinctly different from habitat in adjacent reference zones. In a comparison between reference and varial zones combining all eight tributaries, 13 of the 22 variables surveyed at the habitat unit scale differed significantly (*P* <0.05). Although habitat differences between varial and reference zones were pervasive across all eight individual tributaries, some variation was found in number of differences by tributary. Of the 172 habitat comparisons (six tributaries with 22 variables and two tributaries with 20) analyzed between reference and varial zones in the individual tributaries, 76 significant differences (*P* <0.05) were identified. Varial zones differed consistently from reference zones in having higher embeddedness, less cover and higher velocities. In addition to differences identified between reference and varial zones, some differences were found within the individual varial zones themselves. Measurements of many variables, such as percent surface fines, bank stability as well as vegetation, substrate and total cover showed a correlation to distance downstream from the high water line. Delta formation, or the absence of it, was an important factor in the structure of varial zones. All four tributaries, regardless of size,

at all three reservoirs associated with coarse-grained basin geology types (Idaho Batholith; Trail Creek, Deadwood, Middle Fork Boise and South Fork Boise rivers) formed deltas, as did the two smallest tributaries with finer grained basin geology, Deer and Canyon creeks. In contrast, the two largest tributaries with finer grained basin geology types did not form deltas. Measurements or estimates of variables in the delta habitat units were often outliers at one end or another of the documented range for a variety of different habitat variables such as width, length, gradient, percent surface fines and embeddedness. In the six tributaries where deltas existed, they became longer and wider as reservoir elevations dropped within a single season. Many of the physical differences identified between reference and varial zones (e.g., the higher velocities in varial zones, increased sedimentation and lack of riparian vegetation observed in the lower reaches of varial zones) are explainable in relation to sediment behavior and have the potential to impact aquatic life.

Introduction

Of the considerable research that has been conducted related to sedimentation and water levels in reservoirs (Fan and Morris 1992a, 1992b; Fischer and Ohl 2005; Geraldes and Boavida 2005), most of it has focused on the effects of sediment on reduction in storage capacity (Lee and Foster 2013) and deterioration of valves and turbines (Padhy and Saini 2008). Few investigations have been conducted on the ecological impacts of sediment and reservoir levels on the tributaries that run through them. These physical characteristics associated with changes in aquatic habitat and the changes it undergoes are important for many organisms including, aquatic macroinvertebrates, migratory fish, and fish that congregate near the tributary mouths. In addition to impacts to fish and other aquatic fauna, the changes in reservoir water levels also affect riparian birds by inundating riparian vegetation including nests and potential nest sites (BOR 2005; van Oort et al. 2013).

As part of natural erosion processes, all rivers and streams transport sediment downstream. When dams are built, water velocities are greatly reduced and a portion of that sediment settles out in the reservoir, a proportion referred to as the reservoir's trap efficiency. Although trap efficiency varies widely among reservoirs depending on reservoir size, bathymetry and operations (McCully 1996), Mahmood (1987) estimated that overall, sedimentation fills in almost 1% of global reservoir volume each year. This sediment settles out in a relatively predictable physical pattern and changes many physical aspects of the original stream/river channel (Figure 2.1). Larger substrate settles out first, decreasing the gradient from the original bed and creating a topset slope (Fan and Morris 1992a; BOR 2006). At the downstream end of the topset slope is a pivot point where the slope increases greatly forming the foreset slope (Fan and Morris 1992a; BOR 2006). The gradient then returns to that similar to the original bed slope with the finest sediment settling out on the bottomset slope (Fan and Morris 1992a; BOR 2006).

Sediment delivery from rivers to reservoirs does not occur at a steady or highly predictable rate. River sediment becomes suspended in the water column or begins to move as bed load on the hydrograph's ascending limb with deposition typically occurring on the descending limb, so that sediment is transported to the reservoir at lower concentrations on the descending limb than on the ascending limb. Typically, up to 50% of annual sediment delivery to a reservoir occurs during a 5-10 day period of the ascending limb in spring (McCully 1996). Reservoir water elevations often change during these times and determine where the sediment initially settles out within the reservoir (Fan and Morris 1992a, 1992b). As peak flows subside and outflows begin to exceed inflows, reservoir water levels drop, exposing some of this sediment while expanding the area of flowing water. The area where a tributary runs through the dewatered portion of a reservoir is hereafter referred to as a varial zone. Tributaries can downcut through portions of the topset slope and continue to move sediment downstream as reservoir levels drop (Fan and Morris 1992b). The flow volume, slope and velocity a tributary has while running through a varial zone determines the size and amount of sediment it is able to move as well as the shape of the channel that forms (Chitale 1972; Simon and Rinaldi 2006; Bowman et al. 2010).

Reservoir operations can effect sediment deposition as well as down cutting and re-suspension patterns (Fan and Morris 1992a, 1992b). Reservoirs are operated differently depending on their purpose; where incoming sediment initially settles out depends in part on that purpose. Flood control reservoirs may be nearly empty during peak flows whereas reservoirs created for recreation may be nearly full. Reservoir operational flexibility may allow water managers to change the sedimentation patterns, thereby changing the physical attributes of the tributary habitat within varial zones (Fan and Morris 1992b; Lee and Foster 2013; Shokri et al. 2013). Knowledge of the relations among reservoir level and the physical characteristics of varial zones are also important because the physical characteristics provide habitat for riparian communities (Enns and Enns 2012) and aquatic life (Wesche et al. 1987), including migratory fishes moving through these zones.

Few studies have been conducted on the relations among reservoir levels, varial zones, and the migratory fishes, who, as part of their life cycle, may be required to ascend through reservoirs and adjacent varial zones to spawn. The changing water levels of reservoirs in relation to substrate and other physical characteristics continually change the habitat for fish in the tributaries traversing varial zones. Areas near the high water line may only be inundated for days to months before they return to their tributary form while other areas may be inundated for years before they are exposed during a drought year. Topography of the varial zone itself along with physical characteristics of the drainage basin as a whole interact with reservoir operations to create the wide variety of conditions. Although specific conditions vary from reservoir to reservoir, year-to-year and even within one season, an evaluation of several varial zones may allow some generalizations to be made.

The objective of this chapter is to characterize and compare the physical characteristics associated with aquatic habitat in varial and upstream reference zones as it is affected by fluctuating reservoir water levels. Based on observations of varial and reference zones at several localities, the hypotheses to be tested were that:

1. Gradients would be higher in reference zones than in varial zones.
2. Depth variables (maximum, minimum and mean depths; pocket pools per meter and pocket pool depths) would be greater in reference zones than varial zones.
3. Measures of aquatic habitat variables related to cover (undercut banks, large woody debris, overhanging vegetation, substrate, and depth greater than 0.5 m) would be higher in the reference zones than varial zones.
4. Key substrate variables (minimum, mean and maximum embeddedness as well as percent surface fines) would be lower in reference than varial zones
5. Bank stability would be higher in reference zones than varial zones.
6. Velocities would be lower in reference zones than varial zones.
7. Rates of water temperature increase (°C per km) during the summer would be higher in varial zones than reference zones.

Methods

The study was conducted in eight tributaries of six reservoirs in the states of Oregon (Phillips Reservoir- Powder River and Deer Creek; Beulah Reservoir- North Fork Malheur River), Idaho (Deadwood Reservoir- Deadwood River and Trail Creek; Arrowrock Reservoir- Middle Fork Boise River (MFBR); Anderson Ranch Reservoir- South Fork Boise River) and Montana (Sherburne Reservoir- Canyon Creek). The six reservoirs are managed by the U.S. Bureau of Reclamation (BOR) foremost for irrigation and flood control with Anderson Ranch Reservoir being managed additionally for hydropower generation (BOR 2014a).

Operations of the six reservoirs are similar; each reaches its annual low water level at the end of the irrigation season (i.e., September-October), re-fills throughout winter and, depending on reservoir size and snowpack, may be drawn down to release floodwaters before reaching annual peak water levels in May or June. Phillips Reservoir differs slightly from the others in that it has exclusive flood control space that cannot be used for storing irrigation water. If Phillips Reservoir uses any of this exclusive flood control space during periods of high reservoir inflow, it is emptied as soon as the flood risk is diminished and no water is stored within this flood control space for future irrigation use.

Deadwood, Beulah and Phillips reservoirs have bottom-release valves close to the original streambed; Arrowrock and Anderson Ranch reservoirs, however, have water below the release valves that cannot be drained (referred to as dead pool). Sherburne Reservoir is a raised lake and has a similar dead pool in the area of the original lake.

The water supply for all six reservoirs is provided predominantly by snowmelt. Mean annual precipitation in the drainage basins of each reservoir varies widely from 155 to 477 cm per year (Table 2.1). The youngest reservoir is 47 years old (Phillips) and the oldest 100 years old (Arrowrock; Table 2.2). The sizes of tributary drainages in the study range from 166 to 5,700 km^2 encompassing a wide range of possible stream sizes and characteristics. However, some drainages are very similar in size (i.e. Powder and Deadwood Rivers, 189 and 166 km^2 respectively, as well as Canyon and Trail Creeks, 20 and 25 km^2 respectively) allowing for investigations into impacts of other variables such as geology type. With maximum reservoir elevation fluctuation ranging between 14 and 38 m, the maximum varial zone lengths of the study reservoirs range from 1,225 to 9,850 m.

To relate basin and reservoir characteristics to differences in habitat conditions among reservoirs, general basin characteristics were estimated in StreamStats (USGS 1995) or ArcMap 10.2 (ESRI). The reservoir characteristics were obtained from the BOR or estimated in ArcMap (BOR 2014a; BOR 2014b). Basin characteristics included drainage sizes, surficial geology, mean annual precipitation, percent forest cover as well as minimum and maximum elevations. Reservoir characteristics included maximum storage capacity, maximum water elevation fluctuation, reservoir age, and maximum varial zone length. The influence of surficial geology type (grouped as fine-grained and coarse-grained (Chapter 1) on sediment deposition and re-suspension on varial zones was characterized. Differences in grain sizes were investigated to help understand and analyze differences in sedimentation and channelization patterns among study sites.

At each of the eight tributary-reservoir interfaces, habitat variables were measured in both the varial and upstream reference zones. Reaches in the reference zone were chosen randomly from the area between the high water mark and the first major tributary upstream from the high water mark. Random points along the stream were generated in GIS and the first habitat unit upstream from that point determined the downstream boundary of the reach. The entire exposed varial zone was sampled in each tributary except the Powder River and Deer Creek in Phillips Reservoir. Phillips Reservoir does not have a consistent full pool elevation because of flood control space that is not used in most years. As a result, the upper sections of the possible varial zone, which are only inundated for short periods of time in extremely high water years, were not surveyed. In all, 510 varial zone and 240 reference zone habitat units were surveyed over three years on eight tributaries associated with six reservoirs. These units encompassed a combined 28,072 m of varial zone and 11,783 m of reference zone. The maximum length of varial zones at the study reservoirs ranged from 1,225 m on Trail Creek at Deadwood Reservoir to more than 8,450 m on the MFBR at Arrowrock Reservoir (Table 2.2).

Some tributaries were only sampled once during the three year study period whereas others were sampled in multiple years and multiple water levels within years. Flows for the tributaries were monitored by USGS/BOR stream gauges or estimated based on reservoir elevation changes and monitored outflows during the study. An acoustic Doppler Sontek Flow Tracker was used to determine the partitioning of flow if channels split in the varial zone before meeting the reservoir. At the zone scale, sinuosity was calculated over the entire length of the varial or reference zone, using GIS for each tributary. Sinuosity is the ratio of channel length to valley length, where valley length is the straight line distance between the top and bottom habitat units. A more channelized stream section had lower sinuosity closer to one, whereas winding channels had higher sinuosity.

Individual habitat units (i.e., pools, runs, riffles, deltas and braided channels) were the sampling units. Additional sampling unit breaks within these habitat types were formally recognized if there were changes in the habitat variables being collected. If individual habitat types were broken into multiple sampling units, it was typically in response to changes in substrate, gradient or width. The habitat characteristics were quantified through direct measurement or estimated using these habitat units as boundaries. Some generalizations were made to characterize variables likely to exist in the maximum length of the varial zone based on reservoir bathymetry and past water levels, but direct sampling and analysis was limited to the water levels available during sampling events.

A sub-meter accuracy GPS (Trimble GeoExplorer, Trimble Inc.) was used to mark the top and bottom of each habitat unit. In the wider tributaries, i.e., the Powder, Deadwood, South Fork Boise and MFBR, the tracks function collected GPS points every 5 seconds, which was used to map the banks. In the smaller tributaries, i.e., Trail, Deer and Canyon creeks as well as the Malheur River, the tracks function was used to map the middle of the channel. GIS (ArcMap 10, ESRI) was used to make polygons based upon on the tracks or centerline and ground width measurements to make a visual representation of the channel (e.g. Figure 2.2). A subset of length and width measurements was also checked on the ground with a 2 m wading rod and laser rangefinder.

Individual habitat units within varial and reference zones were used as the boundaries for variable measurements or estimates. Habitat unit boundaries were visually identified by the same observer at every reservoir. Habitat conditions within sampling units were characterized based on a range of habitat variables measured in both varial and reference zones. A modified version of the U.S. Forest Service's R1/R4 habitat survey protocol (Overton et al. 1997) was used to characterize the habitat. Variables measured for each habitat unit were separated into five categories: dimensions, depth, cover, substrate and velocity. The Dimension category included length, width, area, and gradient. The Depth category included maximum depth, minimum thalweg depth and depth in a representative cross-section as well as pocket pools per meter and average pocket pool depth. The Cover category included undercut banks, large woody debris, overhanging vegetation, substrate, depth greater than 0.5 m and depth greater than 0.5 m that was visually identified as minimal velocity resting habitat. The Substrate category included percent surface fines, Wolman (1954) pebble counts, bank stability, as well as minimum, mean and maximum embeddedness. Velocity was in its own category. Gradient calculated at the habitat unit scale with a clinometer following USFS R1/R4 habitat survey protocols (Overton et al. 1997). Gradient and velocity were added to the sampling methods after preliminary analysis of 2011 data. Deer Creek was dewatered in 2012 and 2013 and the South Fork Boise River had forest fires that limited access in the same years. These two tributaries therefore do not have velocity or gradient data analyzed in this paper.

Several different depth-related measurements were made in each habitat unit. Maximum depth was identified, when safely possible, and estimated visually with reference to surrounding depths and topography when not safe to wade. Minimum thalweg depth (the deepest part of the shallowest cross section) was identified and recorded. In riffles and runs, depths were taken at ¼, ½, and ¾ of the channel width in a representative cross section. In pools, depths were measured at ¼, ½, and ¾ of the channel width at a cross section halfway between the maximum depth and the tailwater control of the pool. Pocket pools were counted and an average pocket pool depth was obtained by averaging the maximum depth of all of the pocket pools for each habitat unit. Because of the variation in habitat unit length, the count of pocket pools for each habitat unit was divided by the length of that habitat unit to get a more comparable pocket pools per meter number.

Six different cover types were visually estimated: undercut banks, large woody debris, overhanging vegetation, substrate, depth greater than 0.5 m and depth greater than 0.5 m that was visually identified as minimal velocity resting habitat. The percent of the total bank length for each habitat unit that was undercut at least 0.1 m, was visually estimated. For the remainder of the cover variables, visual estimates were made of the percentage of the total wetted area of the habitat unit consisting of each cover type. The observer made these estimates as if they were overhead looking straight down. The same observer conducted these estimates at each tributary for consistency. In addition to being analyzed individually, the cover types, not including undercut bank, were added together to create a cumulative total cover category. Areas with multiple cover types (e.g. overhanging vegetation and depth) were counted for both cover types; this approach allowed the total cover measure to be greater than 100 in many instances.

Four different measures of substrate were used. The percent of the wetted area covered by surface fines less than 8 mm was visually estimated for each habitat unit. The observer's visual estimates of percent surface fines were calibrated with pebble counts from this and other studies. Substrate in the wetted channel was quantified using Wolman pebble counts (Wolman 1954). A gravelometer was used for the pebble counts to consistently identify the size category of 100 pieces of substrate. Pebble counts were not conducted in each habitat unit. Pebble counts conducted in the delta of each varial zone and 3 riffles with similar slopes evenly spread out in each varial and reference zone. Bank stability was also documented. The percent of the bank length, including both banks, which would not be readily subject to erosion, was visually estimated. Embeddedness was measured as the portion of a piece of substrate's surface area that is covered by fine sediment. This varies among individual pieces of substrate within individual habitat units so visual estimates of minimum, mean and maximum embeddedness were made for each unit.

In addition to the surveys of substrate variables described above for all reservoirs, additional methods were used to determine sediment behavior in Deadwood and Arrowrock reservoirs over multiple years. Habitat surveys and photos at multiple water levels allowed for a comparison between past bathymetric surveys of Deadwood and Arrowrock reservoirs to conditions in 2013. Bathymetry was used from a 1997 survey at Arrowrock and a 2002 survey at Deadwood Reservoir (BOR 1998; BOR 2003). GPS locations of the transition between river and reservoir were collected or identified from time-lapse digital cameras and aerial images. The corresponding reservoir elevation for the date and time of the GPS position or image were identified on BOR's Hydromet website (BOR 2014b). These elevations were then compared to what the elevation at each location was during the bathymetry survey. The difference in observed elevation and bathymetry elevation represented the sediment deposition at each point since the bathymetry surveys were completed.

Velocity measurements were taken at the representative cross sections used for width and depth measurements in each habitat unit using an acoustic Doppler Sontek Flow Tracker. Velocity measurements were taken at 0.15 m above the substrate, i.e, near the bottom. If the channel was unsafe to wade, an attempt was made to collect velocity measurements close to the banks; notes and digital photographs were used to describe conditions.

Water temperatures were monitored throughout the season as well as during sampling. Temperature loggers (TidBit, Onset Computer Corp.) were installed above the high water mark to monitor hourly temperatures at the upstream entrance to the varial zones throughout the year. Instantaneous temperature measurements were collected throughout the varial and reference zones of Canyon Creek. Additional temperature loggers were deployed at multiple locations within the varial and reference zones of Trail Creek in 2013 and 2014. In 2013, the low water temperature logger in Trail Creek was buried by sediment during a rainstorm and was not found before water levels in the reservoir increased. Temperatures from this logger are not available. Rates of temperature increase (°C per km) were calculated between each temperature logger.

Because the habitat in the varial zones changes constantly as reservoir water levels change, multiple habitat surveys throughout the irrigation season (i.e., as reservoir levels dropped) were conducted in Trail Creek and the Deadwood River. In 2013, digital photographs of the transition zone between river and the fluctuating reservoir were taken weekly from June to October on the MFBR. Time-lapse digital cameras were set up in Trail Creek to monitor and characterize habitat changes between sampling events.

High turbidity levels were sometimes seen during site visits. Increased sedimentation from fires and mass wasting events in the Boise River Basin allowed for investigation of how sediment is cycled within the varial zone as water levels decreased. Turbidity readings (Nephelometric Turbidity Units; NTU) were collected with a Hydrolab Ds5 (Hach Environmental) at multiple locations on the MFBR as well as profiles in the reservoir near the confluence of river and reservoir on three occasions in summer of 2014 (Figure 2.3). Idaho state water quality standards are expressed in NTU (IDEQ 2014), but USFWS (2010) describes adverse impacts to bull trout and their habitat in terms of total suspended solids (TSS). A subset of these Hydrolab readings were paired with water samples for laboratory analysis of (TSS).

A Wilcoxon ranked sum test was used to test for differences in individual habitat variables between reference and varial zones of individual tributaries in R version 3.0.2 (R Core Team 2013). The null hypothesis for each habitat variables was that there was no significant difference between varial and reference zones. Both Deer and Canyon creeks split into multiple channels before reaching their reservoirs during surveys. Habitat was surveyed in all channels, but for statistical analysis the habitat data from the main channel was used for comparison to the reference zone. Up to 22 individual habitat variables were analyzed from the data collected. To correct for the type 1 error rate in multiple comparison tests, a false discovery rate (FDR; Benjamini and Hochberg 1995) correction was made for each statistical test. Some researchers have suggested not only rejecting the typical Bonferroni correction for multiple comparisons in favor of FDR in ecological studies (Garcia 2004) but not applying a correction at all. Based on this insight, I considered both uncorrected and FDR corrected data and conducted my analysis on the uncorrected data.

Six variables could to be calculated on the reach scale (sinuosity as well as each percent habitat type; pools, riffles, runs, braided channels and deltas). The same Wilcoxon ranked sum test was conducted on these variables, but only by combining all tributaries together for analysis. The same FDR correction was applied to these variables. To test for longitudinal patterns within the varial zones Spearman's rank correlations were run between each variable and distance downstream from the high water line.

Results

Varial and reference zone habitat differences- all tributaries combined—Overall, physical conditions associated with aquatic habitat in varial zones were distinctly different from habitat in adjacent reference zones. In a comparison between reference and varial zones combining all eight tributaries, 13 of the 22 habitat unit scale variables differed significantly rejecting the null hypothesis for those 13 variables ($P < 0.05$; Table 2.3-2.4). Six of seven cover variables (undercut banks, large woody debris, overhanging vegetation, substrate, depth greater than 0.5 m visually identified as minimal velocity resting habitat and total cover) were significantly greater ($P < 0.05$) in the reference zones than varial zones. All of the variables associated with substrate (minimum, maximum and mean embeddedness, percent surface fines as well as bank stability) were significantly different ($P < 0.05$) between the reference and varial zones; the three embeddedness estimates and surface fines were greater in the varial zone while bank stability was greater in the reference zone. Of the ten additional variables other than those in the cover and substrate categories, only two - mean velocity and pocket pools per meter - were significantly different (*P* <0.05) between reference and varial zones. Mean velocities were higher and pocket pools fewer in the varial zones than in reference zones.

Varial and reference zone habitat differences- individual tributaries— Although habitat differences between varial and reference zones were pervasive across all eight individual tributaries, some variation was found in number of differences by tributary. Trail Creek had the highest number of habitat variables (15 of 22) with significant differences (*P* <0.05) between reference and varial zones. Six of the tributaries showed between 8 and 11 significant habitat differences between reference and varial zones (Table 2.3-2.4). Although the South Fork Boise River had by far the fewest differences (3 of 20); it was surveyed only in 2011, a high water year for the Boise Basin, when the length of the varial zone exposed and subsequently surveyed was less than 20% of the maximum varial zone length (1,479 of 7,550 m). Aerial photos from other years as well as reservoir bathymetry suggest more differences would be identified in years with longer varial zones.

Of the 172 habitat comparisons (six tributaries with 22 variables and two tributaries with 20) analyzed between reference and varial zones in the individual tributaries, 76 significant differences (*P* <0.05) were identified. A majority (61) of these significant differences were for variables in the cover or substrate categories. Even though differences were concentrated in these categories, the only variables where a significant difference was not seen in at least one tributary were length, area and gradient.

Varial and reference zones differed consistently in embeddedness, cover and velocities. All three embeddedness estimates (minimum, mean and maximum) were higher in the varial zone of each tributary. Differences for mean and maximum embeddedness were significant ($P < 0.05$) for seven of the eight tributaries those for minimum embeddedness were significant ($P < 0.05$) for five of the eight tributaries. Only six of the 56 cover type comparisons documented more available cover in varial than reference zones. Thirty-seven of the 50 comparisons where cover was greater in the reference zone were significant ($P < 0.05$) whereas none of the six comparisons where cover was greater in the varial zone were significant ($P < 0.05$). Mean water velocities were numerically higher in all eight varial zones than in their reference zones; in four cases these differences were significant ($P < 0.05$). The difference was most pronounced on the Powder and North Fork Malheur rivers where 27.5% and 20% respectively of the mean velocities in the varial zones were higher than any mean velocity documented in the reference zones.

Habitat differences within varial zones— In addition to differences identified between reference and varial zones, some differences were found within the individual varial zones themselves. Measurements of many variables, such as percent surface fines, bank stability as well as vegetation, substrate and total cover showed a correlation to distance downstream from the high water line. Some of these variables, such as percent surface fines, changed throughout the length of the varial zones (Figure 2.4, 2.5). Other variables such as vegetation cover changed quickly within the upper 5-20% of the maximum varial zone length of each tributary and stabilized for the rest of the length, typically at their maximum or minimum. These correlations were significant (P <0.05) for Deadwood, MFBR, Trail, and Deer for both variables as well as for Canyon for surface fines and North Fork Malheur for vegetation.

Deltas—Delta formation, or the absence of it, was an important factor in the structure of varial zones. All four tributaries, regardless of size, at all three reservoirs associated with coarse-grained basin geology types (Idaho Batholith; Trail Creek, Deadwood, Middle Fork Boise and South Fork Boise rivers) formed deltas, as did the two smallest tributaries with finer grained basin geology, Deer and Canyon creeks. In contrast, the two largest tributaries with finer grained basin geology types, Powder and North Fork Malheur rivers, did not form deltas. At the tributaries where deltas formed, they were present at the river-reservoir confluence at all reservoir elevations below full pool. With most of these reservoirs filling every year, the result is that every habitat unit that is exposed in any year at some point during that year is covered by a delta as the water recedes from full pool. The amount of time each habitat unit was exposed and the efficiency of the tributary transporting fine sediment downstream determined many of its habitat characteristics. When down cutting occurred through this delta formation, some fine sediment was left on the banks, which led to bank sloughing (Figure 2.6).

Measurements or estimates of variables in the delta habitat units were often at one end or another of the documented range for a variety of different habitat variables such as width, length, gradient, percent surface fines and embeddedness.

For example, the delta widths in the MFB, South Fork Boise and Deadwood river varial zones were 178, 71 and 77 m and the corresponding widest reference zone habitat widths were only 51, 44.5 and 20 m. The surficial substrate of all deltas was 100% fine sediment, causing all three embeddedness measurements to be 100% as well. Gradient was so close to zero percent slope it was not measurable in any of the deltas.

In the six tributaries where deltas existed, deltas became longer and wider as reservoir elevations dropped within a single season. For example the Trail Creek delta ranged from 9.1 m long on July 10, 2013 up to 115.9 m long on September 4, 2013 (Figures 2.7-2.8 and Table 2.5). Between-year variations in inflows and associated stream power also played a role in the length of deltas, with higher flows at similar water elevations leading to shorter deltas (e.g. Table 2.5).

Temperature— The temperature data collected indicated that longitudinal rates of temperature increase within varial zones were greater than within reference zones. In early September 2013, rates of increase in daily maximum temperature within the upper varial zone of Trail Creek, the only stream with multiple temperature loggers allowing estimation of temperature changes, reached 3.10°C per km (Figure 2.9); increases in the reference zone were only 0.43°C per km. Similar high rates of temperature change (3.13°C per km) were documented in the main channel of the varial zone on Canyon Creek at Sherburne Reservoir in August, 2013.

Rates of change in temperature also differed within a varial zone. In the varial zone of Trail Creek on September 10, 2014, rates of temperature increase were greatest (3.30°C per km) in the first 200 m downstream from the high water line (Figure 2.10), but less over the next 119 m (1.64°C per km) as well as in the lower 139 m to the 2014 low water level (1.79°C per km). All of these rates were much higher than the rate of temperature increase in the reference zone of 0.25°C per km on the same day. Varial zones were also less insulated from low water temperatures. In both 2013 and 2014 minimum temperatures were lower in the varial zone than the reference zone (Figures 2.9 and 2.10).

Sedimentation—Data were not available to fully evaluate how estimated sedimentation rates varied among reservoirs. Up to 2.5m of sedimentation was documented in the varial zone of Arrowrock Reservoir in the 16 years since the 1997 bathymetric survey (0.156 m/yr; Figure 2.11); similarly up to1.9m of sedimentation was documented in the Trail Creek varial zone at Deadwood Reservoir in the 11 years since 2002 (0.172 m/yr; Figure 2.12). Similar data were unavailable from the other reservoirs.

Within these two reservoirs, however, sedimentation rates were found to vary greatly between specific locations. Some areas saw high levels of sedimentation, whereas other areas saw relatively little and annually scoured down close to the original channel bed. For example, estimated rates of sedimentation in the varial zone of Trail Creek (Figure 2.12) ranged from 0.052 m/yr just below the high water line, down to a low of 0.025 m/yr (1,623 m asl, 138 m downstream of high water line) up to a high of 0.172 m/yr near the 2012 low water level (1,618 m asl, 494 m downstream of the high water line) and back down to 0.065 m/yr at the 2013 low water line (1614 m asl, 911 m downstream of the high water line). A similar pattern was seen in the varial zone of the MFBR; however, rates did not decrease again at the downstream end of the exposed varial zone in 2013 like they did in Trail Creek (Figure 2.11).

Pebble counts indicated a predictable pattern in the size of sediments deposited longitudinally within varial zones. Fine sediment within the channel was concentrated at the downstream end of varial zones (e.g. Figure 2.13). By the end of the irrigation season, habitat units in the upper sections of the varial zones had pebble counts that resembled reference sites. Time lapse photos showed that this pulse of fine sediment moved downstream with the receding reservoir level (Figure 2.14). Habitat units farther from the reservoir water level and exposed for a longer period had substrate which more closely resembled that in the reference zone. Larger tributaries with more stream power were more efficient at cleaning out fine sediment from the upper sections of varial zones. When reservoir water levels were stable, fine sediment continued to be flushed from upstream habitat. It settled out at the river-reservoir interface, enlarging any existing delta.

Turbidity— Seasonally high turbidity levels were documented during site visits within the varial zone of Trail Creek as well as the Deadwood and MFBR. During sampling events on the MFBR in 2014, background turbidity levels above the high water line of the reservoir ranged between 0.9 and 11 nephelometric turbidity units (NTUs). Maximum turbidity levels of 305 NTU (1126 mg/l TSS) were found at the transition between river and reservoir on July 24, 2014. On August 29, 2014 shortly after Arrowrock Reservoir elevations started to increase and active down cutting decreased, turbidity levels dropped to 266 NTU. On November 12, 2014, when the reservoir had refilled to the same elevation as the highest documented turbidity during decreasing water levels (305 NTU on July 24, 2014) samples were taken again documenting a maximum turbidity of 12.9 NTU. Turbidities and total suspended solids varied seasonally as well as longitudinally through the varial zone. Turbidity levels in the varial zone were highest as reservoir water levels were actively decreasing (Figure 2.15) and decreased as reservoir water levels rose (Figure 2.16).

Visual observations of turbidity on Trail Creek and Deadwood River were consistent with the measured values (higher during decreasing reservoir water levels and lower during increasing reservoir water levels) on the MFBR, although high turbidity levels were observed over a wider range of water levels on Arrowrock Reservoir (MFBR) than Deadwood Reservoir (Trail Creek and Deadwood River). Digital photographs from the time-lapse cameras showed that down cutting and bank sloughing were more prevalent during reservoir drawdown and actively increased suspended sediments. When reservoirs started to re-fill near the end of irrigation season, active downcutting and bank sloughing was reduced.

Time lapse Habitat Observations—Time-lapse cameras documented extreme habitat changes in Trail Creek that were not always documented during the on the ground habitat surveys. Time lapse cameras documented the downstream migration of fine sediments and exposure of larger substrate over time (Figure 2.14). Photos also documented delta migration as well as bank sloughing that would otherwise had to have been merely assumed by individual site visits (Figure 2.14). Hourly photos showed the transition of habitat units from being inundated by the reservoir through delta migration, bank sloughing and substrate cleaning to their eventual stable state before being inundated again.

Multiple Channels—Multiple channels that split the flow within the varial zone were documented in two of the eight study tributaries (Deer and Canyon creeks). Deer Creek split into two separate channels in 2011, 2012 and 2013 when it encountered an old roadbed in the reservoir. The river right channel then split again when it encountered a second old roadbed. In 2012 and 2013 each of the multiple channels making up Deer Creek went sub-surface or evaporated before reaching the low water pool of Phillips Reservoir (Figure 2.17). In 2011, a high water year, each of the multiple channels still contained flowing water when they met the reservoir. In 2014, a low water year in the Powder River Basin, Deer Creek did not split and flowing water persisted all the way to Phillips Reservoir.

Similar to Deer Creek, Canyon Creek's flow was divided into multiple channels that contributed to the significant habitat differences identified between varial and reference zones. Canyon Creek's multiple channels however, were not the result of anthropogenic habitat alterations like the road beds in Deer Creek. An alluvial fan extended out into Sherburne Reservoir that likely began forming long before Lake Sherburne Dam was built. In 2013 the main channel divided multiple times before reaching the reservoir pool leading to a total of twelve separate channels (Figure 2.18). Some of these channels dried up before meeting the reservoir, leaving seven of these twelve channels still having flowing surface water upon reaching the reservoir. Only 22% of the 0.343 m^3 per second (cms) flowing in Canyon Creek upstream of the varial zone, remained in the largest channel when it reached the reservoir.

The observed splitting of the channels at both Deer and Canyon creeks (Figure 2.18) was consistent with the measured significant differences in depth between reference and varial zones (Table 2.3-2.4). Of the eight tributaries in the study, Deer and Canyon creeks were the only ones with significant differences between reference and varial in minimum thalweg depth. Deer Creek was dewatered at its shallowest and the shallowest minimum thalweg depth for Canyon Creek's varial zone was half that (0.05 m) of the shallowest minimum thalweg depth for their reference zones (0.1 m).

Discussion

The differences in cover, substrate and velocity identified between reference and varial zones in this study provide some of the first results of an evaluation explicitly designed to assess differences in aquatic habitat between these zones in river and reservoir systems. Many of the differences can be explained by physical processes associated with water level fluctuations and sediment deposition and re-suspension. The physical processes of delta formation as well as subsequent downcutting and widening of stream channels identified in this study are in many ways similar to those associated with dam removal (Fan and Morris 1992a; Pizzuto 2002) and water level loss in natural lakes (Bowman et al. 2010; Scoppettone et al. 2014). The lack of vegetative cover in the lower reaches of all surveyed varial zones is similar to patterns documented in other reservoirs (Enns and Enns 2012) and to those identified after dam removal (Bednarek 2001). Other forms of cover can be buried by meters of fine sediment (Fan and Morris 1992a), but can be exposed again by high flows as documented after dam removal (Kanehl et al. 1997). Sediment processes after dam removal, similar to after delta migration, the physical process of sediment cleaning from a channel can take from months to decades (Bednarek 2001). This physical recovery occurs much more rapidly than biological recovery (Ryan 1991).

One of the most distinctive and diagnostic differences identified among sampled tributaries was the formation, or lack thereof, of a delta at the transition between tributary and reservoir. Although delta deposits are typical of reservoirs (Fan and Morris 1992a), the absence of delta formation in two tributaries suggested that their formation is not guaranteed, but may be dependent on a tributary's stream power relative to the sediment grain size. Finer sediment entering the reservoir is dispersed more evenly before settling (Fan and Morris 1992a). The two tributaries that did not form deltas (North Fork Malheur and Powder rivers) had fine-grained geology; their sediment was distributed throughout the reservoir and the rivers had a defined channel in place of a delta.

Sedimentation— Although riparian vegetation and large woody debris may be directly influenced by fluctuating reservoir water levels, most of the differences in physical characteristics between reference and varial zones can be explained in relation to sediment behavior. Sedimentation within reservoirs has been intensively studied (Mahmood 1987; Fan and Morris 1992; BOR 2006; Kansas Water Office 2008). However, fluctuations in reservoir water levels are not typically discussed in the reservoir sedimentation literature with the exception of sediment mitigation, as might occur during emptying for sediment flushing (Lee and Foster 2013; Shokri et al. 2013). Habitat changes after dam removal (e.g. Kenehl et al. 1997) provide the most comparable habitat information to compare with this study. Channel downcutting, and subsequent widening due to bank sloughing documented in this study is consistent with theory (Cantelli et al. 2004) and dam removal literature (Bednarek 2001; Kanehl et al. 1997). The cleaning out of fines and increase in mean substrate size documented over time during flushing events (Lee and Foster 2013; Shokri et al. 2013) and after dam removals (Kanehl et al. 1997) is consistent with longitudinal patterns identified in this study.

Temperature— The differences identified between rates of temperature increase in the reference and varial zones show the influence of physical characteristics on water temperature. Rates of temperature increase documented at Trail and Canyon creeks were similar to the 3.33°C per km described in Ryan et al. (2013) in an experiment where riparian vegetation was removed. Changes to the tributary and associated reservoir mouth temperature are caused by a cascade of impacts triggered by fluctuating water levels. The lack of shading in the varial zone is likely one of the main causes of increases in maximum temperatures (Ryan et al. 2013). The larger rate of temperature increase in the upper 200 m of varial zone (where riparian vegetation does exist) suggest additional physical characteristics such as percent pools, channel width, depth and velocities also impact rates of temperature increase within the varial zone as seen in Hawkins et al. (1997).

Multiple Channels— Braided channels, such as documented at Deer and Canyon creeks, are often formed when sediment inputs are greater than what can be moved downstream (Chitale 1972).The multiple channels may have been entirely caused by interactions with the old road beds in Deer Creek. However, in the case of Canyon Creek, its multiple channels may have arisen even without the influence of the reservoir. When Canyon Creek enters the Swiftcurrent Creek valley the stream gradient drops, stream power is decreased and sediment from Canyon Creek is deposited. An alluvial fan created by sediments from Canyon Creek likely existed in Lake Sherburne before it became a reservoir. The high water line of Sherburne Reservoir is close to the confluence of Canyon and Swiftcurrent creeks. If the reservoir is near full during high flow events, none of this sediment can be pushed downstream, exacerbating the natural alluvial fan. This aggradation from both natural and reservoir effects not only causes braiding, but often leads to a highly unstable migrating channel (Chitale 1972). This response is confirmed by historic aerial imagery of the varial zone of Canyon Creek showing at least three separate channel paths through the alluvial fan between 2005 and 2013.

Potential Impacts to Aquatic Life— The numerous physical differences between reference and varial zones identified in this study (e.g., the higher velocities in varial zones, increased sedimentation and lack of riparian vegetation observed in the lower reaches of varial zones) have the potential to impact aquatic life. Fluctuating reservoir water levels limit riparian vegetation (Enns and Enns 2012) that provides habitat for birds (van Oort et al. 2013) and insects (Kawaguchi et al. 2003) buffers water temperatures (Ryan et al. 2013) and provides overhead cover for aquatic life (Wesche et al. 1987). Sedimentation associated with fluctuating reservoir water levels fills in interstitial spaces (Kemp et al. 2011) important for aquatic fauna from macroinvertebrates to fish (Wood and Armitage 1997). Sedimentation also decreases surface roughness, further affecting the aquatic habitat by increasing water velocities (Morvan et al. 2008). Physical changes to aquatic habitat caused by fluctuating reservoir water levels and associated sedimentation can affect migratory fish through impacts to prey base (Kawaguchi et al. 2003), metabolism (Cooke et al. 2012) and stress (Hinch et al. 2006) as well as physical alterations to the migratory corridor (Scoppettone et al. 2014). More investigations are needed on the linkages among reservoir water level fluctuations, characteristics of varial zones at the reservoir and tributary interface, and how habitat for the diversity of riparian and aquatic biota may be affected.

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Figures

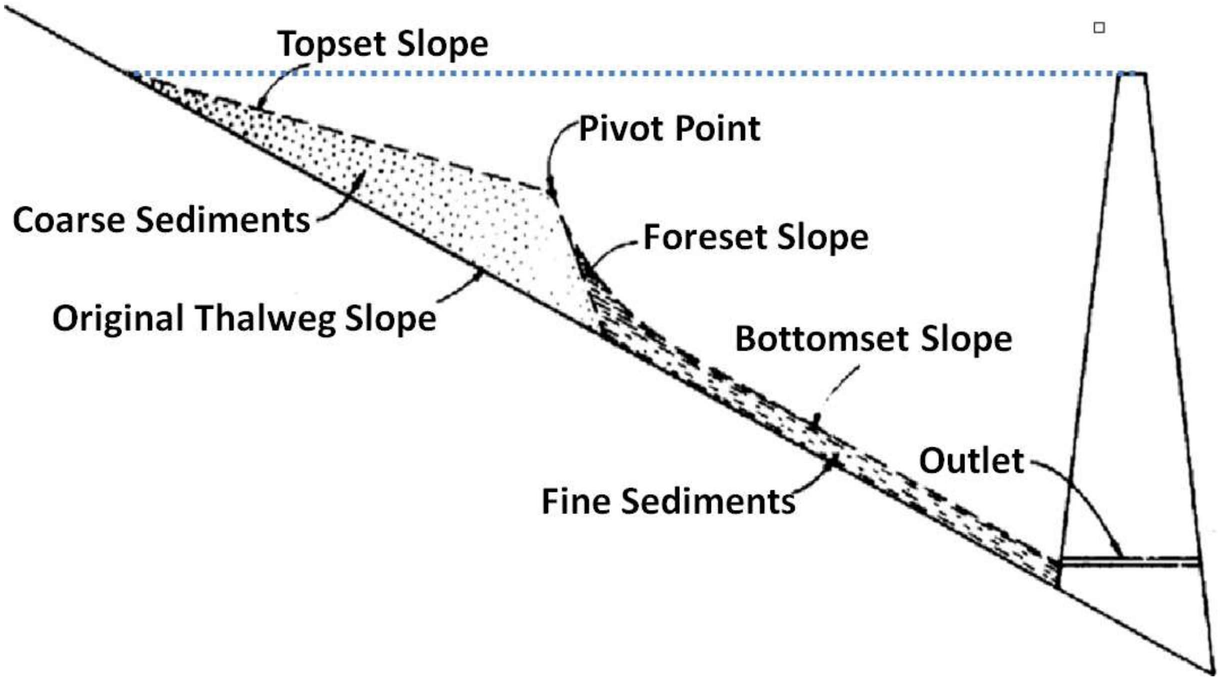

Figure 2.1. Cross Sectional view of a typical sedimentation pattern in a reservoir. (Source: BOR 2006.)

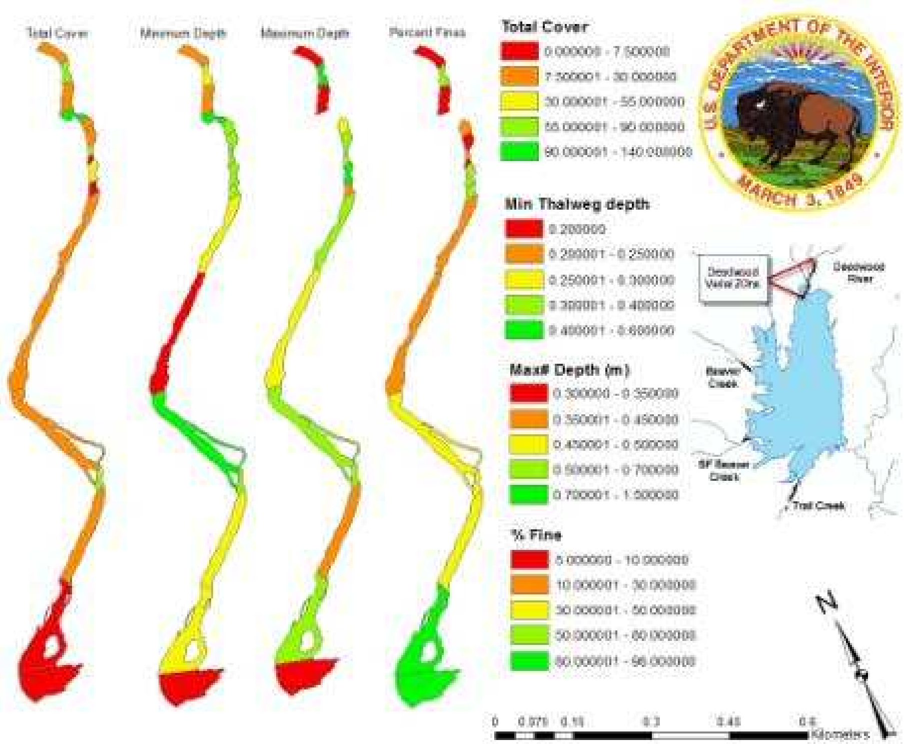

Figure 2.2. Comparison of selected habitat variables among the different habitat units in the Deadwood River varial zone. Data collected in 2011.

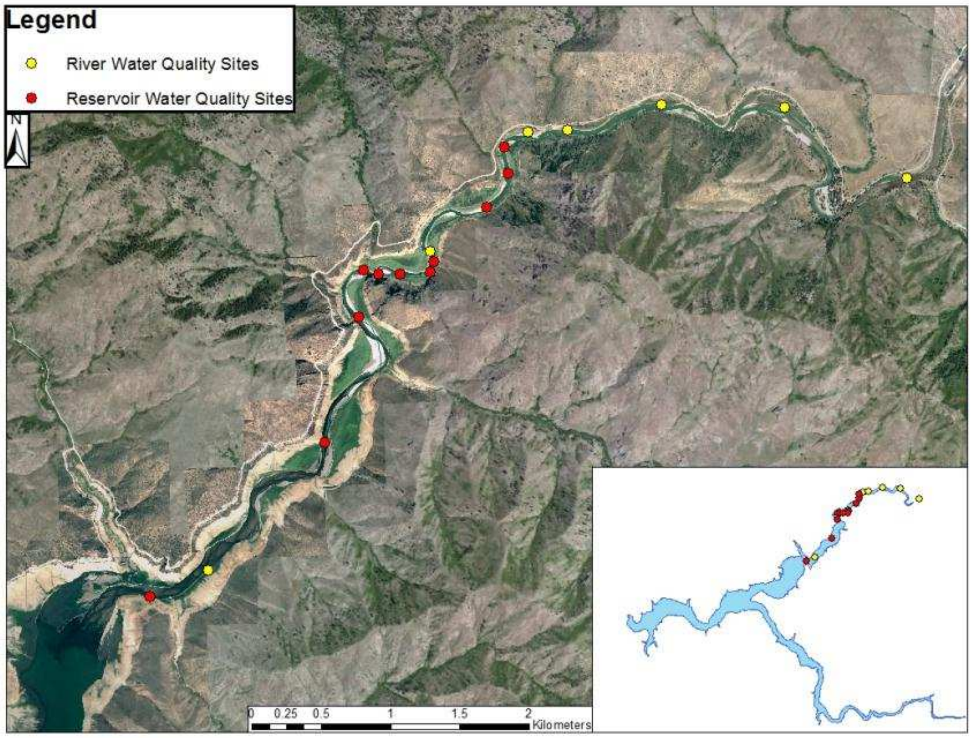

Figure 2.3. Map of water quality sites on Arrowrock Reservoir and the MFBR in 2014.

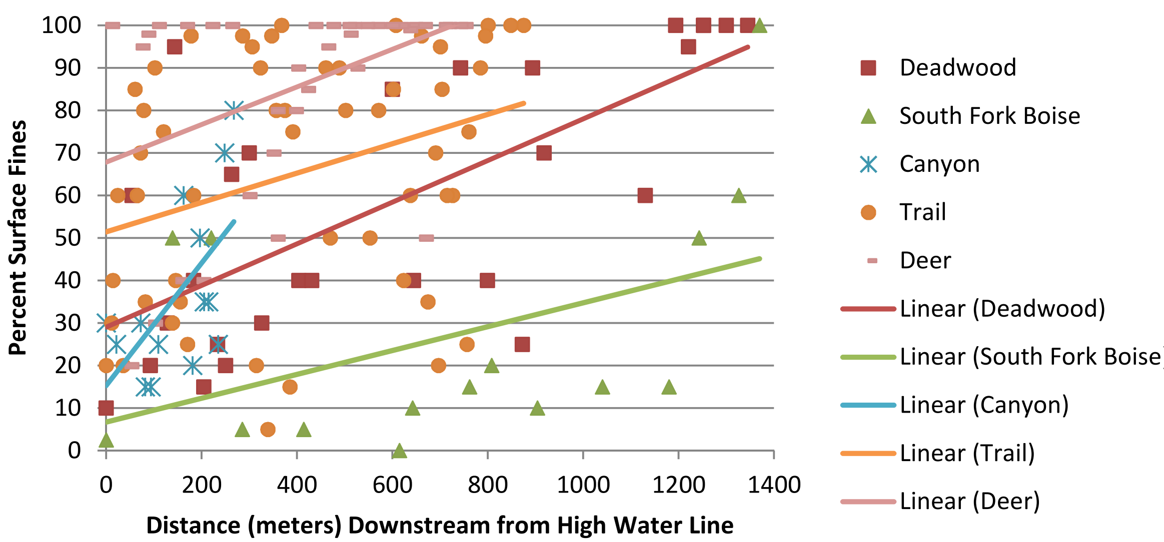

Figure 2.4. Within varial zone relationships between percent surface fines and distance downstream from the high water line at the from the five shorter varial zone surveys.

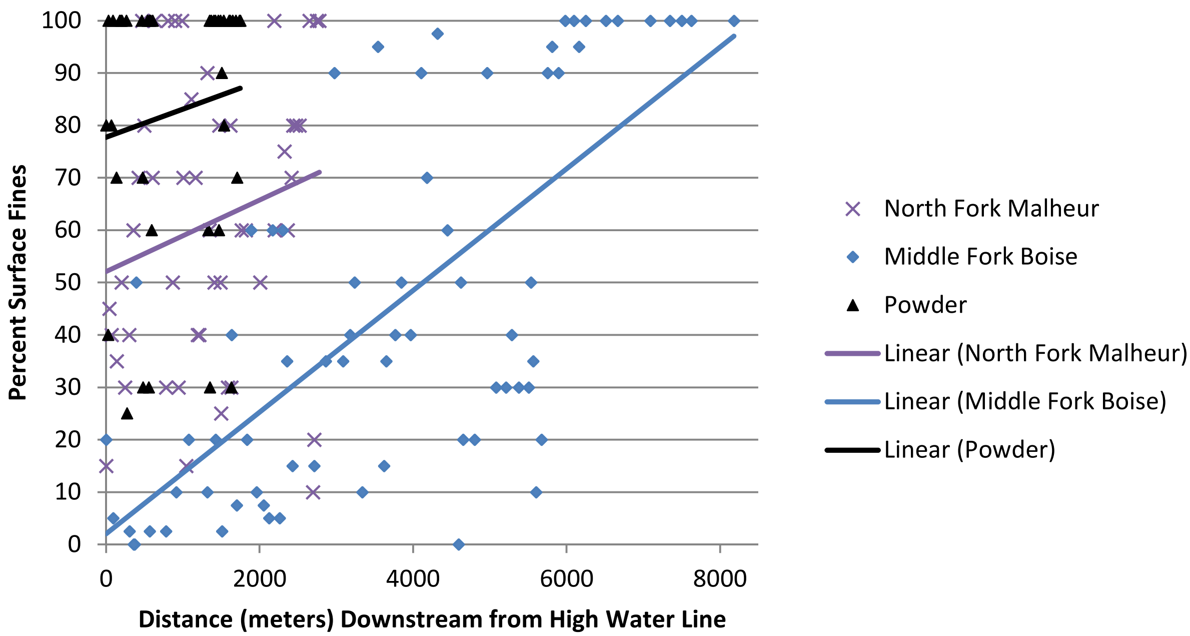

Figure 2.5. Within varial zone relationships between percent surface fines and distance downstream from the high water line at the from the three longer varial zone surveys.

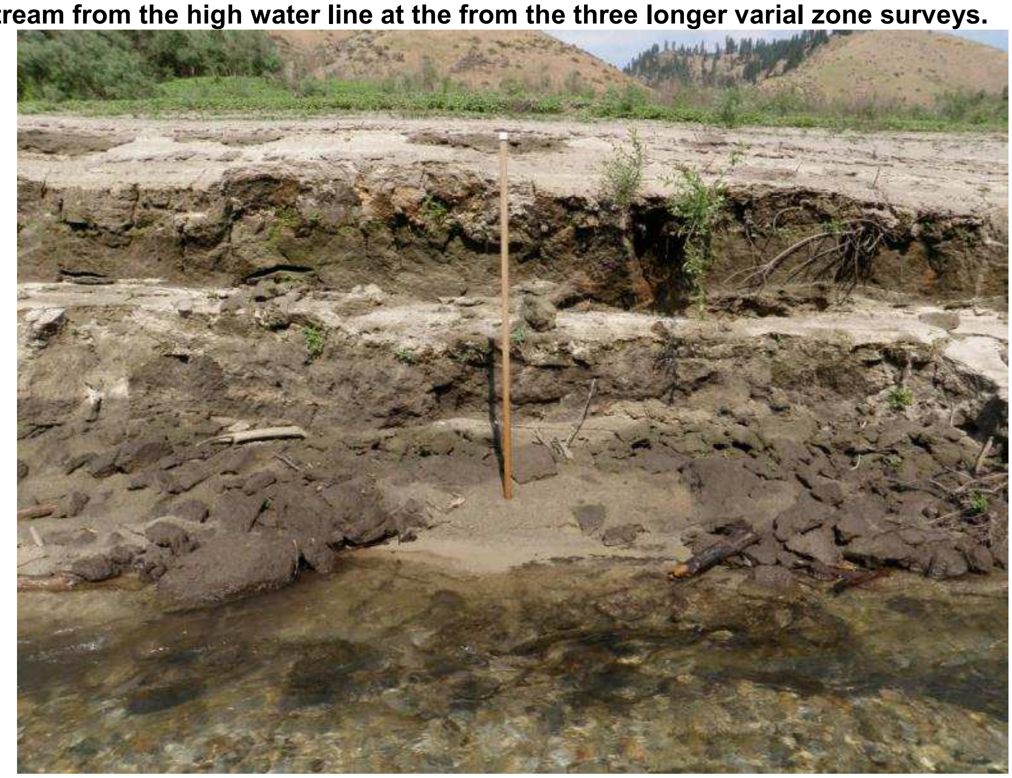

Figure 2.6. Example of unstable bank in the varial zone of the MFBR, Arrowrock Reservoir. Other sections of bank were actively sloughing off, but unsafe to photograph. A 2 m long stadia rod is in center of the photo for scale.

Figure 2.7. Relatively short and narrow delta in the varial zone of Trail Creek, Deadwood Reservoir. This photo was taken at a relatively high water level (1622.4 m asl) on August 8, 2014.

Figure 2.8. Relatively long and wide delta in the varial zone of Trail Creek Deadwood Reservoir. This photo was taken at a relatively low water level (1616.4 m asl) on August 21, 2013.

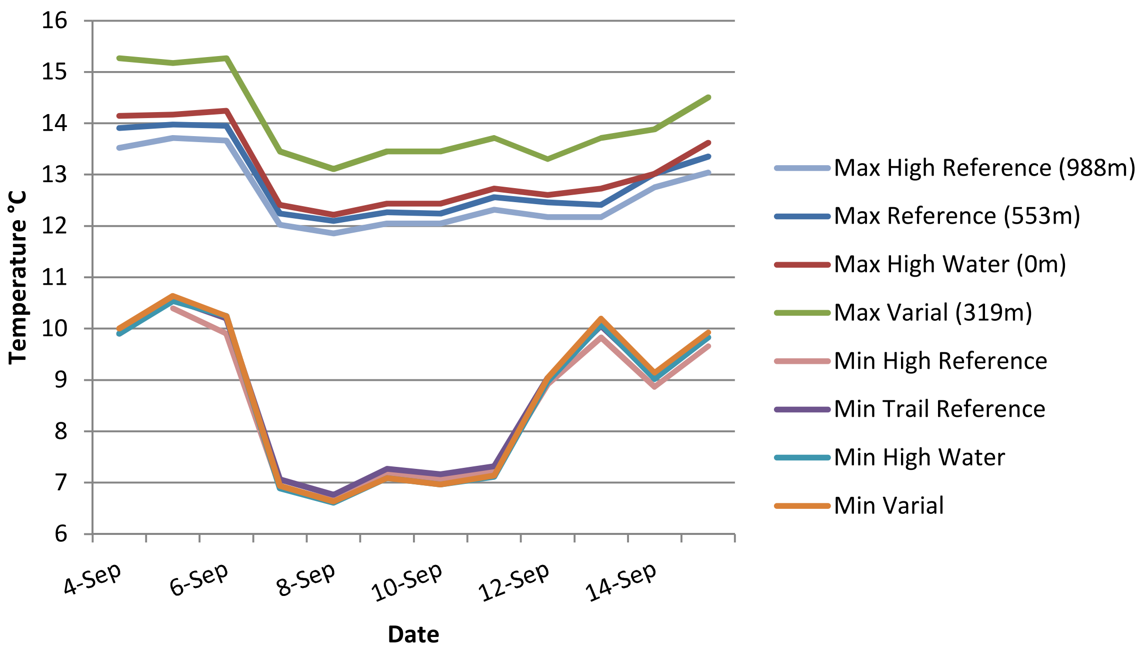

Figure 2.9. Maximum daily temperature increases as water travels downstream within the reference and varial zones of Trail Creek.

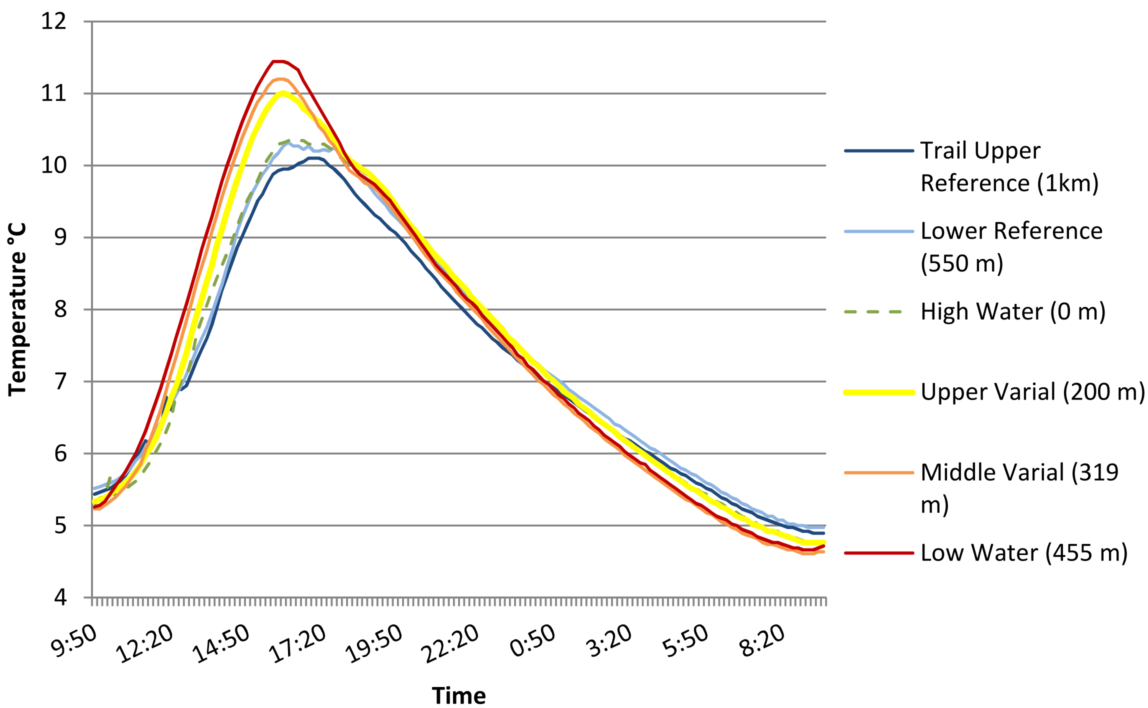

Figure 2.10. Temperatures within the reference and varial zones of Trail Creek September 9 to 10, 2014.

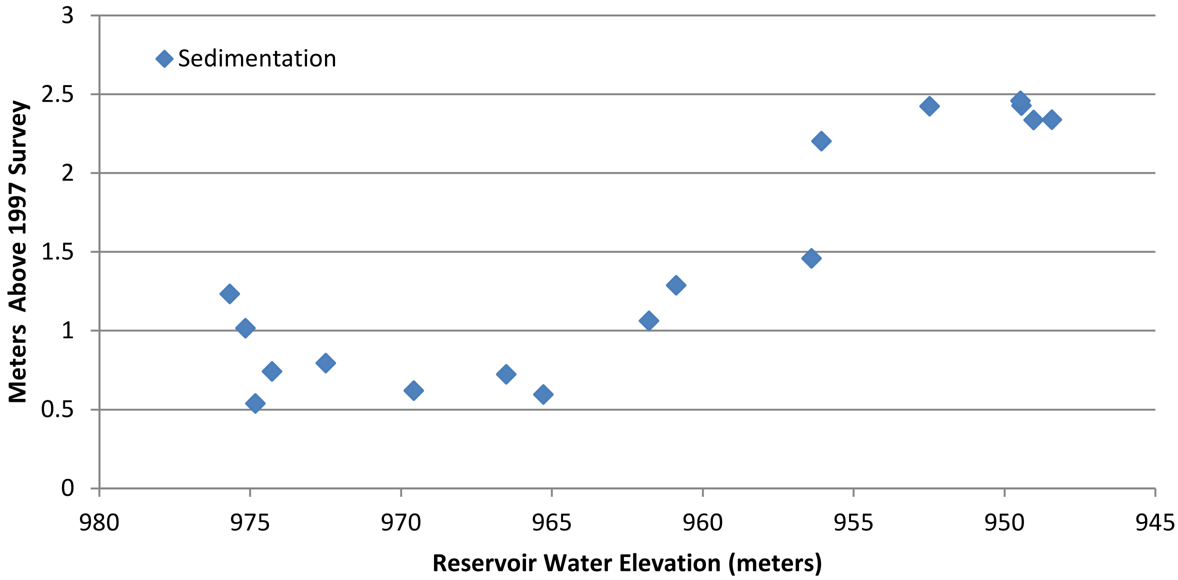

Figure 2.11. Increase in substrate elevation (sedimentation) between bathymetric survey completed in 1997 and surveys in 2013 at Arrowrock Reservoir.

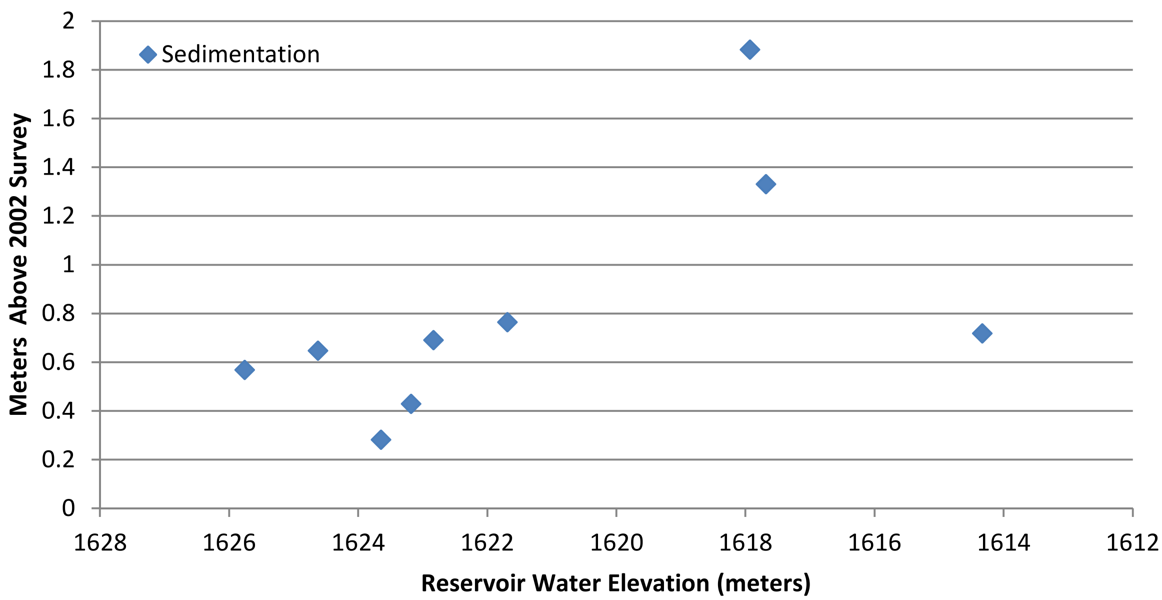

Figure 2.12. Increase in substrate elevation (sedimentation) between bathymetric survey completed in 2002 and surveys in 2013 at Deadwood Reservoir.

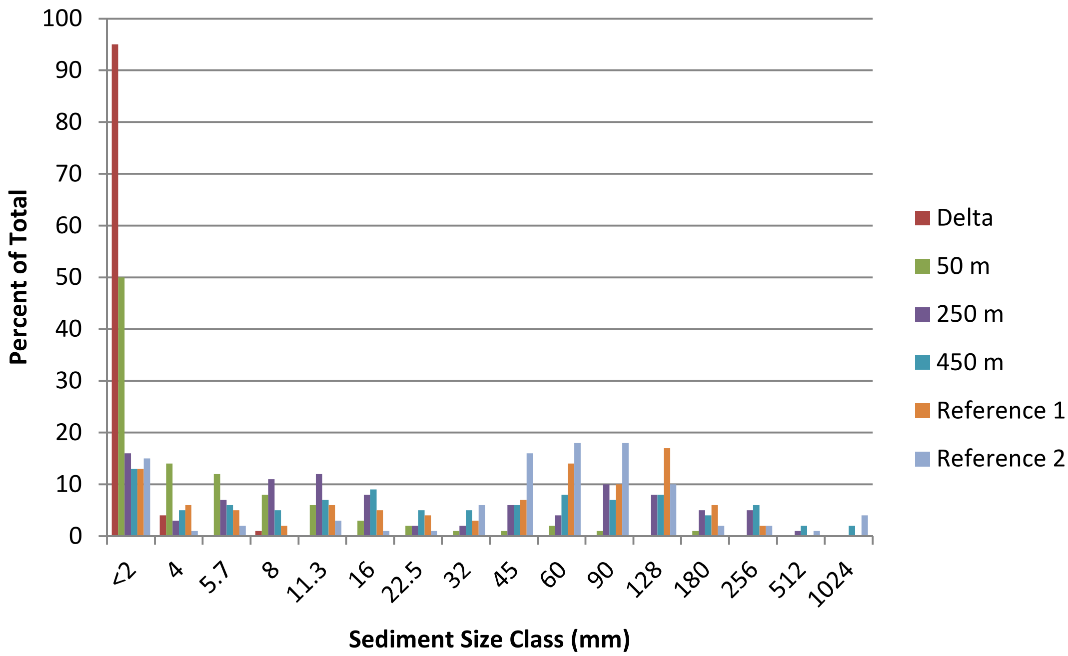

Figure 2.13. Wolman pebble counts from Trail Creek in 2011. Delta is for the delta habitat unit the next three series are listed as their distance upstream from the delta. All samples accept for those in the delta were taken in riffles. For reference, the total varial zone length during this survey was 530 m.

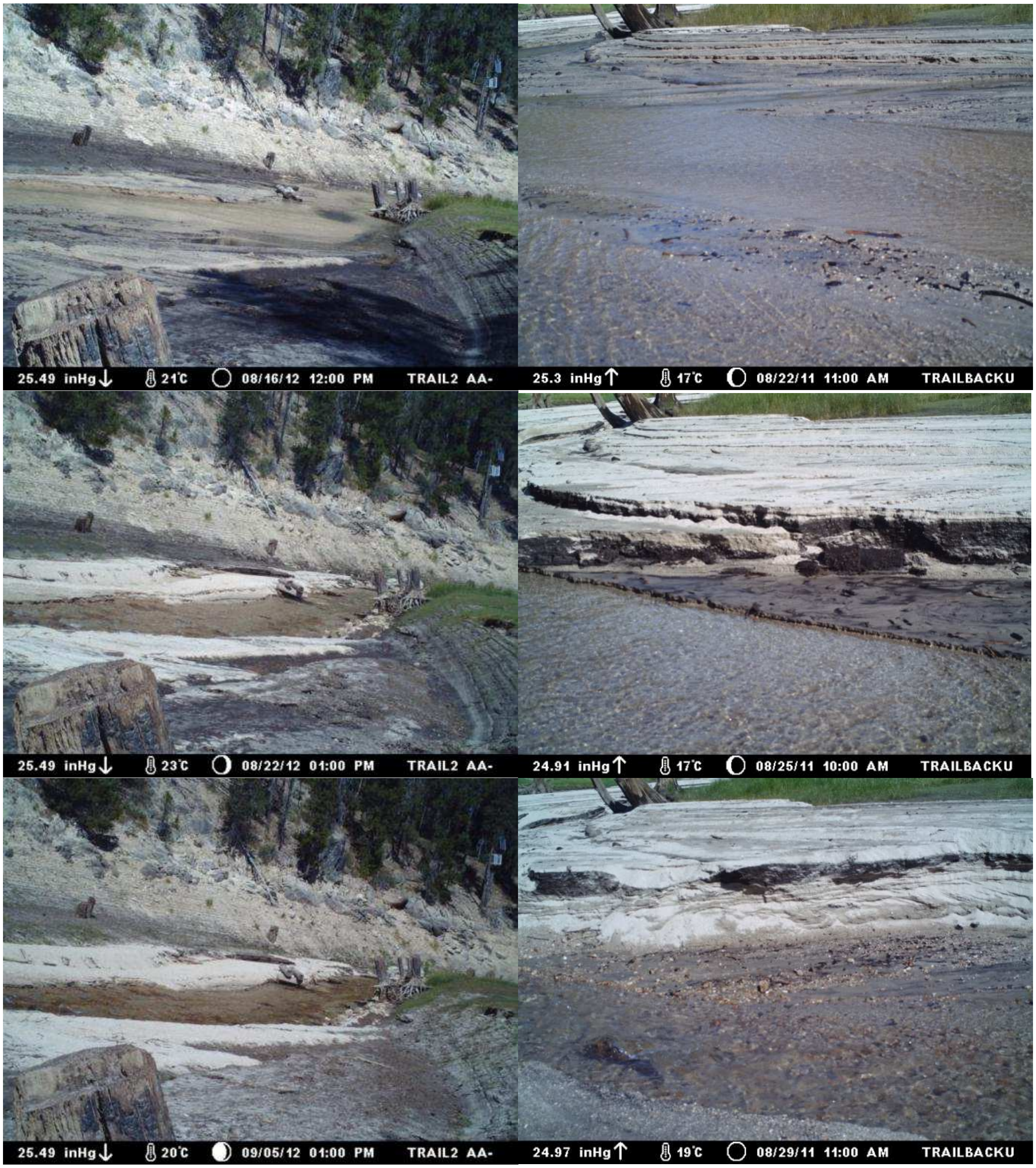

Figure 2.14. Changes in stream habitat over time as reservoir water level drops and fine sediment gets pushed further downstream into Trail Creek's varial zone at Deadwood Reservoir.

Figure 2.15. Turbid water in the delta of the MFBR, before Arrowrock Reservoir started re-filling. Photo taken on July 26, 2013.

Figure 2.16. Delta of the MFBR after Arrowrock Reservoir started re-filling. Turbidity levels are lower than those in Figure 2.15 and the sandy substrate can be seen. Photo taken on September 9, 2013.

Figure 2.17. River right channel split of Deer Creek going dry before reaching the Phillips Reservoir in 2012.

Figure 2.18. Multiple braided channels of the river right channel of Canyon Creek, Sherburne Reservoir in 2013. Three splits in the channel existed upstream of this location.

Figure 2.19. Relatively short and narrow delta in the varial zone of the MFBR Arrowrock Reservoir. This photo was taken at a relatively high water level (966.7 m asl) on July 31, 2012.

Figure 2.20. Relatively long and wide delta in the varial zone of the MFBR, Arrowrock Reservoir. This photo was taken at a relatively low water level (948.4 m asl) on August 7, 2013.

Figure 2.21. Example of high velocity habitat in the varial zone of the North Fork Malheur River, Beulah Reservoir.

Figure 2.22. Example of slow velocity habitat in the varial zone of the Powder River, Phillips Reservoir.

Tables

Table 2.1. General basin characteristics for each of the eight study tributaries.

Reservoir	Tributary	Mean Annual Precipitation (cm)	Maximum Elevation (meters)	Percent Forest Cover	Drainage area size (km^2)
Beulah	Malheur	155	2444	53	885
Deadwood	Trail	223	2505	75	25
Phillips	Powder	167	2576	79	189
Deadwood	Deadwood	221	2697	68	166
Phillips	Deer	178	2765	78	87
Sherburne	Canyon	477	3039	42	20
Anderson	SFB	223	3170	51	1664
Arrowrock	MFB	209	3231	50	2174

Table 2.2. Reservoir and varial zone characteristics for each of the eight study tributaries.

Reservoir	Tributary	Maximum Reservoir Elevation Fluctuation (m)	Reservoir Age (years)	Maximum Reservoir Volume	Reservoir Elevation (m)	Maximum Varial Zone Length (m)	Surveyed Length (m)
Beulah	Malheur	24	80	73	1,019	5,750	3,299
Deadwood	Trail	14	86	62	1,628	1,225	911
Phillips	Powder	23	47	91	1,238	4,450	2,473
Deadwood	Deadwood	14	86	62	1,628	2,300	1,564
Phillips	Deer	23	47	91	1,238	3,400	1,300
Sherburne	Canyon	30	94	80	1,459	3,950	268
Anderson	South Fork Boise	36	65	585	1,279	7,550	1,479
Arrowrock	Middle Fork Boise	38	100	335	980	9,850	6,427

Figure 2.3. Means and uncorrected p-values (Wilcoxon ranked sum test) for differences between reference and varial zones for cover, substrate and velocity variables. P-values <0.01 are highlighted in dark grey. P-values between 0.01 and 0.05 are highlighted in light grey. P-values that would not be significant (p<0.05) after False Discovery Rate correction for multiple comparisons are in bold and underlined. Means are in bold for the zone with the higher value.

P<0.05	P<0.01			Percent Cover							Substrate					Velocity
Reservoir	Tributary	Reach	Test	Total Cover	Boulder	Vegetation	Slow Depth	Under cut Bank	Large Woody Debris	Depth	Embeddedness Maximum	Embeddedness Mean	Embeddedness Minimum	Percent Fine <8mm	Bank Stability	Mean
Combined	Combined	Varial vs Ref	P-value	<.0001	<.0001	<.0001	0.0011	<.0001	0.0175	0.0816	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
		Reference	Mean	**56.59**	**15.12**	**6.95**	**20.79**	**9.16**	**3.60**	**28.92**	73.76	46.27	19.24	33.61	**76.65**	0.30
		Varial	Mean	34.26	8.38	1.16	11.83	0.04	1.30	23.12	**83.35**	**60.30**	**37.70**	**60.49**	19.05	**0.42**
Deadwood	Trail	Varial vs Ref	P-value	<.0001	0.0047	<.0001	0.0028	<.0001	0.0002	0.0028	0.0130	0.0144	0.0964	0.0032	<.0001	<.0001
		Reference	Mean	**53.33**	**16.57**	**14.54**	**8.80**	**23.85**	**13.15**	**9.07**	76.25	42.00	13.60	43.65	**86.35**	0.29
		Varial	Mean	19.41	11.78	2.76	1.05	0.00	3.55	1.32	**86.84**	**61.95**	**33.95**	**66.58**	10.86	**0.46**
	Deadwood	Varial vs Ref	P-value	0.0029	0.0011	<.0001	0.1758	0.0001	**0.0321**	0.1715	**0.0315**	0.0024	0.0003	0.0067	0.0001	0.5180
		Reference	Mean	**56.00**	**26.50**	**5.75**	**15.50**	**5.25**	**3.25**	**20.50**	68.00	34.50	0.00	28.50	**86.00**	0.38
		Varial	Mean	22.59	8.84	0.36	10.54	0.18	1.07	12.32	**85.71**	**60.71**	**41.07**	**59.11**	35.71	**0.42**
Beulah	Malheur	Varial vs Ref	P-value	0.0007	<.0001	<.0001	0.0092	<.0001	0.5052	0.3998	0.0630	0.0088	0.0058	0.0000	0.0000	0.0005
		Reference	Mean	**51.70**	**19.55**	**5.18**	**17.32**	**5.89**	**0.80**	**26.16**	71.43	41.61	10.36	26.70	**59.02**	0.41
		Varial	Mean	26.11	2.79	1.88	5.96	0.00	0.67	20.77	**80.20**	**56.96**	**33.73**	**62.06**	0.19	**0.57**
Phillips	Powder	Varial vs Ref	P-value	0.0003	0.0023	<.0001	0.1760	<.0001	0.3942	0.1760	<.0001	0.0090	0.0586	<.0001	<.0001	0.1943
		Reference	Mean	**31.77**	**3.47**	**6.94**	**21.37**	**7.98**	0.00	**21.37**	88.39	67.74	48.39	48.31	**75.97**	0.04
		Varial	Mean	12.19	1.69	0.00	10.38	0.00	**0.13**	10.38	**98.50**	**82.75**	**68.00**	**82.63**	1.25	**0.09**
	Deer	Varial vs Ref	P-value	<.0001	0.1610	<.0001	0.6109	1.0000	<.0001	0.4896	<.0001	0.0107	0.1541	<.0001	0.1541	
		Reference	Mean	**18.41**	**3.86**	**6.14**	**8.18**	0.00	**0.23**	**8.18**	90.91	59.09	36.36	34.09	**28.64**	
		Varial	Mean	9.32	0.68	1.59	6.93	0.00	0.11	6.93	**97.95**	**87.50**	**76.82**	**87.39**	2.50	
Arrowrock	Middle Fork Boise River	Varial vs Ref	P-value	**0.0262**	**0.0420**	0.0009	**0.0197**	0.5345	0.8382	0.0958	0.0031	**0.0171**	0.0065	<.0001	<.0001	0.2546
		Reference	Mean	**98.25**	**18.50**	**1.22**	**39.79**	**0.21**	1.00	**67.71**	57.50	33.33	5.83	13.96	**83.40**	0.39
		Varial	Mean	72.50	15.80	0.39	24.86	0.04	**1.12**	54.11	**74.00**	**50.09**	**27.45**	**43.86**	47.86	**0.46**
Sherburne	Canyon	Varial vs Ref	P-value	0.0006	<.0001	0.2177	0.3994	0.7803	0.1429	0.2084	0.0069	<.0001	0.0003	0.9137	0.8768	0.0098
		Reference	Mean	**49.41**	**32.65**	**10.44**	**0.88**	**5.88**	**1.76**	**3.68**	64.12	34.41	0.00	11.91	2.06	1.34
		Varial	Mean	20.00	10.54	8.57	0.00	0.54	0.89	0.00	**89.29**	**48.57**	**4.29**	**36.79**	**3.21**	**2.35**
Anderson	South Fork Boise River	Varial vs Ref	P-value	0.4534	0.2629	0.5288	0.4451	**0.0306**	0.6830	0.8490	**0.0308**	0.2629	0.0709	0.4148	0.4465	
		Reference	Mean	55.00	**23.50**	5.50	22.00	**2.25**	**2.00**	24.00	58.00	27.50	0.00	14.50	**89.00**	
		Varial	Mean	**62.83**	9.67	**7.50**	**29.67**	0.00	1.67	**44.00**	**65.00**	**37.00**	**8.00**	**27.17**	71.33	

Table 2.4. Means and uncorrected p-values (Wilcoxon ranked sum test) for differences between reference and varial zones for substrate, velocity and gradient variables. *P*-values <0.01 are highlighted in dark grey. *P*-values between 0.01 and 0.05 are highlighted in light grey. *P*-values that would not be significant (*P* <0.05) after False Discovery Rate correction for multiple comparisons are in bold and underlined. Means are in bold for the zone with the higher value.

P<0.05	P<0.01			Depth					Habitat Unit Size			
Reservoir	Tributary	Reach	Test	Maximum	Mean	Minimum	Pocket Pools/m	Pocket Pool Depth	Length	Width	Area	Gradient
Combined	Combined	Varial vs Ref	P-value	0.2213	0.3381	0.1695	**0.0332**	0.8931	0.1379	0.5112	0.5135	0.9073
		Reference	Mean	0.68	**0.26**	0.30	**0.02**	**0.73**	49.28	16.67	**1178.16**	**1.11**
		Varial	Mean	**0.70**	0.24	**0.32**	0.01	0.73	**56.29**	**18.00**	1094.65	0.96
Deadwood	Trail	Varial vs Ref	P-value	0.0003	0.2674	0.4410	0.5454	0.0328	0.4388	0.0114	0.8068	0.9095
		Reference	Mean	**0.48**	**0.14**	**0.19**	**0.06**	**0.91**	12.02	**4.92**	61.22	**1.92**
		Varial	Mean	0.33	0.12	0.18	0.04	0.51	**16.19**	4.37	**108.47**	1.44
	Deadwood	Varial vs Ref	P-value	0.0661	0.2012	0.1278	0.0559	0.6286	0.4556	0.4555	0.4040	0.0592
		Reference	Mean	**0.58**	**0.23**	0.25	**0.01**	0.48	43.45	49.55	634.60	**1.85**
		Varial	Mean	0.56	0.21	**0.27**	0.00	**0.60**	**55.86**	**51.77**	**962.25**	1.00
Beulah	Malheur	Varial vs Ref	P-value	0.9595	0.9795	0.0881	0.1032	0.4754	0.5450	<.0001	0.1099	0.9590
		Reference	Mean	0.66	**0.24**	0.33	**0.01**	0.66	45.05	**13.59**	622.65	**1.02**
		Varial	Mean	**0.67**	0.24	**0.37**	0.00	**0.72**	**64.18**	8.95	**634.38**	0.98
Phillips	Powder	Varial vs Ref	P-value	0.1446	0.1619	0.0570	0.4057	1.0000	0.6221	**0.0213**	0.8939	0.8600
		Reference	Mean	**0.52**	**0.25**	**0.10**	**0.01**	0.35	25.40	**5.74**	**193.37**	0.39
		Varial	Mean	0.33	0.10	0.08	0.00	**0.40**	**26.84**	4.17	168.00	**0.41**
	Deer	Varial vs Ref	P-value	0.0506	<.0001	**0.0397**	0.0507	0.0005	0.7442	0.1995	0.2023	
		Reference	Mean	**0.39**	**0.15**	**0.10**	**0.02**	**0.31**	26.45	4.09	109.90	
		Varial	Mean	0.22	0.10	0.06	0.00	0.30	**29.55**	**5.31**	**149.06**	
Arrowrock	Middle Fork Boise River	Varial vs Ref	P-value	0.5879	0.0643	0.3154	0.5499	0.0620	0.5350	0.3743	0.3432	0.7801
		Reference	Mean	1.17	0.41	**0.63**	**0.00**	0.94	**126.21**	33.22	4445.21	0.98
		Varial	Mean	**1.31**	**0.50**	0.59	0.00	**1.28**	123.24	**34.35**	**5481.39**	**1.09**
Sherburne	Canyon	Varial vs Ref	P-value	0.0084	0.7148	0.0007	0.9628	0.8495	0.3561	0.7506	0.5179	0.9784
		Reference	Mean	**0.36**	**0.59**	**0.20**	**0.00**	0.30	**23.16**	4.82	**117.17**	**2.35**
		Varial	Mean	0.26	0.45	0.18	0.00	0.30	21.14	**4.91**	113.67	1.71
Anderson	South Fork Boise River	Varial vs Ref	P-value	0.8213	0.4526	0.5231	**0.0192**	0.2027	0.7815	0.5235	0.6830	
		Reference	Mean	**1.01**	**0.55**	0.42	0.00	**0.90**	**99.60**	33.74	3327.56	
		Varial	Mean	0.97	0.55	**0.53**	**0.01**	0.82	98.60	**34.45**	**3355.07**	

Table 2.5. Length of sandy delta area in Trail Creek, Deadwood Reservoir at various reservoir elevations and inflows.

Date	100% fine Length (m)	Reservoir elevation (m asl)	Calculated inflow (m^3)
July 10, 2013	9.1	1,623.4	3.68
August 8, 2012	34	1,622.5	3.65
September 8, 2011	37	1,618.2	2.94
August 30, 2012	104.5	1,618.5	2.08
September 6, 2013	113	1,614.2	2.20
September 4, 2013	115.9	1,614.2	1.94

CHAPTER 3: HABITAT CHARACTERISTICS AND BULL TROUT *SALVELINUS CONFLUENTUS* ECOLOGY ASSOCIATED WITH FLUCTUATING RESERVOIR WATER LEVELS IN TWO IDAHO RESERVOIRS.

Abstract

Fluctuating reservoir water levels create varial zones that tributaries must flow through to get to the reservoir pool during low water levels. This study investigated how habitat alterations associated with fluctuating water levels impacted timing and speed of bull trout migrating through varial and reference zones of two Idaho tributaries; Trail Creek (Deadwood Reservoir) and the Middle Fork Boise River (MFBR; Arrowrock Reservoir). Bull trout movements were tracked using remote radio telemetry stations from 2011-2013 to investigate fish speeds and migration timing. Data from ground and aerial tracking conducted by the Bureau of Reclamation at Deadwood Reservoir (2006-2008) as well as remote station data from Arrowrock Reservoir (2002 downstream migrations and 2003 upstream migrations) were also used in analysis of migration timing. Dates of individual upstream migrations into Trail Creek varied (107 day range; June 9 to September 24). The mean date fish left the Deadwood Reservoir (on their first migration of the year) varied up to 53 days among six years of available data (2006-2008, 2011-2013). Inter-annual variation in physical parameters in Trail Creek (water temperature, calculated reservoir inflows and reservoir elevations) were significantly correlated to differences in mean migration dates. Mean dates when fish left Arrowrock Reservoir varied by 34 days, from April 20 to May 24 among three years of available data (2003, 2012-2013). Dates of individual upstream migrations on the MFBR varied (156 day range; February 2 to July 8) much more than dates for downstream migration (54 day range; September

13 to November 6). Upstream migration of fish from Arrowrock Reservoir occurred at a wide range of reservoir elevations both on the ascending and descending limbs of the hydrograph. Where temperature information was available, bull trout initiated migrations at a wide range in river temperatures, but always before temperatures exceeded 18.6°C. Bull trout migrating into tributaries and back to the reservoir multiple times within the same year was documented at both reservoirs. Downstream migration speeds in Trail Creek were significantly higher through the varial zone than through the reference zone. Downstream migration speeds through the Trail Creek varial zone also varied between reaches with some bull trout being documented with their backs out of the water as they traversed the shallow delta. Mean downstream migration speeds in both varial and reference zones were significantly higher on the MFBR than Trail Creek. In 2012 at least four of 22 (18%) and in 2013 at least four of 19 (21%) bull trout died, expelled their tag or were eaten by predators during migrations through the varial zone of Trail Creek. This ranged from 33 to 50% of the total mortality, tag expulsion or tag failure that occurred during the entire spawning migration distance and time frame. Habitat alterations caused by fluctuating reservoir water levels have impacted bull trout travel speeds and probably the timing of the migrations.

Introduction

The bull trout (*Salvelinus confluentus)* is a species of charr (Family Salmonidae) native to the cooler regions of Western North America. Its range extends from northern Nevada, north to the Yukon and from coastal Washington and Oregon east to Glacier National Park in Montana (Cavender 1978; Bond et al. 1992;

USFWS 2010a). In the Continental United States, this cold-tolerant, glacial relict species is near the southern geographical edge of its habitat suitability (Haas and McPhail 1991).

The bull trout displays a wide diversity of life histories, including resident, fluvial, adfluvial and anadromous forms. Whereas resident forms remain in tributaries throughout their lives, the other forms typically rear for some period in the tributaries and then migrate down into larger flowing waters (fluvial form; Hogen and Scarnecchia 2006), into lakes or reservoirs (adfluvial form; Watry and Scarnecchia 2008), or into the ocean (anadromous form; Brenkman and Corbett 2005) to grow and mature before migrating back into tributaries to spawn in fall. The lake and reservoir habitats that adfluvial bull trout, a common form, rear and overwinter in have abundant food resources that allow adults to reach larger sizes than resident bull trout (McPhail and Baxter 1996). The larger body size of adfluvial adults enables them to have a higher fecundity and produce more offspring than resident forms. The depth available in lentic environments also provides cover from predators (Power and Kerfoot 1987; Randle and Chapman 2004).

Most of the lentic habitat available for adfluvial bull trout in the continental United States is in water regulated by dams (84% of lentic surface area listed as critical habitat; USFWS 2010a). Some effects of dams on bull trout and other salmonids are well documented, including blockage of upstream spawning migrations (Rieman and McIntyre 1993; McPhail and Baxter 1996; USFWS 2002; Underwood and Cramer 2007) as well as altered flows and temperatures regimes below dams (Annear et al. 2002). Other impacts are less well studied. Although the physical aspects of geomorphological change and delta formation where tributaries run through the dewatered portion of reservoirs (hereafter called varial zones) have been documented since the 1950's (Harrison 1952; Mahmood 1987; Graf 1988; Fan and Morris 1992; BOR 2006), the ecological effects of these varial zones are still not well understood (Kline 2006; Salow and Hostettler 2004; IDFG 2007; Prisciandaro and Harbison 2007; Teuscher 2009).

Migration timing of bull trout has been investigated in multiple studies, but most studies have been short in duration (1-2 years; Dare 2006) and have not encompassed the range of inter-annual variability in climactic conditions as they affect water temperature, flow volume and timing of peak flows. Differences in timing of both upstream and downstream migration of adfluvial bull trout varies greatly across populations. Upstream migrations of bull trout have been documented to begin as early as February (Dare 2006) to as late as October (Brenkman et al. 2001) while downstream migrations have ranged from late August (Swanberg 1997) to late December (Brenkman et al. 2001). Although the influence of inter-annual variation in environmental variables on downstream migration has been investigated in some detail (Dare, 2006; Monnot et al. 2008), less is understood about their influence on upstream migration timing. Some literature suggests upstream migration is cued on the descending limb of the hydrograph (Swanberg 1997). However, more recent research has shown upstream migrations begin on all stages of the hydrograph (Brenkman et al. 2001; Salow and Hostettler 2004). Water temperatures are also thought to cue upstream migration; however, this influence may be in a rate of temperature increase rather than a specific temperature threshold (Swanberg 1997).

More multi-year studies are needed to assess the influence of inter-annual environmental variability and the potential impacts of climate change on migrations.

The role of the varial zone in bull trout life history and survival can be complex. The length of the varial zone in each reservoir changes with fluctuating reservoir water levels both within and between years. Sedimentation combined with frequently changing water levels affect many physical and biological habitat attributes in these zones (Chapter 2). Habitat within the reservoir pool at the mouths of tributaries where bull trout stage to spawn are also affected by altered temperature regimes, sedimentation and water level fluctuations (Chapter 2).

Many habitat variables, including shallow water depths (Auble et al. 2009), high water temperatures (Naughton et al. 2005; Clabough et al. 2008; Caudill et al. 2013), high turbidity levels (Bjornn and Reiser 1991) and high velocities (Hinch and Bratty 2000) similar to conditions documented in varial zones (Chapter 2) may impede fish migrations. With numerous altered habitat features caused by fluctuating water levels, it is necessary to identify the specific habitat alterations leading to effects on bull trout in particular situations. Monitoring use, travel speeds and mortalities of individual fish along with the physical habitat variables (Chapter 2) they encounter allows for identification of impacts to fish in areas of reservoirs affected by water level fluctuations.

Physical habitat differences between the reference and varial zones are not the only aspects of fluctuating reservoir water levels that may impact migrating adfluvial fish. The habitat just downstream of the tributary in reservoirs is typically used as a staging area for adfluvial fish prior to their spawning migration. The physical structure as well as temperature regime of this critical staging area is impacted by fluctuating reservoir water levels. Outside of reservoir operations, negative impacts to fish may result from fish being scared away from these critical staging areas by angling, boating and other human activities. Knowledge of the relationships between aquatic habitat characteristics, fish migration timing and travels speeds as well as barriers to migration is important in understanding the cascading ecological impacts of fluctuating reservoir water levels.

The objective of this chapter is to identify habitat characteristics associated with fluctuating water levels that impact migration timing and speed of bull trout in two Idaho reservoirs. My hypotheses were that

1. Migration timing will be impacted by habitat conditions that change as reservoir water levels decrease, including temperature and available cover.
2. Bull trout travel speeds will be slower in varial zones than in reference zones.

Methods

The study was conducted at Deadwood and Arrowrock reservoirs, two U. S. Bureau of Reclamation (BOR) reservoirs in southern Idaho. In Deadwood Reservoir, bull trout were captured at the mouth of Trail Creek, an inflowing stream, using fyke nets. The fyke nets measured 1.22 m x 1.22 m x 0.91 m and had 4 fykes per net and 30.48 m x 1.22 m lead lines. At Arrowrock Reservoir, bull trout were captured at temporary picket weirs on the North and Middle Forks of the Boise River, upstream of

Arrowrock Reservoir, during their downstream migration from spawning as well as in multiple size gill nets throughout the reservoir.

Radio telemetry was used for assessing speeds and timing of movements through the varial and reference zones. Bull trout to be radio-tagged were anesthetized using an electronarcosis unit (Hudson et al. 2011) measured for total length to the nearest mm and weighed to the nearest g. Lotek radio tags (models SR-TP11-25, SR-TP16-25, MCFT-3A, MST-930, NTC6-2 and NTC6-1) were inserted into the body cavity, following the shielded needle technique outlined in Ross and Kleiner (1982). To limit overlapping signals multiple frequencies (11 at Deadwood and 9 at Arrowrock) as well as multiple burst rates (4.5, 5 and 5.5 seconds) were used. All radio tags were uniquely identifiable by the frequency and tag code. The SR-TP11-25 and SR-TP16-25 series radio tags also relayed temperature and pressure (depth) measurements of the tag back to the receivers. Tags ranged from 2.8 to 16g and in no case exceeded a 4% tag weight to fish weight ratio. After tag implantation fish were immediately released close to their capture location. The 75 fish at Deadwood Reservoir implanted with radio tags between 2006 and 2013 ranged in length from 230 to 585 mm fork length and in weight from 219 to 2190 g. The 155 fish from Arrowrock Reservoir implanted with radio tags between 2010 and 2013 ranged in length from 192 to 770 mm fork length and in weight from 50 to 4,550 grams.

In all, seven remote radio telemetry stations were used to track the fish from 2011-2013. Of the three remote radio telemetry stations in Trail Creek at Deadwood Reservoir, one covered the entire varial zone, a second, more precise, small scale one (smaller antennas with shorter detection ranges) covered the upper section of the varial zone, and a third station monitored fish movements in the reference zone above the varial zone. The length of the varial zone of the MFBR on Arrowrock Reservoir required three separate stations in the varial zone that did not overlap, and one additional station in the reference zone. Technical difficulties in 2011 at all MFBR remote stations caused receiver outages. Fish speeds (when available) from 2011 were used in analysis in this paper, however due to an incomplete dataset migration timing data from 2011 on the MFBR was not used.

Each remote station was operated with a Lotek SRX 600 receiver and had multiple (2 to 4) antennas set up to extend the detection range and determine directionality of movements. All remote stations except the small scale varial zone station at Deadwood used directional Yagi antennas. The small scale station used a combination of two (20 cm) whip antennas and two underwater antennas. The underwater antennas were constructed by exposing 20 cm of multi-stranded core from RG58-A/U coaxial cable as well as three cm of the braided sheath. The exposed cable (antenna) was secured to a wooden stake and installed within the wetted channel.

Each remote station was calibrated at multiple reservoir water levels and tributary flows by towing a radio tag in the water below a GPS (Trimble GeoExplorer Trimble Inc). The radio tag was set to a 5 second burst rate and the GPS collected a new point every 5 seconds. Each signal strength recorded at each antenna at a remote station was linked to the GPS position closest to the same time stamp. The smaller scale remote station within the detection range of the larger scale Trail Creek varial remote station as well as test tags left out for periods of time were used to identify any variability in signal strengths on both daily and seasonal time scales. All of the tags from Arrowrock Reservoir fish and 46 of the 75 tags from Deadwood Reservoir fish were equipped with temperature and depth sensors that were also used as an additional means to confirm timing of movement between the reservoir and tributary.

Migration timing was quantified as the date and time a fish left or returned to the reservoir pool, regardless of the reservoir elevation. Reservoir elevations, tributary inflows and tributary temperatures were compared to migration timing at the two reservoirs in each year. Additional migration timing data from these reservoirs was available from past BOR studies and used to add additional variation in water years to the data set. The past BOR studies used the same capture and tagging methods with the exception of using tricaine methanesulphonate to anesthetize the fish rather than an electronarcosis unit. Migration timing was obtained for the previous studies on the MFBR with an individual remote station upstream of Arrowrock Reservoir for downstream migration in 2002 and upstream migration in 2003. Migration timing for previous studies on Trail Creek were obtained from weekly tracking from a helicopter, boat and on foot from 2006-2008. Specific migration dates were estimated from tracking events as the average of the date each fish was last tracked in the reservoir and the date they were first tracked in Trail Creek or vise versa.

Fish speeds were calculated within the detection ranges of each remote station on Trail Creek based on multiple passes of the “test” tag and GPS (Figure 3.1). The increased water depth and wetted width of the MFBR caused higher variation in signal strengths between test tag runs. However, during multiple test tag runs on different sides of the river and different flows, the transition between upstream and downstream antennas at each remote station always occurred at the same cross section no matter what the associated signal strength was. This consistent occurrence allowed for fish locations to be determined at each remote station and fish speeds were calculated between stations. Using these methods, the varial zone of Trail Creek was separated to calculate fish speeds in five reaches and the reference zone into four. The MFBR had two varial zone reaches and one reference zone reach. Habitat data collected and described in Chapter 2 was split into the same reach breaks for analysis with the fish speeds. Reaches were numbered from downstream to upstream in each zone with zones denoted by an V(varial) or R(reference) before the number to identify the zone. For example V1 is the most downstream reach and R4 is the most upstream reach in Trail Creek. To prevent pseudoreplication when calculating fish migration speeds, only one upstream migration and one downstream migration event was used for each fish.

The remote telemetry stations combined with ground tracking to recover tags allows for the time and location of tag loss events to be determined. Although tags recovered out of the water suggested mortality, perhaps from predation, more than tag expulsion, the cause of mortality was unknown. Outside of the detection range of the remote stations a combined mortality/tag loss/tag failure was estimated during the time spent in Trail Creek. This was done simply by comparing the number of fish that migrated upstream past the varial zone remote station to the number that subsequently migrated downstream past the varial zone remote station.

Stream flows (available 1911 to present) and water temperatures (available 1998 to present) from U.S. Geological Survey gauge station 13185000 were used to correlate environmental variables to fish movement on the MFBR. Calculated reservoir inflow available from BOR's Hydromet website (http://www.usbr.gov/pn/hydromet; available 1927-present) and water temperatures from an Onset Tidbit in Trail Creek just above the high water line (BOR unpublished data available June 2006-present) were used to correlate environmental variables to fish movement on Trail Creek.

To investigate relationships between migration timing and environmental variables as well as differences in fish migrations speeds within and between zones, all statistical analyses were conducted in R version 3.0.2 (R Core Team 2013). Relationships between migration timing and physical/hydrological parameters (calculated inflow, tributary water temperature and reservoir elevation) were investigated using linear regression of the ordinal dates for mean migration and each physical parameter. The physical parameters investigated for water temperature included, summer maximum, maximum temperature on June 1, the ordinal date temperatures exceeded each 12, 13, 14 and 15 °C as well as the ordinal date the 7 day average daily maximum first exceeded 13 °C. The physical parameters investigated for flow included; maximum, ordinal date of maximum, ordinal date flows decreased below 5.66 m^3/sec (200 cfs) as well as the maximum flow on June 1. The physical parameters investigated for reservoir elevation included; ordinal date full, minimum volume and the ordinal date the reservoir elevation decreased below the last riparian vegetation in the varial zone (1623 m). Speeds were compared between individual reaches, separately by up and downstream migration with a Wilcoxon ranked sum test. Overall differences among speeds in individual reaches were compared with Wilcoxon ranked sum tests. Variances of medians were compared with a Fligner-Killeen test. The Fisher's Exact test was used to determine significant differences between years in the proportion of fish that made multiple migrations. In all tests, $P < 0.05$ was required for significance.

Results

Migration Timing—

Deadwood Reservoir/Trail Creek- Radio tagged bull trout concentrated at the mouth of Trail Creek before their spawning migrations. Three bull trout that spent up to two weeks in this area were eventually documented migrating into a different tributary to spawn with little or no holding time at the mouth of that tributary. In July of 2013, 26 bull trout were counted near the mouth of Trail Creek within the first 25 m of the reservoir (Figure 3.2; Pers. Obs. July 10, 2013).

Data from Deadwood Reservoir during this study (2011-2013) as well as available unpublished data from BOR (2006-2008) encompassed a wide range of migration dates and water year conditions (Table 3.1). Dates of individual upstream migrations varied widely (107 day range; June 9 to September 24). The mean date fish left the reservoir (on their first migration of the year) varied up to 53 days (July 2 to August 24) among years. The earliest documented upstream migration in each year varied up to 68 days (June 9 to August 16) among years and the date of the last upstream migration varied up to 45 days (August 10 to September 24).

The water years with migration data (2006-2008, 2011-2013) also varied widely with daily average peak reservoir inflow ranging from 26 to 78.2 m^3/sec and maximum Trail Creek water temperatures ranging from 14.2 to 18.1 °C. The years with available migration timing data covered a wide range of natural variability. Over the past 45 years of record only two years had higher and eight years had lower maximum flows than the range migration timing data is available for.

Inter-annual variation in physical parameters (water temperature, calculated reservoir inflows and reservoir elevations) were significantly correlated to mean migration date (Table 3.2). Relationships (R^2) between mean migration date and the physical parameters investigated were strongest for the date temperatures first exceeded 12 °C each year, with fish migrating earlier the earlier temperatures exceeded 12 °C (R^2 =0.89; P =0.0051). The strongest relationship between mean migration date and flow was for the date flows dropped below 5.66 m^3/sec (200 cfs), with fish migrating earlier the earlier flows dropped below 5.66 m^3/sec (R^2 =0.69; P =0.040). The strongest relationship between mean migration date and reservoir elevations was for the date elevations dropped below the last riparian vegetation (1623 m), with fish migrating earlier the earlier reservoir elevations dropped below 1623 m (R^2 =0.87; P =0.0064).

Individual fish that were tracked during multiple years showed similar changes in migration dates in different environmental conditions. On their first migrations upstream in each year, all five fish that were tracked migrating in both 2012, a year of average water temperature (Table 3.1) and 2013, a year of above average water temperature (Table 3.1) migrated earlier in 2013 (mean 39 days, range 24-56 days;

Table 3.3). Similar patterns were seen for the three fish that migrated in both 2006, a year of average water temperatures) and 2007, a year of above average water temperatures); with all fish migrating earlier in 2007 (mean 49 days, range 46-58 days; Table 3.4).

Arrowrock Reservoir/MFBR - In contrast to Trail Creek, bull trout did not congregate to stage at the confluence between the MFBR and Arrowrock Reservoir before their spawning migrations. Fish did tend to spend a few days near the confluence of river and reservoir after their downstream migration in the fall.

Data from Arrowrock Reservoir during this study (2012-2013) as well as unpublished data from BOR (2002-2003) covered a wide range of migration dates and water year conditions. Mean dates when fish left the reservoir varied over the years 2003 and 2012-2013 by 34 days; from April 20 to May 24. Dates of individual upstream migrations varied widely (156 day range; February 2 to July 8), much more so than dates for downstream migration (54 day range; September 13 to November 6).

The water years with migration data also varied widely with daily average peak flows ranging from 99.4 to 354.0 m^3/sec and maximum MFBR water temperatures ranging from 23.9 to 25.8 °C. The years with available migration timing data covered a wide range of natural variability. Over the past 45 years of record, 2012 (a study year) had the highest flows and six years had lower maximum flows than the range migration timing data were available. The study years also contained the year with the highest maximum water temperatures in the river (2013) in the 14 years with available data since records began in 1998. Five of those 14 years however had lower maximum water temperatures than the study year with the lowest water temperatures (2012).

Upstream migration of fish from Arrowrock Reservoir occurred at a wide range of reservoir elevations both on the ascending and descending limbs of the hydrograph (Figures 3.3, 3.4). Where data is available, bull trout initiated upstream migrations at a wide range in river temperatures, but always before temparatures exceeded 18.6°C (Figures 3.3, 3.4). With only four years of migration timing data and the temperature logging station not being operational in one of the study years (2002) more specific relationships between migration timing and physical/hydrological parameters could not be discerned.

Bull trout in the MFBR migrated upstream earlier in the spring than those in Trail Creek with little overlap in any year. The early migration timing corresponded to higher Arrowrock Reservoir water levels and led to only five fish migrating while the upper reach of the varial zone was exposed and no fish migrating upstream while the lower reach was exposed. In both years of remote station operation during downstream migration (2012 and 2013) the delta of the MFBR was downstream of the lowest reach where speeds could be calculated. The lowest antenna covered this habitat and fish slowed down, but because of the width of the channel (up to 178 meters; Chapter 2) accurate speed calculations could not be obtained in the MFBR delta.

Multiple migrations – Bull trout migrating into tributaries and back to the reservoir multiple times within the same year were documented at both reservoirs. Multiple migrations were more prevalent at Trail Creek and overall more prevalent in years with lower flows and warmer water temperatures. In 2012, 4 of the 17 (23.5%) fish that migrated into Trail Creek migrated back to the reservoir and up into Trail Creek at least a second time. In 2013, 13 of the 19 (68.4%) fish tracked conducted multiple migrations into Trail Creek. The difference in proportions of fish making multiple migrations was significant between these two years (P =0.0096). One individual fish migrated up and back to the reservoir a total of five times in 2013. Maximum water temperatures in Trail Creek (recorded upstream of the varial zone) were 15.9°C in 2012 and 16.7°C in 2013, with a total of nine days in 2012 and 34 days in 2013 exceeding 15°C. Inflows to Deadwood Reservoir were lower in 2013 than 2012 and reservoir water elevations dropped more rapidly to a lower end of irrigation season level in 2013 than 2012 (Figure 3.5). In the MFBR there was one fish that was documented migrating in and out of the reservoir twice in 2013.

Fish speeds—

Trail Creek- . In Trail Creek, bull trout movement during daylight hours was mostly limited to the reference zones (Figures 3.6 and 3.7); on only seven occasions were bull trout tracked in any section of the varial zone during daylight hours. When fish did move during daylight hours movements were slower and shorter than during darkness. No bull trout initiated their upstream migration through the varial zone during daylight hours. Three downstream migrating fish were documented starting to enter the varial zone of Trail Creek during daylight, only to turn around and wait in the reference zone until dark before resuming their downstream migration. This initial daylight downstream migration into the varial zone was always limited to reaches V4 and V5. Therefore, speed estimates for fish in Trail Creek during daylight hours were not used in any further analysis.

Total time spent within the varial zone during individual upstream migration events ranged from 46 minutes to 22 hrs (mean 3hrs 52 min) whereas downstream migrations ranged from 18 minutes to 14 hrs (mean 2hrs 33 min). Maximum length of the varial zone during migrations was 553 m in 2011, 649 m in 2012 and 932 m in 2013. Upstream migration speeds were not significantly different between reference zones (median, 2.65 m/minute) and varial zones (median 2.05 m/minute; P =0.130). Downstream migration speeds, in contrast, were significantly higher in varial zones (median, 11.76 m/minute) than in reference zones (median, 7.08 m/minute; P = 0.0007). Variances in speed between reference and varial zones were not significantly different for upstream migration (reference, 4.5; varial 2.0; P =0.1848), but were significantly higher in the varial zone than in the reference zone for downstream migration (reference, 96.7; varial, 531.3; P < 0.0001).

More significant differences in migration speeds were found between reaches for downstream migration than for upstream migration (Figure 3.8 and 3.9). Downstream migrating fish speeds in V3 were significantly higher than all other varial and reference zone reaches (P <0.002). Downstream migration speeds in V2 were significantly higher than all other reaches with the exception of V3 and R3 (P <0.05). Although all three reaches contained similar habitat characteristics, downstream migration speeds in V1 differed more from the adjacent V2 and V3 than any of the other reaches in the study. Eighty percent of upstream and 74% of downstream migration speeds in V1 were slower than the slowest migration speeds in V3. Although the most significant differences in downstream migration speeds were found between reaches in the varial zone, overall both the fastest and slowest speeds documented in this study were through reference zone reaches.

MFBR— No significant differences in fish speeds were detected for up or downstream migration, nor were there any significant difference in variance between reaches in the MFBR. The MFBR is a larger system and therefore had longer reaches on the scale of kilometers while Trail Creek's reaches were on the scale of hundreds of meters. This greater length resulted in only one fish migrating upstream through any entire reach during one night. The remainder of the fish had at least a portion of travel or holding within reaches during daylight hours. Downstream migrants were able to travel through entire reaches during one night. Downstream migrations during the day (mean 1.89 m/min) did occur, but were significantly slower than during the night (mean 69.09 m/min; P <0.0001).

Trail Creek vs. MFBR— Downstream migration speeds were significantly faster on the MFBR than in Trail Creek for both reference zones (P <0.0001; medians 70.02, 7.08) and varial zones (P <0.0001; medians 67.78, 11.76). Upstream migration speeds through the reference zones were significantly faster in Trail Creek than in the MFBR (P =0.0044; medians 1.52, 2.65). No significant differences were identified between tributaries for upstream migrations through the varial zones (P =0.07; medians 2.22, 2.05).

Mortalities—

Trail Creek-In 2012, at least four of 22 (18%) and in 2013 at least four of 19 (21%) bull trout died, expelled their tag or were eaten by predators while in the varial zone of Trail Creek (Chapter 4). Combined mortality, tag loss and tag failure upstream of the varial zone was 4 of 22 (18%) in 2012 and 8 of 19 (42%) in 2013. Bull trout spent much more time upstream of the varial zone than within the varial zone itself; 49 days on average in 2012 and 56 days on average in 2013 compared to less than one day total in any one year within the varial zone. All bull trout in this study migrated upstream past the 654 m long reference zone and unpublished data from BOR shows that bull trout migrate up to 5km up Trail Creek during their spawning migration. During spawning migrations bull trout spent on average 32 (2012) and 37 (2013) times longer in Trail Creek above the varial zone than the longest time spent by any individual within the varial zone. However, tag loss rates were the same in the two areas in 2012 and only two times higher upstream of the varial zone in 2013.

MFBR- On the ground verification of mortalities in the MFBR was not as thorough as Trail Creek. The remote stations did, however, document that at least three of the 19 bull trout (16%) that migrated downstream through the varial zone of the MFBR in 2013 never made it out of the delta area. These fish were presumed to have suffered mortality or tag expulsion while within the detection range of the lowest remote station.

Discussion

Migration timing—

Timing and environmental conditions The wide variation in mean migration timing in Trail Creek and the MFBR among the study years (Trail Creek: July 2 in 2013, August 24 in 2011: MFBR, April 20 in 2013, May 24 in 2012) is similar to data reported by other investigators, where, substantial variations in inter-annual timing have been reported. For example, Swanberg (1997) documented mean migration dates of June 7 in 1994 and July 2 in 1995. Hanson (2006) showed variation in individual upstream migration dates between May 6 and August 18 as well as variation in peak migration date by up to 4 weeks. Overall, results indicate that such variations are typical among bull trout populations.

For both tributaries, the wide range in initial mean migration timing among years (53 days in Trail Creek, 34 days in the MFBR) suggests that some environmental factors likely influence the decision on when to migrate. In Trail Creek, bull trout do not have to travel far (<5km) to get to suitable spawning habitat. The bull trout upstream migrations into Trail Creek, which were initiated on the descending limb or even at summer base flows, contrasts with a study by Fraley and Shepard (1989) that documented bull trout migrations beginning on the ascending limb of the hydrograph. The difference may relate to the importance of other environmental factors rather than the hydrograph direction *per se* as necessarily leading to the initiation of migration. For example, in this study the main factors in Trail Creek that appeared to be associated with bull trout migration timing were tributary water temperature and the reservoir elevation of 1,623 m as it related to the last overhanging riparian vegetation 140 meters downstream from the high water line. In the MFBR, the wide range in individual bull trout upstream migration timing (February 2 to July 8) over only 3 years of data makes it hard to determine any relationships between timing and environmental conditions. Temperatures and flows of the MFBR varied drastically between the earliest documented upstream migration in February and the latest in July. Bull trout did all migrate before temperatures increased above 18.6°C, but there was no one temperature that initiated a majority of migrations. The relatively cool water of Trail Creek not only provides a staging area, but allows bull trout to migrate much later than those in Arrowrock Reservoir. In contrast to Trail Creek the mouth of the MFBR in Arrowrock Reservoir was not used as a staging area prior to upstream migrations. This is likely because of the differences in available temperatures in the two systems. Water in Trail Creek is typically colder than all of the water in Deadwood Reservoir. Arrowrock Reservoir on the other hand typically contains colder water (at depth) than the incoming river. There is no need for acclimating to the colder water and the associated lower metabolic rates. Whether bull trout migration timing is directly influenced by distance to spawning grounds, hydrograph direction, habitat changes or indirectly through changes in water temperature is unknown and should be investigated further.

Trail Creek Multiple Migrations— An unanticipated result of this study was the multiple, back and forth migrations of bull trout between the reservoir and Trail Creek. Salmon have been documented migrating in and out of tributaries for temperature refugia when water temperatures are high on their migration up the Colombia River

(Goniea et al. 2006; Clabough et al. 2008). One hypothesis is that the migrations occur due to the critical tradeoff between higher food availability in the reservoirs and lower metabolic costs in the lower-temperature tributaries. The higher prevalence of multiple migrations in warmer years observed in this study supports this hypothesis. In such a tributary-reservoirs movement, however, such an adaptive movement may be complicated by the shallow water and high mortality rates documented in varial zones. If temperature increases caused by the varial zone (Chapter 2) can be mitigated for, fish may be able to use the cooler water at the tributary mouth as temperature refugia within the reservoir, rather than migrating back and forth through the varial zone. No matter the reason for multiple migrations, they make it more important to understand the issues identified for fish migrating through varial zones.

Migration speeds—

Trail Creek— In this study, variations in fish speeds were not shown to be different for migratory fish between varial and reference zones. This result was found even though varial zones have been shown in Chapter 2 to have higher mean water velocities, and shallower depths than reference zones, providing less resting area and less cover for migrating fish. Water temperatures, at least in the smaller tributaries, have been shown increase at a significantly higher rate in the varial zones than reference zones. Variables typically associated with better fish habitat (pocket pools per meter (Saffel and Scarnecchia 1995), percent undercut bank (Bjornn and Reiser 1991) and percent stable bank (Salow and Hostettler 2004) are significantly greater in the reference zones. All of the embeddedness variables as well as the percent surface fines <8mm (both typically associated with lower quality fish habitat;

Bjornn and Reiser 1991) are greater in the varial zones. In view of these documented differences, it is important to understand why the no overall differences in speed between varial and reference zones as a whole were observed.

On a smaller scale analysis, the variations in fish speeds documented between the different reaches within each zone of Trail Creek show the influence of habitat conditions. The relationships between fish speed and habitat variables however are not linear and therefore not straightforward. Fish may be moving at similar speeds in different reaches for different reasons. In very general terms, there are two main options, they have to or they choose to. If water is too shallow or fast and fish struggle to make it through they have to go slow (Figures 3.10 to 3.12). If water is deep and has plenty of cover fish may choose to rest, in turn going slow through that reach.

The lack of statistical differences in both upstream and downstream migrating fish speeds identified between reaches V1, R1 and R4 initially suggests there may be other similarities between these reaches. Migration speeds in these three reaches are some of the slowest in the study, but fish may not be traveling slow in all three reaches for the same reasons. Bull trout have been documented with their backs out of the water in the shallow delta of reach V1 (Figure 3.10). Reach R1 has a small (approximately 0.5 meters tall) natural bedrock cascade that may be slowing fish down. Reach R4 on the other hand has one of the “best” habitat units in the entire study area containing cover of every type measured and a maximum depth of 0.73 m (Figure 3.13). This habitat unit in reach R4 provides slow, deep water with complex cover and fish are likely choosing to rest here, contributing to their slow travel speed through reach R4 for an entirely different reason than reach V1 or R1.

The delta likely slows bull trout during their upstream migration. Mean speeds were slower when the delta was present in a reach, but not significantly slower. This is likely because the higher the reservoir elevation the shorter the delta feature was and the delta never was a majority of the length of any reach. Based on increased fish speeds in reaches V2 and V3, once fish slowly move through the delta they likely speed up through the rest of the reach. As fish travel upstream the first place they “choose” to slow down is reach V4 where the first overhanging vegetation cover is found during their journey. This is consistent with personal observations of kokanee that are always actively moving upstream until reaching the overhanging vegetation in reach V4. This is also consistent with other studies where fish paused upstream migration to rest after navigating difficult passages (Økland et al. 2001).

Reach V4 is also the last reach fish migrated downstream through during daylight hours before turning around. Just downstream of this in reach 3, minimum depths are 0.1 m, where some bull trout would not be fully submerged. Whether fish are choosing to turn around and wait for dark because of the lack of cover or because of the insufficient minimum depths is unknown. There is evidence in the literature for upstream migrating fish to wait for daylight to migrate over waterfalls (Neave 1943), but no other literature was been found on diurnal patterns in migrating difficult passages.

MFBR—The lack of statistically significant differences in fish speeds between any of the reaches on the MFBR may be due to several factors. Migration speeds were determined over long reaches, which were not always traversed by fish in a single night. This caused most upstream migration speed estimates to contain periods of holding during daylight hours. The delta area where the largest impacts to habitat were documented (Chapter 2) was downstream of the lowest reach. It is unknown if this area impacted fish speeds. This delta area also showed increased turbidity that would lead to adverse impacts to bull trout as well as bull trout critical habitat (Chapter 2; USFWS 2010). Additional studies with shorter reaches may allow for any impacts this study may have missed to be identified.

Trail Creek vs. MFBR- The significant differences between tributaries for downstream migration speeds are likely caused by habitat differences between the tributaries. This study, however, was unable to confirm the specific habitat variables that lead to these differences. Although the total volume of water was significantly different between tributaries, water velocities were not significantly different. The faster downstream migration speeds in both varial and reference zones of the MFBR may have been due to the uninterrupted depth cover available. This difference is easier to explain when comparing varial zones because of the documented slowing in the delta of Trail Creek. The significant differences in downstream migration speeds between reference zones is not as easily explained. Additional research looking at shorter reaches on the MFBR where known differences in habitat exist could improve the understanding of differences in downstream migration speeds.

Temperature, fish migration, and fish speeds in Trail Creek- The increased temperatures caused by the conditions in the varial zone of Trail Creek have the potential to impact many aspects of bull trout ecology from growth rates to migration timing and the number of migrations. Feeding rates and maintenance costs in fish have been shown to be exponential functions of temperature (Broekhuizen 1994). Increased temperatures have also been shown to decrease resistance to disease and decrease successful reproduction (Ryan et al. 2013). Murdoch and Power (2013) showed that Arctic charr (*Salvelinus alpinus*) growth was limited in years when water temperatures warmed more quickly. Other authors suggest growth rates of another close relative to bull trout, lake trout (*Salvelinus namaycush*) are driven by the amount of time with suitable temperatures in shallow productive habitat (King et al. 1999).

Bull trout may be spending large amounts of time at the mouth of Trail Creek because of the relatively cold water that is still present there, even with the temperature increases caused by the varial zone. Trail Creek is the only north facing drainage in the Deadwood basin above Deadwood Reservoir. This leads to Trail Creek being the coldest tributary entering the reservoir. The Trail Creek arm of the reservoir is also narrow compared to the other tributaries, which allows cold tributary water to enter the reservoir without mixing quickly. This deeper water at the mouth of Trail Creek is typically the coldest water in the reservoir during the summer.

Acclimation to tributary water temperatures prior to migration may be difficult because of the high rates of temperature increase within the varial zone. Similar to humans building up a higher concentration of red blood cells when acclimating to higher elevations; fish build up more mitochondria and capillaries in their muscles while acclimating to cold water temperatures (Johnston and Dunn 1987). Even though fish that do spawn in Trail Creek may be acclimated to temperatures at the mouth; temperatures only a short distance upstream at the high water line may be up to 3.3°C cooler (Chapter 2). It may take several weeks of holding in the tributary mouth for fish to acclimate to the cooler waters of the tributary (Johnston and Dunn 1987). Increased stream temperatures caused by the varial zones could reduce both cardiac and aerobic scope needed during the physical activity of migration (Figure 3.14; Cooke et al. 2012). Swimming performance has been shown to increase in multiple fish species in cold water as a fish acclimates (Johnston and Dunn 1987). Trail Creek is a relatively small tributary and additional research on the impacts of varial zones on temperature in larger systems is still needed.

The differences in migration timing between years suggests that if the temperature increases caused by the varial zone are mitigated for, bull trout may be able to spend more time feeding and growing in the reservoir before migrating. If temperatures were decreased, the food that they do obtain in the reservoir would also go more to growth and reproduction rather than metabolic costs. The 3.3°C increase documented in Chapter 2 could be the difference between bull trout's optimal 12°C and the upper end of their thermal "preference" at 15°C. Finding a way to decrease the rates of temperature increase within the varial zones could greatly improve the health of bull trout populations and decrease the number of multiple migrations that subject bull trout to the high mortality rates of varial zones.

Mortalities and movements through varial zones— A concentration of bull trout radio tag recoveries was located in the wide shallow area of the MFBR delta. Tag loss or mortality of a tagged fish may have resulted from tag expulsion, gills being clogged with sediment, fish getting buried by bank sloughing, predation in the shallow water, or other factors. Bald eagles (*Haliaeetus leucocephalus*) were documented in this area during this study. Past studies (Salow and Hostettler 2004) showed high predation rates in this area as well as bull trout recovered from under layers of sediment from bank sloughing.

The specific reasons behind the high number of mortalities in varial zones (16-21% of migrants) are unknown. Locations of recovered tags were mostly on the shore and not within the wetted channel, suggesting the possibility that fish were predated upon and eaten on the shore. However the fish could also have died of other causes and been removed from the wetted channel by scavengers. The eight mortality events documented on the remote telemetry station in the varial zone of Trail Creek suggest the tags were in live fish when they were removed from the channel. Game camera and on the ground observations of predators suggest predators are actively hunting live fish (Chapter 4). On top of the mortalities documented within the varial zones, fish encountering increased stress levels from anthropogenic changes during upstream spawning migrations have been shown to have increased, yet delayed mortality rates (Roscoe et al. 2011).

Migration barriers and impediments- Even though fish movement was not monitored in all eight tributaries surveyed in Chapter 2, some inferences can be made by comparing habitat between tributaries where movement was not monitored to those where it was. Deer Creek was the only tributary in this study that contained a full barrier to fish migration in the form of a dewatered channel (Chapter 2). Even though not a full barrier, the shallow wide area of the Trail Creek delta was documented as an impediment to bull trout migration. Bull trout traveling through water shallower than their body depth may not only have increased stress, but may be subject to increased mortality from predators (Chapter 4). Bull trout body depth has been documented ranging from 20 to 25% of total length (BOR unpublished data). The largest bull trout captured during this study (0.6 m) would have a body depth of at least 0.12 m. Any minimum water depths less than that would be expected to result in adverse impacts to migrating fish. Habitat units with minimum thalweg depths less than 0.12 m covered 17% of the length of the Deadwood River varial zone, 43% of Trail Creek, 57% of Canyon Creek, 75% of the Powder River and 100% of Deer Creek.

Habitat alterations caused by fluctuating reservoir water levels have impacted bull trout travel speeds and probably the timing of the migrations. Finding ways to meet irrigation demands while increasing water levels enough to flood deltas before bull trout downstream migration could reduce impacts to bull trout. The shallowest habitat unit in all of these tributaries, except the Powder River, were the delta. Deltas would likely form at some reservoirs even with habitat improvements, but in some cases it may be an option to increase the reservoir water level to flood the delta after irrigation season, but before downstream migration. The variation in delta length documented between and within years makes it hard to predict the increase in reservoir water level needed to flood the shallow delta prior to downstream migration.

In the first two weeks after releases from Deadwood dam were experimentally reduced from 1.42 m^3/s to 0.07 m^3/s in October of 2013, the reservoir water level raised over two feet and flooded the entire delta formation in Trail Creek. If this reduction in discharges could happen immediately after irrigation season is over the delta could be flooded before the earliest documented downstream migration of a bull trout from spawning on September 14. Additional benefits could be seen in the varial zone larger rivers, such as the MFBR to lower turbidity levels and limit bank sloughing with a reservoir water level increase before the downstream migration time frame (Chapter 2).

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Figures

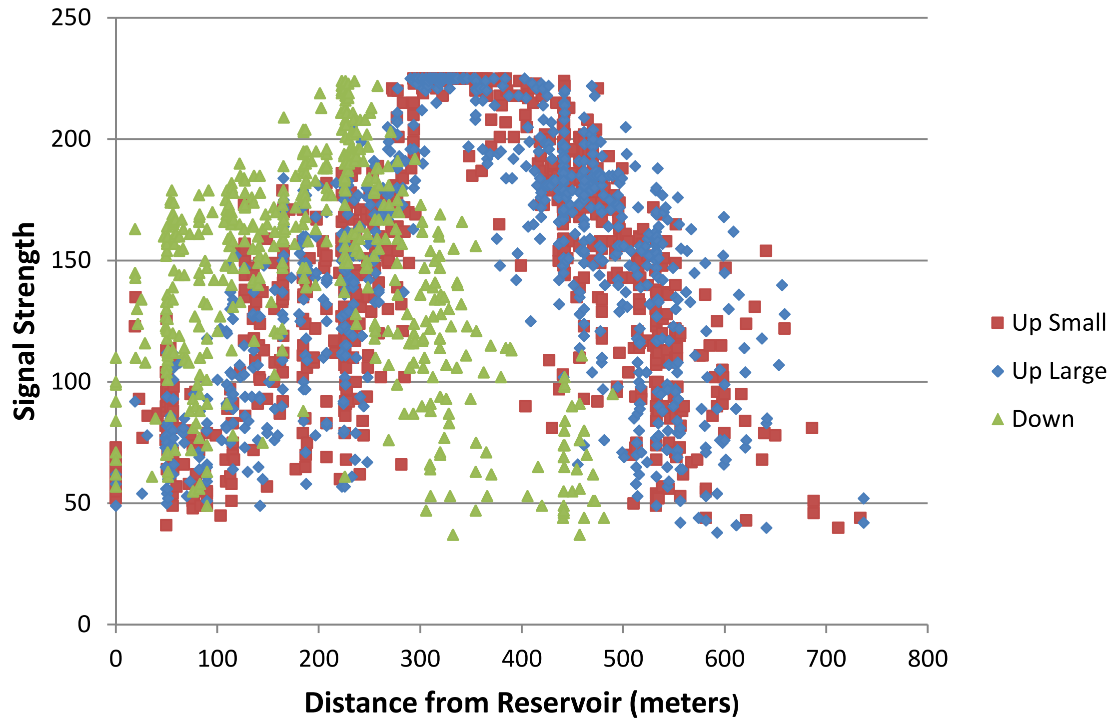

Figure 3.1. Multiple test tag calibration events in 2012 for the Trail Creek varial zone remote station.

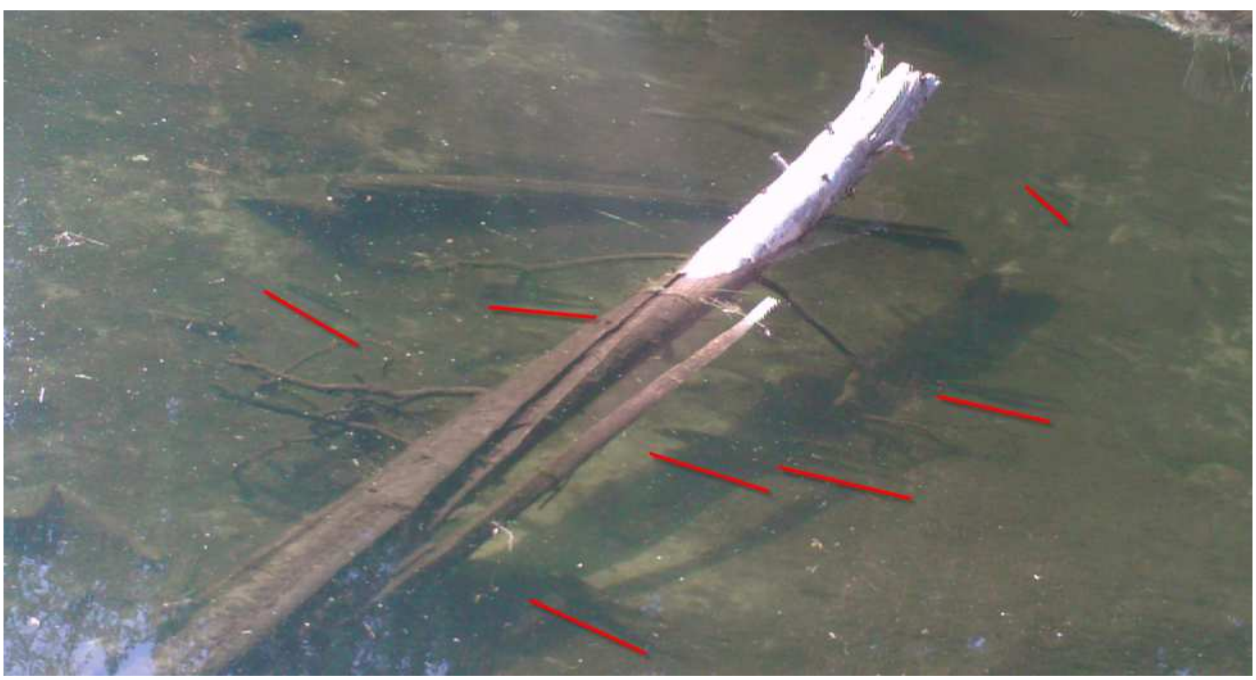

Figure 3.2. Photo of 7 bull trout taken July 10, 2014. Each bull trout is underlined in red. In all, 26 bull trout were counted in this area the same day.

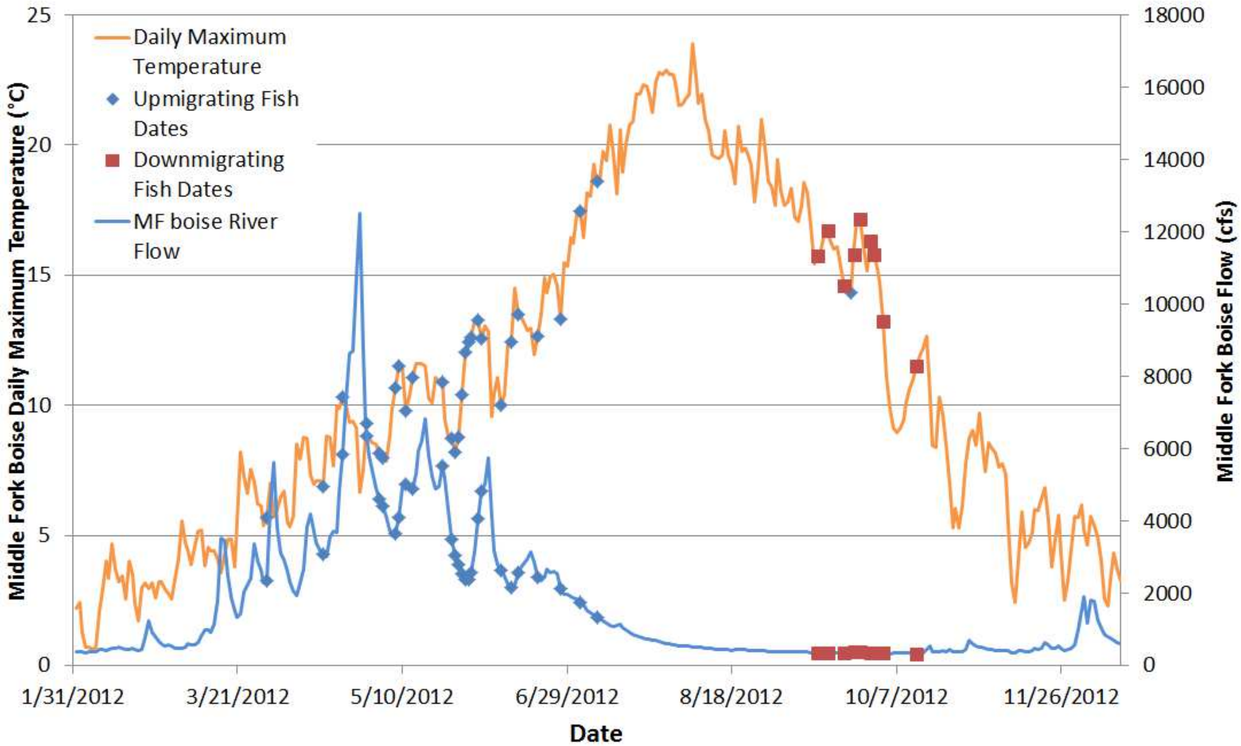

Figure 3.3. Bull trout migration timing compared to temperatures and flows of the MFBR in 2012.

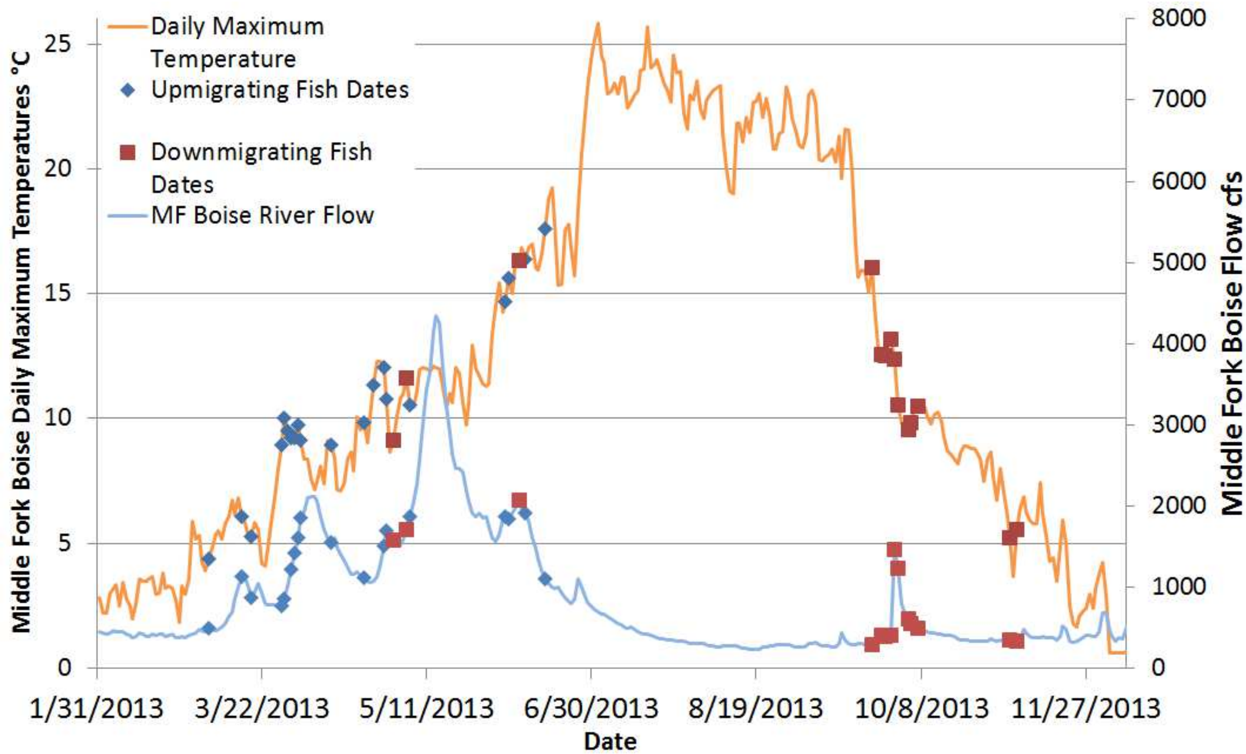

Figure 3.4. Bull trout migration timing compared to temperatures and flows of the MFBR in 2013.

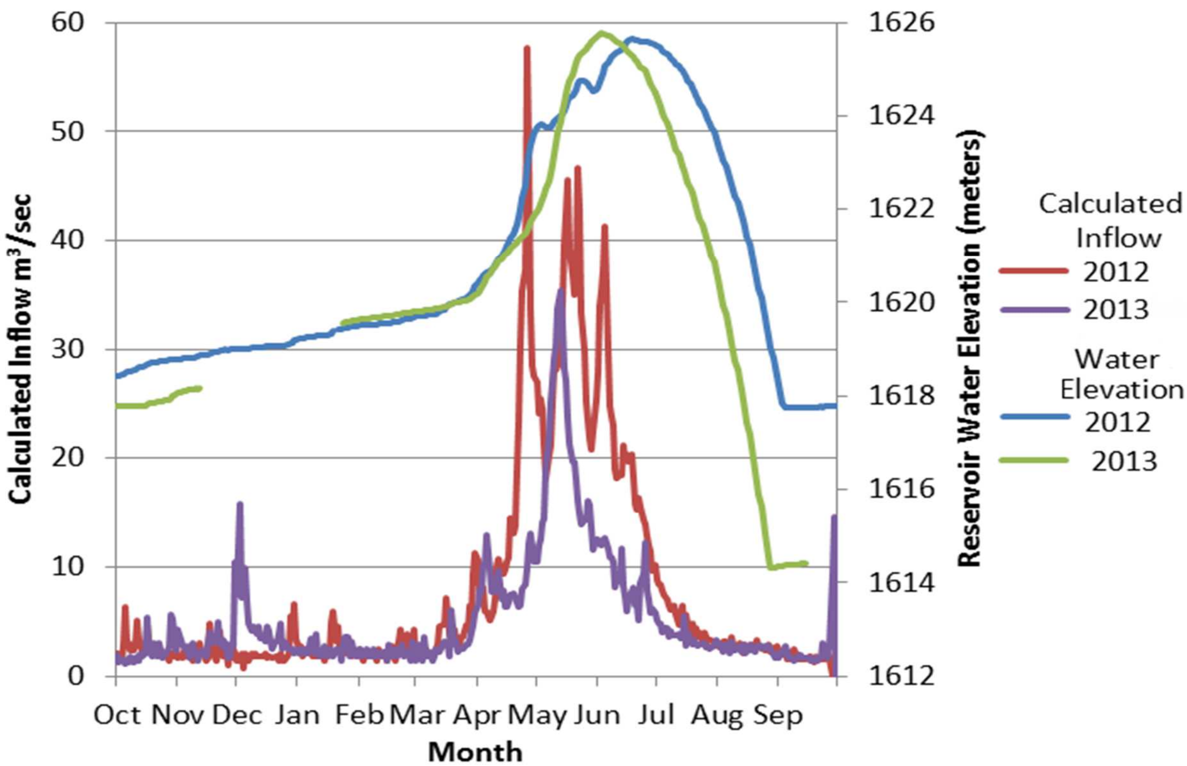

Figure 3.5. Water year hydrologic characteristics for inflows and water surface elevations at Deadwood Reservoir in water years 2012 and 2013.

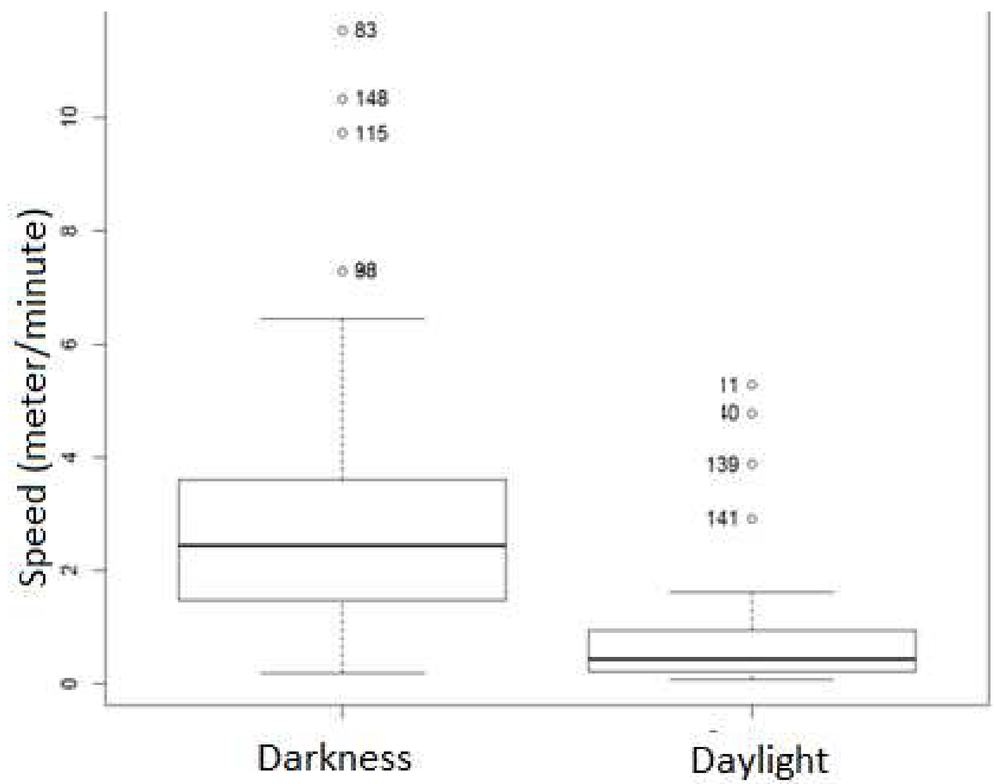

Figure 3.6. Differences in bull trout upstream migration speeds in Trail Creek between fish movement during daylight and darkness.

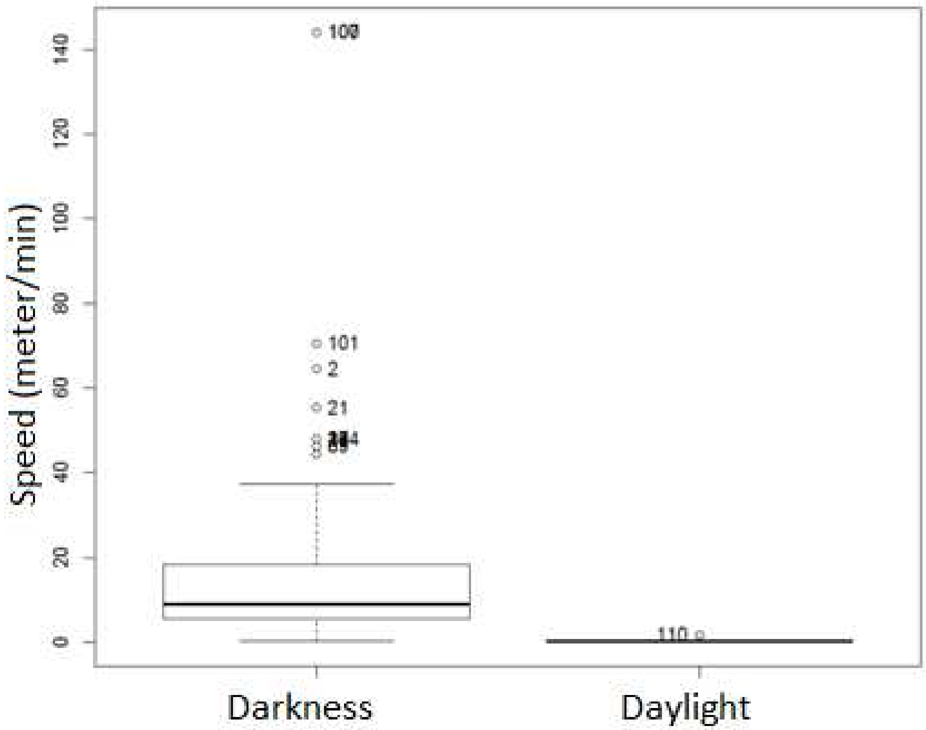

Figure 3.7. Differences in bull trout downstream migration speeds in Trail Creek between fish movement during daylight and darkness.

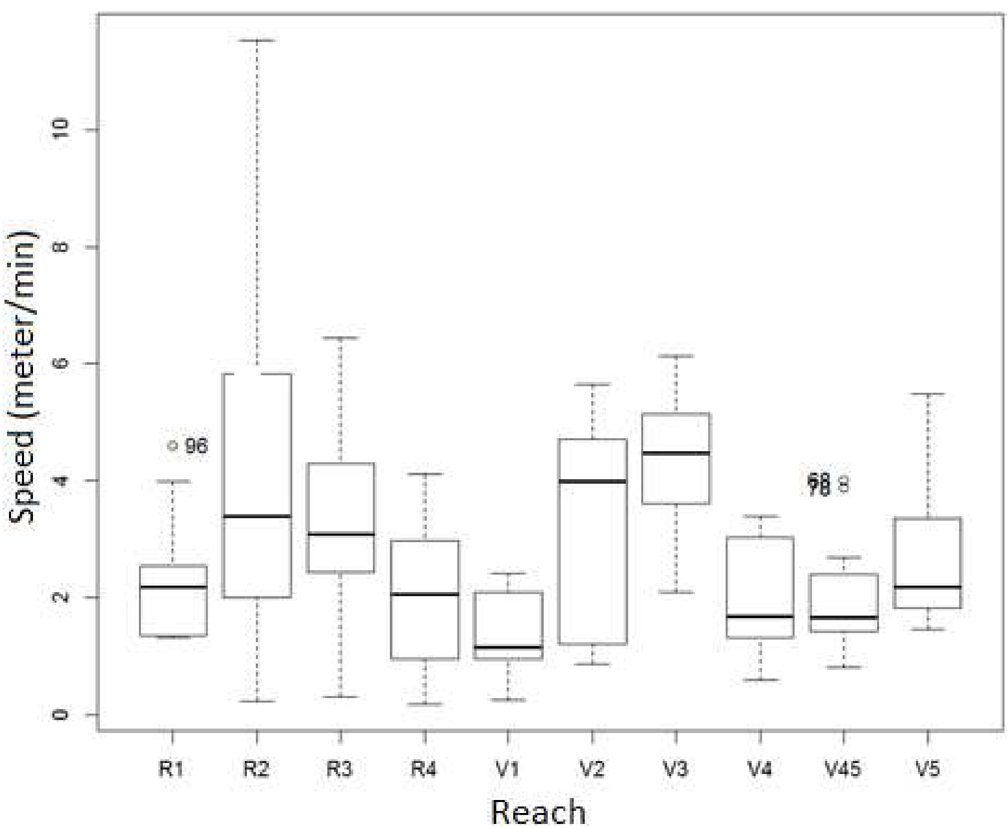

Figure 3.8. Box plot of bull trout upstream migration speeds in reference and varial zone reaches of Trail Creek at Deadwood Reservoir.

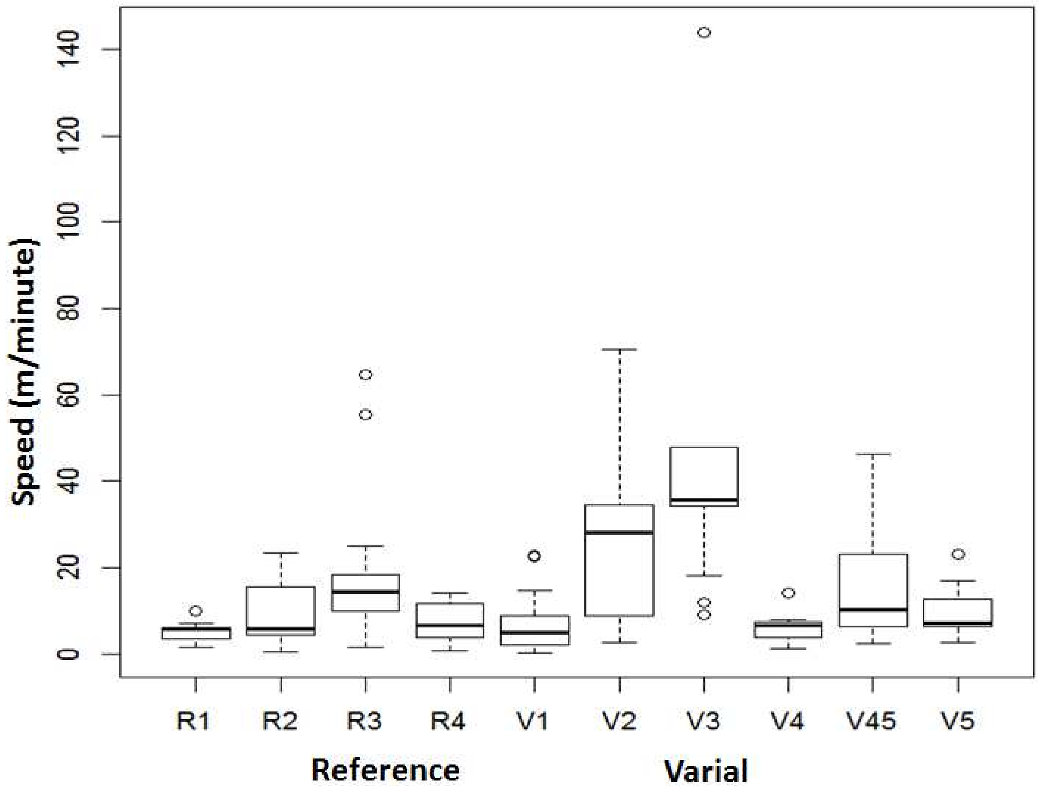

Figure 3.9. Box plot of bull trout downstream migration speeds in reference and varial zone reaches of Trail Creek at Deadwood Reservoir.

Figure 3.10. Infrared photo from a game camera showing a bull trout (circled in red) with its back out of the water in the shallow delta near the transition from Trail Creek to Deadwood Reservoir on the night of September 16, 2013 at 2353 hours.

Figure 3.11. Screenshot from a video of kokanee (circled in red) struggling to migrate upstream through the turbid waters of the delta in the Trail Creek varial zone, Deadwood Reservoir 2007.

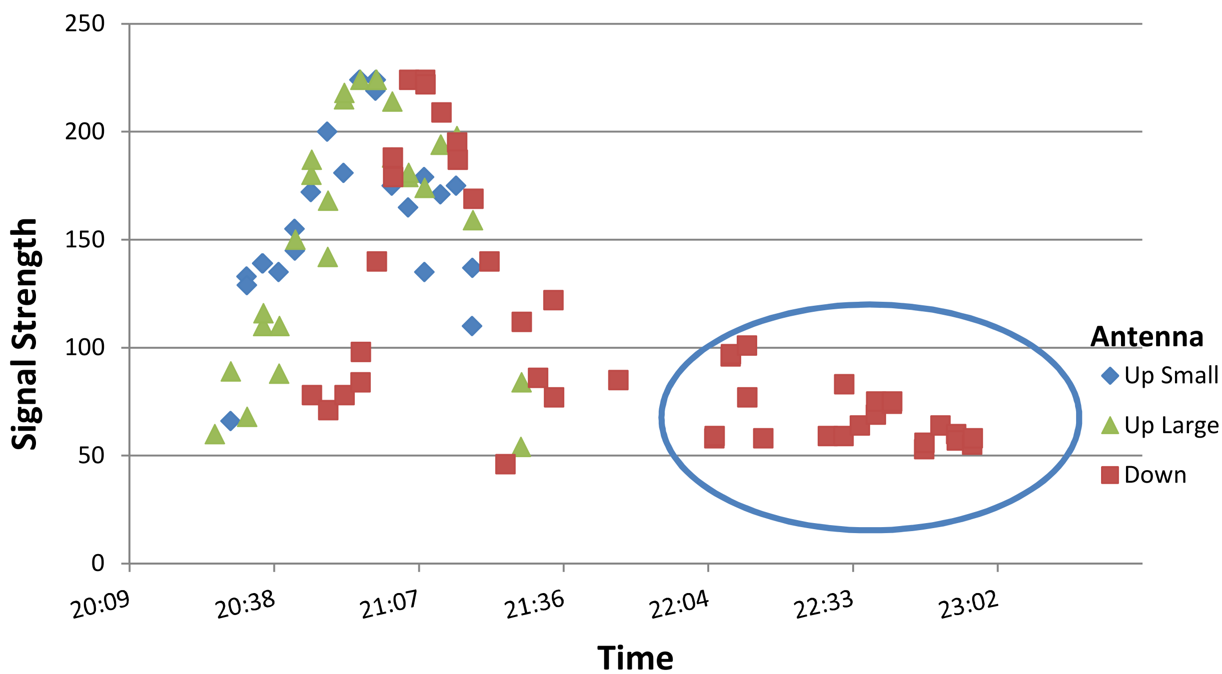

Figure 3.12. Trail Creek remote station data for fish 16 down migrating from spawning on September 16, 2013. The blue circle represents when the fish was in the shallow delta area near the reservoir.

Figure 3.13. Looking upstream from the tailwater control of the habitat unit with the most available cover in the reference zone of Trail Creek. Most of the pool is obscured by large woody debris and overhanging vegetation. This habitat unit had a total cover rating of 150.

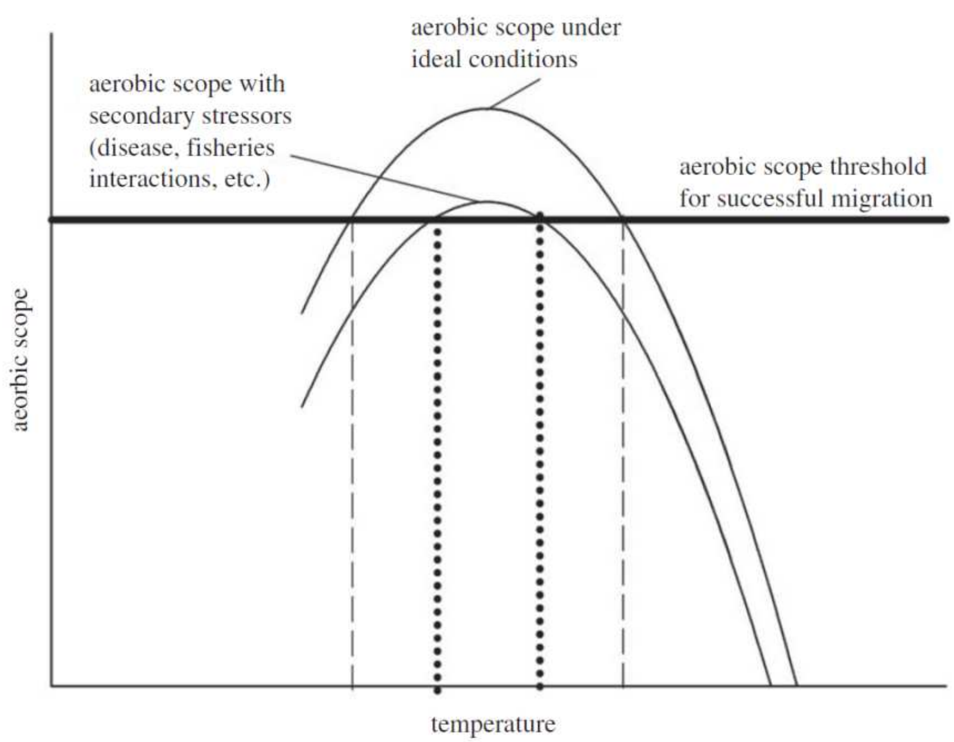

Figure 3.14. Aerobic scope functional diagram. (Source: Cooke et al. 2012.)

Tables

Table 3.1. Bull trout migration dates and water year parameters. ND=no data NA=conditions not seen in that year. For the temperature parameters, the Date 12-Date 15 are the dates that water temperatures in Trail Creek above the high water line first reached 12-15 °C in each year. Date 200 cfs corresponds to the first date with a calculated inflow to Deadwood Reservoir below 200 cfs.

	Migration Date			Temperatures (°C)								Calculated Inflow (m³/sec)				Forebay Elevation (m)		
Year	Mean	First	Last	Water Temperature Category	Maximum	June 1	Date 7 Day Average Max >13	Date 12	Date 13	Date 14	Date 15	Maximum	Date of Maximum	Date 5.66	June 1	Date 1623	Date Full	Minimum
2006	8/21	7/23	9/3	Average	16.6	ND	7/4	6/29	6/30	7/8	7/14	78.2	5/17	7/10	27.33	8/5	6/30	1618.0
2007	7/7	6/13	8/15	Warm	18.1	11.5	6/19	6/11	6/14	6/19	6/30	26.0	5/11	6/15	10.62	7/19	6/23	1613.1
2008	8/5	7/27	8/12	Cool	14.9	6.7	7/9	6/26	7/1	7/23	NA	48.9	5/25	7/9	39.93	7/30	7/1	1616.5
2010	ND	ND	8/19	Cool	14.7	5.9	7/7	6/25	7/6	7/9	NA	68.2	6/3	7/11	19.26	7/24	6/20	1618.3
2011	8/24	8/16	9/24	Cold	14.2	6.2	7/29	7/9	7/22	8/1	NA	47.9	6/21	7/24	22.51	8/15	7/16	1618.3
2012	7/26	6/28	8/27	Average	15.9	8.8	7/4	6/27	7/4	7/8	7/17	57.6	4/24	7/9	28.03	8/3	6/17	1617.8
2013	7/2	6/9	8/10	Warm	16.8	9.7	6/26	6/4	6/15	6/25	6/27	35.3	5/12	6/30	12.54	7/13	6/2	1614.3

Table 3.2. R^2 and p-values for linear regressions between migration dates and physical/hydrological parameters in Trail Creek (2006-2008 and 2011-2013).

P<0.05 / P<0.01	Physical/ Hydrological Parameter	R^2 Mean Migration date	P value Mean Migration date	R^2 First Migration date	P value First Migration date	R^2 Last Migration date	P value Last Migration date
Temperature (°C)	Summer Maximum	0.476	0.13	0.678	0.044	0.207	0.306
	1-Jun	0.744	0.027	0.875	0.019	0.198	0.377
	Date 7 Day Average Max>13	0.653	0.052	0.815	0.014	0.627	0.034
	Date 12	0.89	0.005	0.836	0.011	0.642	0.03
	Date 13	0.727	0.031	0.786	0.019	0.656	0.027
	Date 14	0.682	0.043	0.879	0.006	0.411	0.121
	Date 15	0.671	0.181	0.623	0.211	0.853	0.076
Calculated Inflow (m^3/sec)	Maximum	0.548	0.093	0.272	0.289	0.112	0.463
	Date of Maximum	0.364	0.205	0.603	0.069	0.284	0.218
	Date 5.66	0.69	0.04	0.723	0.032	0.514	0.07
	1-Jun	0.377	0.197	0.395	0.181	0.015	0.794
Forebay Elevation (m)	Date 1623	0.873	0.006	0.795	0.017	0.783	0.008
	Date Full	0.714	0.034	0.812	0.014	0.56	0.053
	Minimum	0.776	0.02	0.613	0.066	0.391	0.133

Table 3.3. Differences in migration timing for fish tracked both in 2012 (an average water temperature year) and 2013 (a warm water temperature year).

Frequency	ID	2012 First	2013 First	2012 Second	2013 Second	1212 Third	2013 Third	2012-2013
148.800	16	8/18	6/25	NA	7/19	NA	NA	54
149.620	38	7/25	6/29	NA	NA	NA	NA	26
149.620	44	8/7	6/12	NA	6/27	NA	7/21	56
149.620	102	7/21	6/27	8/7	7/14	NA	NA	24
149.720	112	8/7	7/1	NA	7/16	NA	NA	37
Mean		8/3	6/24	8/7	7/11	NA	7/21	39.4

Table 3.4. Differences in migration timing for fish tracked both in 2006 (an average water temperature year) and 2007 (a warm water temperature year).

Frequency	ID	2006	2007	2006-2007
148.780	10	8/12	6/15	58
148.780	11	7/25	6/19	36
148.780	12	9/5	7/15	52
Mean		8/14	6/26	48.7

CHAPTER 4: VARIAL ZONE HABITAT AND PISCIVORE PRESENCE IN RELATION TO MORTALITY OF MIGRATORY BULL TROUT SALVELINUS CONFLUENTUS AT DEADWOOD RESERVOIR IDAHO

Abstract

Fluctuation reservoir water levels create varial zones that tributaries must flow through to get to the reservoir pool during low water levels. The habitat conditions in the tributaries flowing through these varial zones have been altered over time as a result of the fluctuating water levels. Recovery location of radio tags from previous work suggests that there are high mortality rates of migratory fish in the varial zone of Trail Creek, a tributary to Deadwood Reservoir in central Idaho. Juvenile bull trout as small as 86 mm have been documented in Deadwood Reservoir expanding the size range of bull trout traversing the varial zone to a minimum range of 86-600 mm. Overall, seven different, avian and mammalian species were documented on camera, during this study, capturing live fish in this size range from Trail Creek and are considered predators for the purposes of this study. Although not documented capturing live fish on camera during the study an eighth species, the common merganser (*Mergus merganser*) was considered a predator for the purposes of this study based on documentation in the literature of fish consisting of a majority of their diet. Listed in order of number of photo documentations highest to lowest the eight predator species in this study were; great horned owl (*Bubo virginianus*), great blue heron (*Ardea herodias*)*,* bald eagle (*Haliaeetus leucocephalus*), belted kingfisher (*Megaceryle alcyon)*, common merganser, human (*Homo sapiens),* black bear (*Ursus americanus)*, and osprey (*Pandion haliaetus)*. Total predator documentations were much higher in the varial (1,957 documentations of 8 species) than reference zone

(18 documentations of 4 species). Within the varial zones itself, a significant majority (97%) of predator documentations were from habitat with substrate consisting of 100% fine sediment. Predation events were captured on camera at reservoir pool elevations ranging from just one meter below high water in the spring through the lowest water levels in the fall. Predators and actual predation events were documented most frequently in late summer and early fall when water levels are at their lowest and large numbers of kokanee (*Oncorhynchus nerka*) migrate to spawn. Adult adfluvial bull trout (*Salvelinus* confluentus) tag loss (tag recovered, documented out of water, buried under sediment, or did not move at bottom of reservoir for >3 months) in the varial zone were spread out through the migration time frame, but concentrated during down migration in late September. The dynamic nature of varial zones would cause any structural mitigation measures to need to be moved or installed/removed on an annual basis. Raising reservoir water levels between the end of irrigation season and the earliest date of documented bull trout downstream migration (September 14) could limit the potential impacts of predators when adult adfluvial bull trout are most vulnerable in the shallow deltas after expending the majority of their energy reserves during spawning. Additional research is needed to determine if and during which time frame predators may be impacting juveniles migrating downstream to the reservoir for the first time.

Introduction

Predators can exert a large impact on fish populations through complex relationships mediated by the available resources and ecological needs for both predator and prey. Fish have been shown to change feeding behaviors (Power and

Kerfoot 1987), habitat selection (Allouche and Gaudin 2001) and even courtship behavior (Fraser et al. 2004) in the presence or threat of predation (Hoeinghaus and Pelicice 2010). Predator numbers have been shown to respond to the number of fish available for them to feed on, through both population size controls (starvation/ competition) as well as immigration or emigration rates (Spencer et al. 1991; Restani et al. 2000). Allouche and Gaudin (2001) suggest that avian predators not only effect fish populations through direct predation, but also through sub-lethal effects on growth and habitat selection.

Anthropogenic changes to the environment can increase predator efficiency by decreasing habitat complexity as well as creating barriers or bottlenecks to migration (NMFS 1997; Scoppettone et al. 2014). One such anthropogenic change that may impact these predator-prey interactions is the fluctuating water levels of reservoirs. Throughout the world, habitat in the areas of tributaries running through dewatered sections of reservoirs (varial zones), as well as habitat within the reservoir near the mouth of the tributary has been altered over time (Chapter 2). Adfluvial fish must travel through varial zones, which have a lack of cover, increased water temperatures and in some cases extremely shallow delta formations (Chapter 2) to get to and from spawning areas. Scoppettone et al. (2014) showed that habitat changes similar to those caused by fluctuating water levels can alter the balance between predator and prey, with white pelicans (*Pelecanus erythrorhynchos)* responsible for up to 90 % of total Cui-ui (*Chasmistes cujus*) mortality in Pyramid Lake.

The modified aquatic habitat of a varial zone is an excellent location to investigate the interactions between aquatic habitat, potential predators and migratory, adfluvial bull trout (*Salvelinus confluentus*). Emigrating juvenile fish as well as adults migrating to spawn and subadults and adults seeking temperature refugia in the tributary must migrate through the altered habitat of the varial zone. Juvenile emigration from the tributaries typically occurs throughout the spring and summer (McPhail and Baxter 1996) while adult migrations occur from June through October (Chapter 2). Both emigrating juveniles and migrating adults could be migrating through varial zones at the lowest tributary flow and lowest reservoir water levels in any given year. The cold water that enters reservoirs from tributaries can also provide important thermal refuge for many fish species (Mackezie-Grieve and Post 2006). This tributary water does not immediately mix with the main reservoir water providing benefits only available in the reservoir, but temperatures more like that of the cool tributary.

In central Idaho, several fish species migrate through the varial zones of tributaries draining into Deadwood Reservoir. Rainbow trout (*Oncorhynchus mykiss)* and cutthroat trout (*O. gairdneri)* spawn in the spring; whereas kokanee (*O. nerka)*, Chinook salmon (*O. tshawytscha)*, mountain whitefish (*Prosopium Williamson)i* and an adfluvial stock of threatened bull trout spawn in the fall. A large (up to 26,000 fish/year with a peak of up to 3,500 fish/day) fall (mid-August to mid-September) run of kokanee annually constitutes the majority of adult fish migrating through the varial zone of Trail Creek. Bull trout, a much rarer species in Deadwood Reservoir have been found to migrate upstream before Kokanee and back downstream close to or just after the end of the kokanee run. Bull trout traversing the varial zone ranged from 86 mm and 8 grams up to 585 mm and 2190 grams (BOR unpublished data). Juveniles migrate downstream through the varial zone to reach the reservoir and larger fish migrate in and out of the reservoir to seek temperature refugia and to spawn in the tributaries.

Trail Creek is the only North facing tributary that drains into Deadwood Reservoir. It is typically the coldest tributary entering the reservoir and also is in a narrow arm of the reservoir that slows the mixing of tributary and reservoir water. Once the main surface and littoral waters of the reservoir begin to warm in late spring bull trout congregate in this “cool” water near the mouth of Trail Creek (Figure 4.1). Of the seven tributaries to Deadwood Reservoir, Trail Creek annually has the highest number of bull trout spawners (Prisciandaro and Harbison 2007) and the second highest number of kokanee spawners (Knight and Hebdon 2006). Even fish that later migrate to spawn in other tributaries, spend large amounts of time at the mouth of Trail Creek (Prisciandaro and Harbison 2007). A total of 26 individual bull trout were counted in this area on July 10, 2013 (Figure 4.1, Pers. Obs.).

The typically shallow water of varial zones, including that in Trail Creek, may make migratory fish especially susceptible to homeothermic predators otherwise less able to access fish in deeper, more natural channels. The largest concentration of Bald eagles (*Haliaeetus leucocephalus*) in the world occurs in Southeast Alaska on the Chilkat River where the inflowing Tsirku River creates a large alluvial fan with shallow depths and unstable channels similar to conditions found in varial zones (Bugliosi 1988). Many different species of salmon migrate up the Chilkat River to spawn, but the concentrations of Bald eagles are highest during late run Chum (*O. keta*) and Coho (*O. kisutch*) spawning which coincide with winter low flows and the shallowest water depths (Bugliosi 1988). Other predators that do not frequently feed on fish, such as the Eastern Screech-Owl (*Megascops asio*) and Barred Owl (*Strix varia*), have been documented capturing fish by wading in shallow water during rapid water level reductions in a Florida slough (Dinets 2011). Salow and Hostettler (2004) observed high mortality rates of bull trout in the varial zone of the Middle Fork Boise River (MFBR) on Arrowrock Reservoir, however specific predator species nor habitat within the varial zone and could not be identified. Observations in the Deadwood River basin above Deadwood Dam from 2006-2009 (the only years extensive basin wide mortality monitoring occurred) indicated that on average 52% (range 50-60%, total 11 of 22) of the total basin wide annual mortality (tag recoveries) of bull trout was occurring in the varial zone and adjacent (within 250 m) forested area of Trail Creek (BOR unpublished data). Bull trout in Trail Creek have also been shown to avoid migrating through the varial zones during daylight hours (Chapter 3). Known homeothermic piscivores documented at Deadwood Reservoir include: bald eagle, belted kingfisher (*Megaceryle alcyon),* black bear (*Ursus americanus)*, Clark's grebe (*A. clarkii*), common loon (*Gavia immer*), common merganser (*Mergus merganser*), Golden Eagle (*Aquila Chysaetos*), great blue heron (*Ardea herodias*), Great Horned Owl (*Bubo virginianus*), human (*Homo sapiens),* North American river otter, osprey (*Pandion haliaetus)*, red-necked grebe (*Podiceps grisegena*), western grebe (*Aechmophorus occidentalis*) and white pelican (Personal Observation; N. Hergenrider, Boise National Forest, Lawman Ranger District, personal communication). Knowledge of the relationships between varial zone habitat and interactions between fish and their predators is important in identifying any mitigation measures to improve migratory habitat.

The objective of this chapter is to investigate how fluctuating reservoir water levels influence homeothermic predator presence, observed fish predation, and bull trout mortality in varial zones. The first goal is to identify which homeotherms are using the varial zone of Trail Creek and if they are actively preying on fish and not scavenging or feeding on other prey items. My hypotheses are that:

1. Homeothermic predators of fish are present more often in varial than reference zones.
2. Homeothermic predators of fish concentrate in shallow habitat units of the varial zone.
3. The presence of homeothermic predators peaks during kokanee migration in the fall.

Methods

Remote still and video cameras as well as remote and mobile radio tracking of fish was used to investigate predator and fish interactions in the varial and reference zones of Trail Creek just above where it enters Deadwood Reservoir. Hourly time lapse photos were taken with remote still cameras (Moultrie Game Spy) from early July through mid-October of 2011 and 2012. Six cameras were set up in the varial zone of Trail Creek each year. Predator presence or absence, species, and general habitat conditions were noted for each photo. Some cameras were periodically moved downstream to monitor the transition to the reservoir as water levels dropped. Other cameras were left at the same location from the time reservoir levels exposed habitat until mid-October when inclement weather prevented site visits.

In 2013, ten additional remote cameras (Bushnell Trophy Cam HD) were deployed. These cameras had improved motion sensors, video capabilities and time lapse intervals ranging from one to 60 minutes. With more cameras available (16 total) monitoring in 2013 was not only conducted in the varial zone, but in multiple locations in the reference zone as well. To maximize likelihood of identifying avian and mammalian picivores in the reference zone, cameras were placed to monitor areas of the reference zone where radio tags from suspected bull trout predation events were recovered in past years. The motion sensor triggered cameras lead to a change in analysis; occupancy in 2013 was calculated by number of photos per hour instead of percent photos with predators present as in past years. Date and time stamps were documented on each photo. These stamps were used to determine seasonal and temporal use of the varial zone by each predator species.

Game cameras used for identifying species occupancy and habitat associations also captured actual predation events. After cameras were removed in October of 2013, photos and video from all three years were reviewed thoroughly to determine which species captured on camera were actually documented preying on fish as well as the size range of fish being captured by each species. Fish size estimates from photos/video were made by comparing the size of the fish to the size of the predator. Both adult adfluvial bull trout migrating to spawn and juvenile fish (as small as 86mm fork length) migrating downstream to rear have been documented migrating through varial zones, therefore any animal documented capturing fish in the varial zone could potentially be a bull trout predator. Based on this review of the photos/video, seven species (great horned owl (owl), great blue heron (heron), bald eagle (eagle), belted kingfisher, common merganser, human, black bear, and osprey) were identified and classified henceforth in this study as predators. An eighth observed species, the merganser, was not observed eating fish but was also classified as a predator based strictly on its well studied, highly piscivorous food habits (Wood 1987). This usage of the varial and reference zones by the eight species, hereafter referred to as predators, was then compared to seasonal and temporal usage of the varial zone by bull trout (Chapter 3) as well as migration timing of other fish species as determined by site visits and the literature. Maximum prey size for each predator species, from observations and literature, was also used to identify possible impacts of each predator species on the different life stages of fish using the varial zone.

Remote and mobile radio telemetry was used to monitor tag loss over time and space within Trail Creek. Tag loss was defined as either a tag that was: recovered, documented out of water (but not recoverable, i.e. in a tree), buried under sediment, or was at the bottom of the reservoir for >3 months without moving. It is not possible to document if the radio tag was expelled by the fish, the fish died and was scavenged upon or the fish was killed by a predator. Remote radio telemetry stations were used to document relative location and timing of when radio tags stopped moving within their detection range from 2011 to 2013 (Chapter 3 for methods). One of these remote stations was able to detect tags within the entire varial zone of Trail

Creek (0-1225m) while the other covered 685m of the reference zone. Ground radio tracking was conducted to recover radio tags from 2006 through 2013 both within and outside of the detection range of the remote tracking stations. Ground tracking in 2013 was limited to the varial zone and lower km of the reference zone. Tag loss documented in 2013 was not included in any of the analysis or summary data. An annual rate of tag loss was calculated as the percentage of tag loss out of the total tags that were actively tracked in each year. While ground tracking, predator tracks and tooth/beak marks were identified on recovered tags. No fish remains were documented with any of the recovered tags during this study.

Game cameras deployed in other anthropogenically modified habitat were used to investigate if an unexpected piscivore (owls) documented in Trail Creek may also be foraging for fish in additional habitat within their range. Multiple cameras were deployed on a seasonal fish weir on the North Fork Boise River. Photos from cameras deployed for a different study on the Deadwood River below Deadwood Dam were also reviewed for species presence.

Statistical Analysis—All statistical analysis was conducted in R version 3.0.2 (R Core Team 2013). A Fisher's Exact Test was used to test for significance in proportions of predators within and between zones. Relationships between annual tag loss rates and physical/hydrological parameters (calculated inflow, tributary water temperature and reservoir elevation) were investigated using linear regression of the ordinal dates for mean migration and each physical parameter. The physical parameters investigated for water temperature included, summer maximum, maximum temperature on June 1, the ordinal date temperatures exceeded each 12, 13, and 14°C as well as the ordinal date the 7 day average daily maximum first exceeded 13 °C. The physical parameters investigated for flow included; maximum, ordinal date of maximum, ordinal date flows decreased below 5.66 m^3/sec (200 cfs) as well as the maximum flow on June 1. The physical parameters investigated for reservoir elevation included; ordinal date full, minimum volume and the ordinal date the reservoir elevation decreased below the last riparian vegetation in the varial zone (1623 m).

Results

Predator Identification—Overall, the eight different homeotherm species classified as predators, listed in order of number of photo documentations highest to lowest (hourly photo documentations/motion sensor documentations), were: the owl (181/1346*),* heron (77/263)*,* eagle (71/129), belted kingfisher (0/124), common merganser (40/68), human (5/27; only those with fishing poles were counted*),* black bear (1/11) and osprey (2/7). Some piscivorous species (according to other studies) known to inhabit the Trail Creek and Deadwood Reservoir area were not documented on camera during this study. North American river otter, white pelican and Golden Eagle have been identified at Deadwood Reservoir (Personal Observations) as well as varial zones of other reservoirs in Idaho, but were not documented in Trail Creek during this study. The common loon, red-necked grebe, western grebe and Clark's grebe are all piscivores that have also been documented at Deadwood Reservoir (N. Hergenrider, Boise National Forest, Lawman Ranger District, Personal Communication), but were not documented in Trail Creek during this study.

Additional species of homeotherms were documented on camera, but are not documented in the literature as frequently preying on fish and were not seen attacking live fish during this study. The crow *(Corvus brachynchos)* was documented feeding on fish carcasses, but never directly eating live fish. Wolves (*Canis lupus)*, red fox *(Vulpes vulpes)*, striped skunk (*Mephitis mephitis)*, sandpiper (Family *Scolopacidae*), Canada goose *(Branta canadensis)*, elk *(Cervus canadensis),* mule deer *(Odocoileus hemionus)* and chipmunk *(Tamias sp.)* were also documented in or near the water, but were assumed not to feed on live fish and were therefore not included in the analysis of the study hypotheses.

Predator Spatial Occupancy

Varial vs. Reference Zone- As hypothesized, predator documentations as well as number of species were much higher in the varial than reference zone. In 2013, a total of 3,820 hours of motion sensor camera operation in the reference zone only documented 18 photos of predators (0.005 photos/hr) and a total of four predator species. In contrast a significantly higher proportion (P <0.0001) of photos documented predators in the varial zone; where 8,436 hours of motion sensor camera operation provided 1,957 photos (0.232 photos/hr) of eight predator species. Black bears were the only species documented more often in the reference zone (11 documentations) than the varial zone (1 documentation).

Within Varial Zone- Habitat differences within the varial zone itself led to significant differences in predator occupancy. Based on preliminary observations predator documentation was split into two different categories based on sediment conditions. Depending on annual sedimentation patterns, channel slope and morphology, the first one to three habitat units upstream from any reservoir water level were typified by 100% fine (<8mm longest edge) substrate (Chapter 2). The length of this area varied depending on reservoir elevation and tributary flows (Table 4.1). Habitat visually identified in photos to have 100% surface fines in the wetted channel was referred to as “sandy” whereas habitat with less than 100% surface fines was referred to as “non-sandy.”

Within the varial zone itself, a significant majority of predator documentations were from sandy habitat. A total of 377 (6%) of the 5,853 hourly photos from 2011 and 2012 documented predators. Sandy habitat was identified in 2,773 (47%) of all hourly photos. Of the 377 predators, 366 (97%) were documented in sandy habitat and only 11 (3%) in non-sandy habitat. The difference in proportions between sandy photos with predators (13%) and non-sandy photos with predators (0.04%) was significant (P <0.0001). Contrary to my hypothesis, shallow water depth alone did not seem to influence predator occupancy. When the sandy areas were over 100 meters long predators did concentrate, however, in the shallowest sandy habitat of the delta formation.

Predator Temporal Occupancy—As hypothesized, predators were documented more frequently in late summer and early fall when water levels were at their lowest and large numbers of kokanee migrated to spawn. The three most prevalent predators (owl, heron and bald eagle) were documented in the varial zone over a wide range of temporal and seasonal variability (Figure 4.2); owls were documented from July through October. Eagles and heron were rarely documented until the kokanee migration began in mid-August. Owls were documented in the varial zone between 2200 and 0700 hours. Heron were documented throughout the day, but most frequently between 1900 and 0800 hours. Eagles on the other hand were only documented during daylight hours between 0645 and 2000 hours. Heron were the only predators that shifted their temporal occupancy. When kokanee numbers dropped and bull trout downstream migration began in mid-September; heron shifted from crepuscular activity to being active and present all night long.

Predator behavior and predation events— Predation events (of fish in general) were captured on camera at reservoir pool elevations ranging from one meter below full pool in the spring through the lowest water levels in the fall. Successful predation events on fish were documented for seven predator species in the varial zone. Only one predation event was documented on camera in the reference zone, by an osprey.

Heron and owls showed different predation tactics within the sandy areas. Heron were typically found within a few meters of the transition between tributary and reservoir, whereas owls were perched on stumps or gravel bars throughout length of the sandy areas. Videos and photos showed that heron were more of an active predator, moving around and only periodically staying in the same place for any amount of time. Owls on the other hand displayed more of a sit and wait tactic, staying in the same exact location for hours. When prey was identified heron would walk quickly toward it, while owls would fly. With the water being so shallow, if an owl missed its target on the first attempt, it would run after it while holding its wings up

(Figure 4.3). Owls were documented both walking and flying back to stumps to consume captured fish.

On multiple occasions multiple predators of the same and/or different species were present at the same time. On the night of September 22, 2013 in particular, two different owls and two different herons were documented in the sandy habitat within the first 50 m upstream from the reservoir pool. Even though two owls were frequently documented in the same area (sometimes with fish in their beak) they were never documented fighting over food (Figure 4.4). Heron on the other hand were documented fighting even when prey items were not visible (Figure 4.5). Owls and heron seemed to coexist, with the heron likely being dominant. One video clip showing a fish splashing in between an owl and a heron, the owl watched as the heron pursued the fish.

Some of the largest fish may be too big for either owls or heron to successfully capture. Owls were documented in photos that also contained large fish with their backs sticking out of the water, but no attempts were documented of owls trying to capture these larger fish. Heron attempted to capture these large fish but were not always successful after multiple attempts even when fish stayed in the same location with much of their body exposed and out of the shallow water (Figure 4.6-4.7).

Even though fish species in the predation events was often difficult to determine, relative size could be estimated. Fish in photos from documented predation events ranged greatly in size. Small sized fish (length range 50mm to 200 mm) were captured by heron and kingfishers (Figure 4.8), medium sized fish (length range 200 mm to 400 mm) were captured by black bear, owls and herons (Figure 4.9), and the largest of the fish (length range 400 mm to 550 mm) were captured by humans, eagles, ospreys and herons. Kokanee, because of their red color, were in most cases the only species of fish possible to positively identify in predation photos or video; they were documented being captured in the varial zone by heron, eagle, osprey and bear. Radio telemetry information combined with relative fish size from photos also suggested that heron successfully and unsuccessfully attacked bull trout (Figure 4.6-4.7).

Tag Loss— Bull trout tag loss was documented with radio telemetry throughout the summer and fall at reservoir water elevations ranging from low pool up to 5 m below the high water elevation. Of the 70 radio tags implanted into bull trout between 2006 and 2012, 42 were documented as tag loss, (tag recovered, documented out of water, buried under sediment, or did not move at bottom of reservoir for >3 months; Table 4.2). Tag recoveries were documented in the varial zones (20), reference zones (16) and 6 tags were determined to have stopped moving in the reservoir. Twelve of the 16 tags from the reference zone were recovered during or after the spawning time frame (August 15 through October). Eleven of the 20 tags from the varial zone were recovered during or after the spawning time frame. Half of the tags from the reservoir stopped moving during or after the spawning time frame. No fish remains were identified in association with any of the tags recovered from bull trout. One tag located in a tree suggests avian predation or scavenging.

Linear regression showed that significant relationships existed between annual rate of tag loss and multiple physical/hydrological parameters (Table 4.3). The most significant relationships were documented for variables in the reservoir elevation category (August 1 and minimum elevation as well as the date the reservoir receded below the last riparian vegetation). However significant relationships were also documented for one variable in each of the other 3 categories; temperature (date 12°C was exceeded), calculated inflow (date flows dropped below 5.66cms) and migration timing (mean migration date).

Some information on bull trout tag loss (relative location and time) was also obtained from radio telemetered fish within the read range of stationary remote telemetry receivers. Over the period 2010-2013, one bull trout tag loss was documented on the reference remote station (September 2012). Remote station data also suggests that another bull trout was sick or injured moving little for four days in 2012 before likely succumbing to death or predation. Tag recoveries (2006-2013) in the both varial (20) and reference (16) zones were mostly on the stream banks with few tags (7) located in the water. In 2012 four of 22 and in 2013 four of 19 bull trout that migrated through the Trail Creek varial zone were documented as tag loss while in the varial zone. Temperatures for one of the radio tags that had been implanted into a bull trout went from 1.2 °C to the maximum temperature the tags can read (34°C) in an hour and fourteen minutes (Figure 4.10). The remote station showed the tag continuing to move, even leaving the detection area and returning 39 hours later. Water temperatures in Trail Creek reached a maximum of only 2.4°C, and air temperatures never exceeded 13°C while the tag was reading 34°C. This evidence suggests that a predator swallowed the fish and the tag. Data suggest that all 8 of the tag loss events documented on the varial zone remote station occurred close to or within the delta that forms at the transition between reservoir and tributary.

Owls—Owls were documented in motion sensor photos more than all other predators combined, for a total of 1,346 photos (69% of predator documentations 0.160 photos/hr). Owls were the most frequently documented predator species present accounting for 48% (181 of 377) of hourly photos containing predator species. Owls were present in 7% of all hourly photos in sandy habitat. With both bull trout (Chapter 3) and owls were present in the varial zone only at night. With night covering 44% of the sampling period, it was estimated that bull trout have a 16% chance of passing an owl during migration through this sandy habitat. Game cameras deployed in other areas outside of the varial zones also documented owls in river channels. Owls were documented on rocks in the Deadwood River below Deadwood Dam during unnaturally low releases from the dam. Owls were also documented fishing from a fish weir on the North Fork Boise River upstream from Arrowrock Reservoir (Figure 4.11).

Discussion

Predator Identification—Of the seven species documented in this study as preying on fish in Trail Creek, only the owl is not widely known to be a typical fish predator. It was also the most frequently documented predator in this study. This high frequency of occurrence contrasts with other studies. The highest estimate for the percent of fish in an owl’s diet documented in the literature was 2.4% (Seidensticker

1968). In the remainder of the studies that documented any fish in owl diets, fish ranged only from 0.1 to 0.5% of their diet (Errington et al. 1940; Marti 1974; Jaksic and Marti 1984; Knight and Jackman 1984; Donazar 1989; Marti and Kochert 1996). Other owl species have been documented as having fish constitute up to 15.9% of their diet (eagle owl, *Bubo bubo*; Donazar 1989). With owls consistently being present in the varial zone at Deadwood Reservoir, it is highly likely that fish make up more of their diet than other areas documented in the literature. Most of the pellet studies in the literature were conducted during the spring when pellets were concentrated around nest sites and easy to collect. This spring timing coincides with high stream flows and limited shallow habitat for owls to catch fish in. In shallow varial zones, fishing opportunities for owls may be much better than in deeper water habitat. Dinets (2011) documented an Eastern Screech-Owl (*Megascops asio*) capturing fish by wading in shallow water. This is similar to the wading by owls observed in this study (Figure 4.3).

Limited data from the literature documents owls eating fish as large as 800 grams (Marti 1974). If 800 grams is the upper size limit owls could capture, this would still leave 67% of the adfluvial bull trout that migrated through the Trail Creek varial zone during this study susceptible to successful owl attacks. Juvenile bull trout migrating downstream to the reservoir for the first time would also be susceptible to owls.

It is difficult to determine why other known piscivores such as the North American river otter, white pelican and golden eagle, all of which are known to use varial zones at Deadwood Reservoir, were not documented on cameras in Trail

Creek. River otters have been documented in the reservoir itself during site visits. They are typically in the water and may not trigger the infrared motion sensor on the cameras. Golden eagles were documented during site visits to the varial zone of the Deadwood River during this study, but it is unknown why they were not documented in Trail Creek. White pelicans have been documented at Deadwood Reservoir by U.S. Forest Service staff (N. Hergenrider, Boise National Forest, Lawman Ranger District, personal communication), but never seen by BOR biologists so they likely rarely use the reservoir. The piscivores known to be present at Deadwood Reservoir that were not documented in Trail Creek typically occur in other habitat types. The three grebe species as well as the common loon are typically found in open water and not the shallow tributary mouths (Personal Observations, 2006-2013).

Predator Spatial Occupancy—The concentration of predators in the sandy habitat of varial zones suggests that this is a favorable fishing area for predators. Minimum depth areas in other sections of the varial zone in Trail Creek are similar to this sandy zone, but they are shorter and have move heterogeneous substrate (Chapter 2). The shorter distances in other sections of the varial zone may not give predators enough time to efficiently detect and capture prey. The substrate heterogeneity may have two impacts; both acting as cover and camouflage as well as causing turbulence and therefore noise to “disguise” the noise of splashing of fish moving through the shallow water.

The presence of bears being documented more often in the reference than varial zone may be due to several factors. These heavy predators may sink into the unstable sediments in the sandy areas where other much lighter predators congregate. Other food resources for bears (huckleberries) may have been plentiful enough during the years of camera operation (2011-2013) that it is not beneficial to expend energy chasing fish (Rogers 1976). With tracks being documented in the varial zones, bears may be more active foragers and their low numbers were never documented on hourly time lapse cameras during the first two years of study.

Predator Temporal Occupancy—The large number of kokanee available in the fall was associated with increasing numbers of predators. This pattern is similar to that of Restani et al (2000), who found that inter-annual variation in eagle numbers was correlated to variation in kokanee numbers. The effect of large numbers of kokanee on bull trout predation would depend on the specific temporal and spatial occupancy and densities of potential predators and prey. Whereas high numbers of kokanee might buffer bull trout from predation, they may also attract more predators and leave more residual predators once kokanee have died. In the latter case, with high concentrations of predators and no more kokanee to feed on the downstream migrating bull trout in Trail Creek may be at greater risk than at reservoirs without kokanee. More investigations would be needed to clarify these relationships.

Similarly, diel predation factors may play a role in the relation between bull trout and predation in varial zones. Even though there were 8 species of fish predator documented in the varial zone, not all of them are present at the same time of day that adfluvial bull trout are migrating (i.e., almost exclusively at night; Chapter 3). Even though osprey and eagles are better equipped to capture large bull trout, they were only active during the day, as conformed in other studies (Flemming and Smith 1990; Steenhof et al. 1980). In contrast, owls and herons were active in varial zones at night, as documented in other studies (Black and Collopy 1982; Rudolph 1978), and are thus more likely to prey on the night-migrating bull trout. The varial zone of Trail Creek, at its longest, is 1,225 m and bull trout migrate through this zone in a single night (Chapter 2). With its short length and travel times the 18-21% of the radio tagged bull trout population dying or expelling their tags in the varial zone of Trail Creek each year is disproportionately high. In addition, the concentration of tag loss in the 100% sandy area of the varial zone, where predators were most prevalent, is consistent with the idea that the physical characteristics of the varial zones may be contributing to higher than natural mortality rates on migratory bull trout. Even though some fish were documented to be too large for predators to successfully capture, they can be injured by predators during passage and may also die later (Figure 4.12).

Possible Mitigation Measures— Although it would be difficult to mitigate for increased predation risk caused by the shallow sandy habitat with physical habitat modifications, but changes to reservoir operations could mitigate for these impacts. Bull trout upstream migration typically occurs before reservoir levels reach their lowest level and varial zones are at their shallowest (Chapter 2). Downstream migration however typically occurs when reservoirs are at or near their lowest levels. If reservoir water level elevations can be raised to flood the shallow delta areas before downstream migration it would probably make it more difficult for predators to capture these threatened fish. Increasing water levels before downstream migration would also limit the amount of active down cutting in turn limiting the risk of bank sloughing and increased turbidity levels.

Other deterrents to predation may be worth considering. The Idaho Department of fish and Game has attempted to mitigate for American white pelican predation on Yellowstone cutthroat trout in multiple ways (Teuscher and Scully 2008). Wires placed across places where “cutthroat trout are highly vulnerable” had flagging tied to them to discourage pelicans. Teuscher and Scully (2008) showed that this decreased the rate of bird scars on cutthroat trout, but they were not specific on habitat conditions where “cutthroat trout are highly vulnerable.” It is unknown if this physical deterrent would work on the species of predators found in Trail Creek. With the near continuous reservoir water level fluctuations during bull trout upstream migration any wires would have to be moved frequently. The relatively stable reservoir water levels and short time frame of bull trout downstream migration may allow for wires and flagging to be installed and remain in place for the duration of bull trout downstream migration each year.

Another possibility would be the addition of overhead cover and channelization of the area outside of the delta zone, thereby potentially reducing predation related mortality in the rest of the varial zone. This would be a more costly endeavor and some of the dynamics of riparian vegetation within the varial zone are unknown. The lack of riparian vegetation below the high water line is likely due to a combination of factors including; sediment deposition, changes in soil chemistry, long term inundation as well as inundation during the reproduction time frame. At 52 years old, the oldest documented willow is younger than all of the reservoirs in this study (Cooper et al 2006). Recruitment of willows occurs in June, when irrigation reservoir water levels are typically at their peak (Johnson 2000). The lack of riparian plants in the varial zone may be due to a lack of recruitment rather than a lack of survival due to fluctuating water levels. Additional research leading to increased survival of riparian plants in varial zones might be the least expensive means to increase overhead cover and decrease the rate of temperature increase within the varial zone.

When the delta migrated past large stumps or boulders the shallow delta itself was split, leaving a deeper channel behind the obstruction. The distance fish would have to migrate at the shallowest depths is decreased (Figure 4.13). Placing large boulders in areas that are at or near the typical end of irrigation season low water line could create breaks in the shallowest sections of the delta, increase depths and decrease predator success during downstream migration. Placing similar boulders periodically throughout the varial zone would give upstream migrating bull trout some time frames when migrating through the delta would not be as difficult. These habitat alterations could also provide habitat for the fish staging in the reservoir at the mouth of Trail Creek. However, boulders and woody debris were used as perches for predators in the varial zone during this study. Ensuring the benefits of structure placement outweigh any advantages they give predators would be an important consideration for any structural mitigation.

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Figures

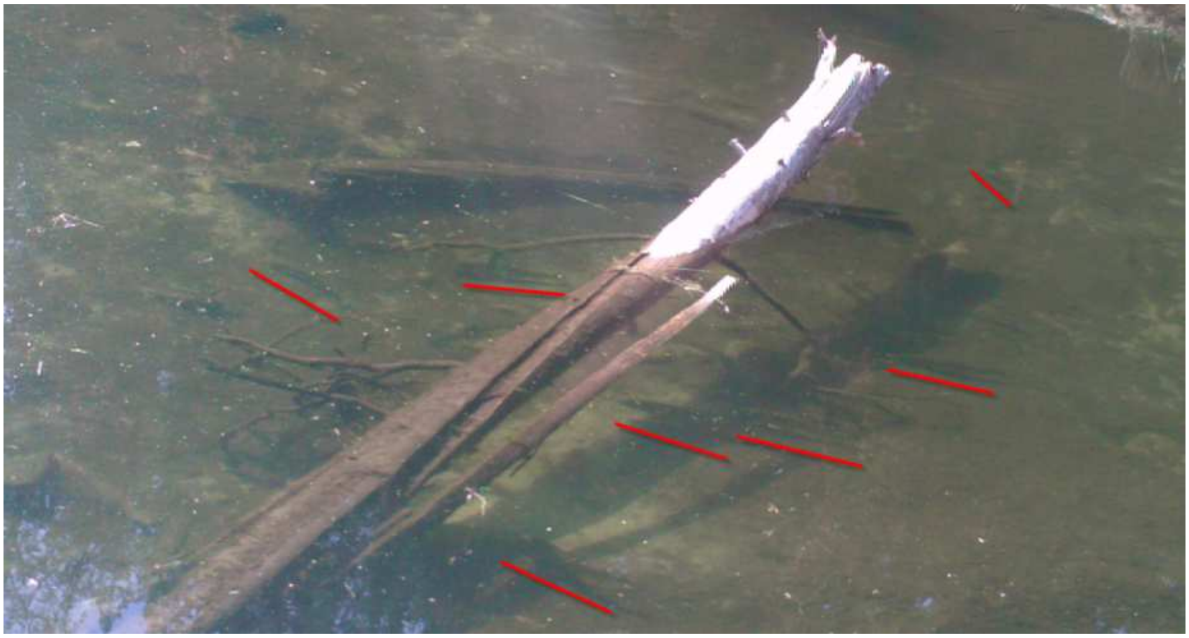

Figure 4.1. Photo of 7 bull trout from July 10, 2014. Each bull trout is underlined in red. A total of 26 bull trout were counted in this area the same day.

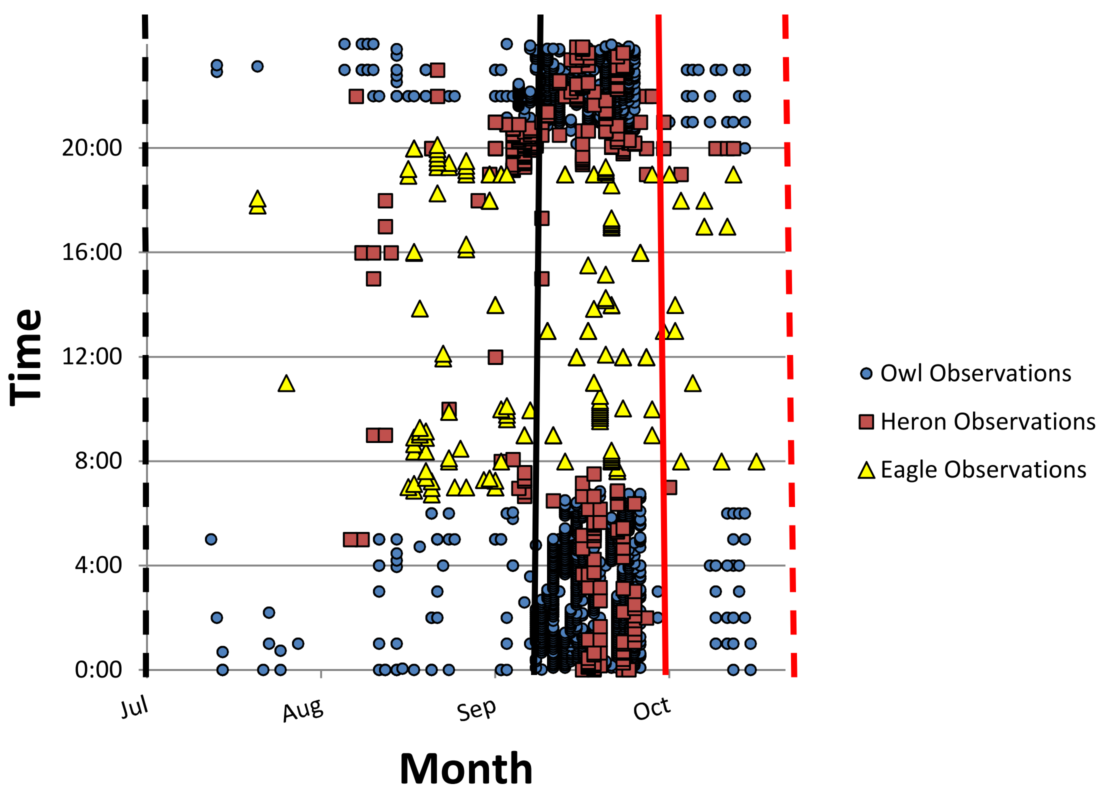

Figure 4.2. Predator seasonal and temporal occupancy patterns 2011-2013 combined. Black and red dashed lines are earliest and latest camera operating times. Black and red solid lines are time frame for bushnell cameras in 2013.

Figure 4.3. Still image from a video of a great horned owl chasing after a fish in the shallow water of the delta in Trail Creek in 2013.

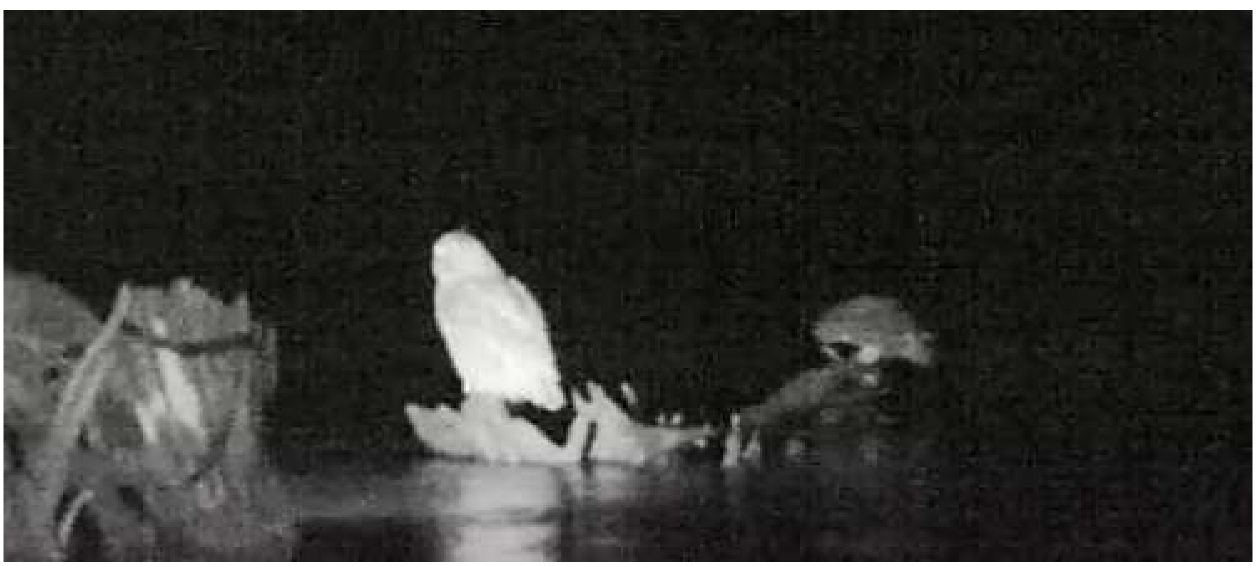

Figure 4.4. Still image from a video with one owl feeding on a fish in the background while a second owl looks for its own meal in the foreground.

Figure 4.5. Image of two great blue heron fighting in the delta of Trail Creek in September, 2013.

Figure 4.6. Great blue heron in an unsuccessful attempt to capture a large fish stranded in the shallow water of the Trail Creek Delta on September 16, 2013. This fish cannot be confirmed as bull trout, however the varial zone remote station documented four bull trout migrating downstream on this night.

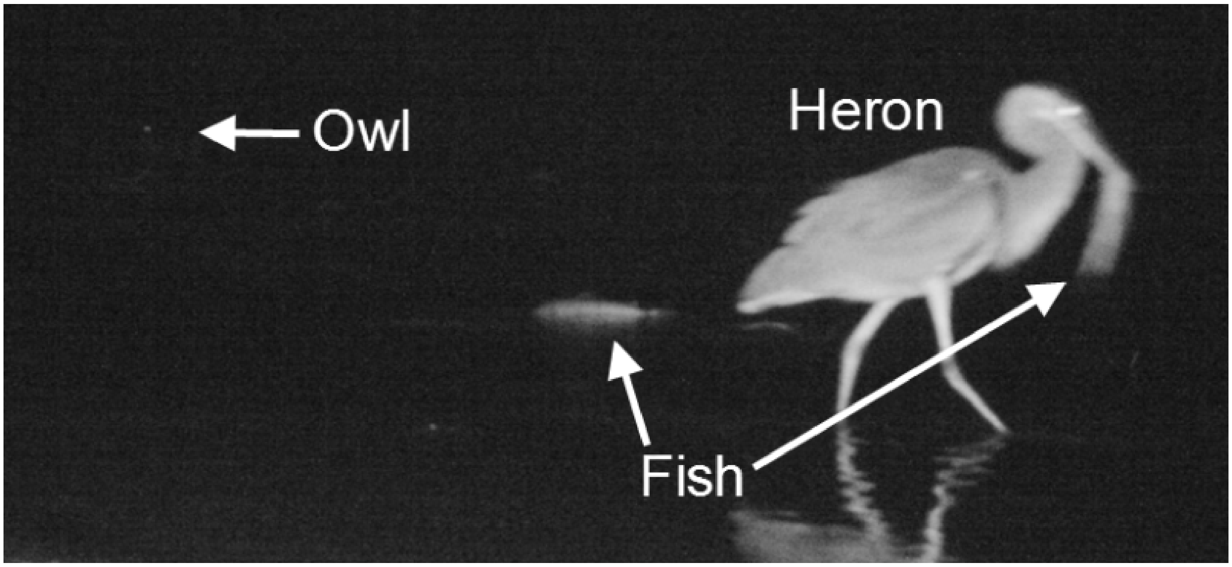

Figure 4.7. Great blue heron with a fish in its mouth and the larger fish it attempted to capture in figure 4.7 still in the background. The reflective glare of eyes in the upper left of this photo was confirmed to be an owl by another of the game cameras. These fish cannot be confirmed as bull trout, however the varial zone remote station documented four bull trout migrating downstream on this night.

Figure 4.8. Belted kingfisher flying over the delta in Trail Creek with a small fish in its beak.

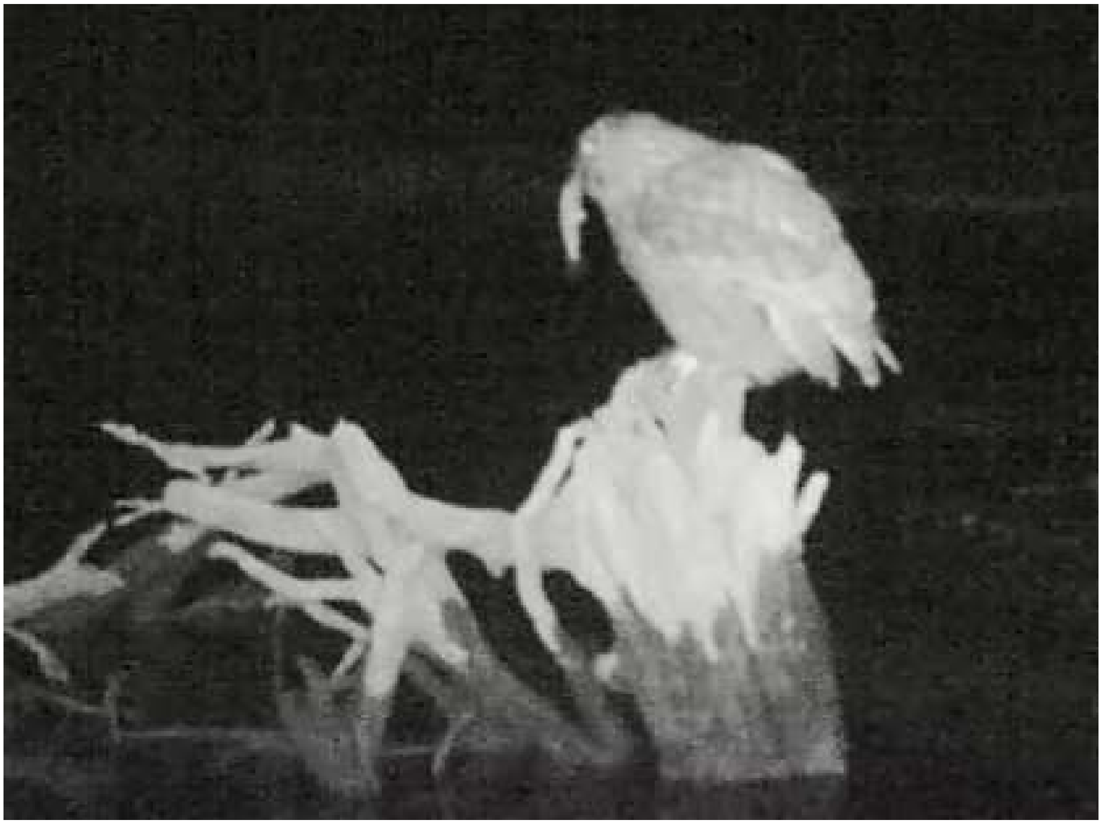

Figure 4.9. Great horned owl sitting on a stump in the "sandy" area of Trail Creek with a fish in its beak.

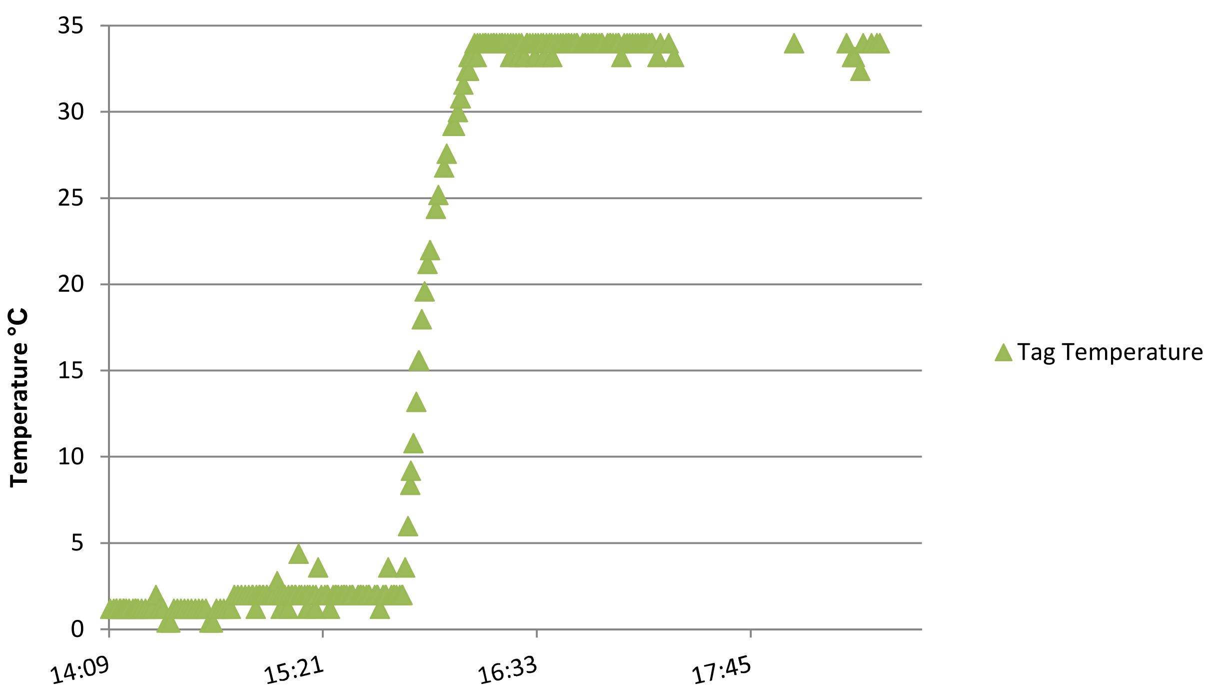

Figure 4.10. Temperature change of a bull trout radio tag swallowed by a predator. All radio tags in this study were set to a temperature scale of -6 to 34°C. Therefore, any temperatures greater than 34°C would read as 34°C.

Figure 4.11. Great horned owl on a fish weir on the North Fork Boise River.

Figure 4.12. Injuries on a bull trout from an unsuccessful predation event.

Figure 4.13. Delta of Trail Creek on September 9, 2014. The boulders in the foreground cause turbulence and create an area free of fine sediment that is deeper than the surrounding delta. The stump further back in the photo does the same thing as well as causing most of the delta to move to the right of the channel and deeper water is available downstream of the stump.

Tables

Table 4.1. Length of sandy delta area in Trail Creek, Deadwood Reservoir at various reservoir elevations and inflows.

Date	100% fine Length	Reservoir elevation	Calculated inflow
July 10, 2013	9.1	5326	129.9
August 8, 2012	34	5323	128.82
September 8, 2011	37	5309	103.77
August 30, 2012	104.5	5310	73.48
September 6, 2013	113	5296	77.7
September 4, 2013	115.9	5296	68.6

Figure 4.2. Numbers of bull trout tagged, actively tracked, determined lost (tag recovered, documented out of water, buried under sediment, or did not move at bottom of reservoir for >3 months) and percent tag loss of total active tags in each year. *Bull trout captured below Deadwood Dam in fall of 2010 and released upstream of the dam were not added to the active tags or tag loss counts until 2011. **Ground tracking was limited in 2013 and tag loss estimates could not be calculated with this methodology.

Year	Bull trout tagged in year	Total fish/tags active in year	Total tag loss in year	Percent tag loss
2006	8	8	2	25.0
2007	9	14	10	71.4
2008	7	10	4	40.0
2009	5	10	5	50.0
2010*	3	7	4	57.1
2011	7	22	4	18.2
2012	31	34	13	38.2
2013**	14	19	**	**
Total	84	124	42	42.9

Figure 4.3. Relationships between total annual percent tag loss (2006-2012) and select physical/hydrological parameters using linear regression.

P<0.05 (light shading); P<0.01 (dark shading)	Physical/ Hydrological Parameter	R^2 Tag Loss Rate	P-value Tag Loss Rate
Forebay Elevation (m)	August 1	-0.9262	0.0027
	Minimum	-0.9606	0.0093
	Date 1623	-0.9587	0.0100
	Date Full	-0.6170	0.2675
Temperatures (°C)	Date 12	-0.9703	0.0061
	Date 13	-0.8776	0.0505
	June 1	0.7130	0.0720
	Date 7 Day Average Max>13	-0.8426	0.0732
	Date 14	-0.8097	0.0968
	SummerMax	0.7811	0.1188
Calculated Inflow (m^3/sec)	Date 5.66 (200 cfs)	-0.9618	0.0089
	Date 2.83 (100 cfs)	-0.7916	0.1105
	July 1	-0.7356	0.1566
	Maximum	-0.7330	0.1589
	Date of Maximum	-0.5104	0.3796
	June 1	-0.4988	0.3923
Migration Timing	Mean Migration	-0.9611	0.0092
	First Migration	-0.8654	0.0581
	Last migration	-0.7648	0.1320