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EXECUTIVE SUMMARY

During 2004-2007 we conducted redd surveys for bull trout in the Arrow Lakes Reservoir to identify which tributaries supported adfluvial populations, to assess adult abundance for the system as a whole, and to determine the relative contribution of individual streams. We identified two non-glacial streams (Caribou and MacDonald Creeks) that contain populations of the southern bull trout genotype in the ALR, and two non-glacial (Halfway River and Kuskanax Creek) and two large, glacial streams with multiple spawning tributaries (Illecillewaet and Incomappleaux Rivers) that support populations of the northern bull trout genotype. Under favourable flow conditions ALR tributaries are well suited to the redd survey method. Redds in glacial streams can also be counted if surveys are conducted later in the fall when glacial runoff subsides. During complete surveys of all study streams in 2006 and 2007, we counted 953 and 846 redds, respectively. These values are likely modest underestimates of the total number of bull trout redds in 2006 and 2007 for the ALR as a whole. In both glacial and non-glacial streams, redd densities were highest in upstream reaches below migration barriers, while lower reaches near the reservoir contained few or no redds. The two larger glacial systems contributed almost two-thirds of the total redd count in both 2006 and 2007. However, we observed the highest density of redds in relatively small, non-glacial streams, or tributaries to the larger glacial streams. Redd counts appear to be an effective tool for assessing bull trout spawner abundance in ALR tributaries. Annual surveys could provide a direct index of the population status of adfluvial bull trout stocks in the ALR.
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1.0 INTRODUCTION

Bull trout (*Salvelinus confluentus*) are the dominant piscivorous salmonid in the Arrow Lakes Reservoir (ALR), with a recent estimated population of 7,500 catchable-sized fish (Sebastian et al. 2000). Bull trout support an annual harvest averaging about 1,000 individuals (Arndt 2004). The molecular genetic analysis of Latham (2002), funded by FWCP, suggested at least two genetic units for conservation and management among adfluvial bull trout populations, which we refer to subsequently as ‘northern’ and ‘southern’ genotypes. An early group, the ‘northern’ genotype, appears to have originally colonized the upper Kootenay River watershed, and had access above barriers (via flooding associated with pro-glacial lakes) and eventually across Canal Flats into the upper Columbia system and many of its above-barrier habitats as far south as Nakusp, where access was barred by ice that had not melted. A second, later group replaced (or amalgamated with) populations below barriers in the upper Kootenay system, which were no longer passable, and colonized habitats in the Columbia system to the south of Nakusp (MacDonald Creek and south – the ‘southern’ genotype), which had become accessible by that time. At least three other genetically distinct populations or groups of populations also exist in the upper Columbia system between Castlegar and the Mica Dam, all found only above current migration barriers in the Woden, Whatshan, and St. Leon/Payne systems (Latham 2002). These populations suggest the occurrence of other waves of colonization that were not successful in habitats downstream of barriers, and that the resident life history has evolved independently a number of times.

The original Arrow Lakes were impounded by the construction of the Hugh Keenleyside Dam at Castlegar in 1969, which raised the mean water level by 12.5 m (Pieters et al. 1998). Adfluvial bull trout losses, from construction of this dam and others (Mica Dam built in 1973 and Revelstoke Dam built in 1984) along the Canadian portion of the Columbia River mainstem, are known to have occurred, but estimates of dam impacts were made using only limited information concerning the distribution and production of adfluvial stocks in tributary habitats (Paish and Associates 1974; Martin
1976; Lindsay 1977a; Sebastian et al. 2000). Major impacts have included flooding of lower tributary reaches, decreased nutrient input from upstream sources, and, most significantly, fragmentation of mainstem habitat including elimination of fish migration from the Arrow Lakes to spawning tributaries upstream of Revelstoke Dam.

Prior to the construction of the Revelstoke Dam, biologists conducted cursory assessments of available bull trout rearing habitat upstream of the dam site, and concluded that recruitment to the ALR would be seriously curtailed by dam construction (Paish and Associates 1974; Martin 1976; Lindsay 1977a; Sebastian et al. 2000). A bull trout hatchery program for the ALR was therefore initiated in 1982 to mitigate assumed reductions in natural production, with a compensation target of approximately 4,000 adult bull trout. The hatchery program was shut down in 2000, however, because of poor contributions to the fishery and concerns about population declines in donor streams (Winsby and Stone 1996; Sebastian et al. 2000; Arndt 2004). Natural production appears to have supported relatively stable catch rates for bull trout in the ALR sport fishery from the 1970s through the 1990s (Arndt 2004). However, little is known about the population dynamics of adfluvial bull trout in the ALR, the relative contribution of the various spawning tributaries to juvenile recruitment in the reservoir, or the size of the total spawning population. In many cases, the more basic question of which tributaries actually support adfluvial bull trout populations remains unanswered.

To address these information gaps, a three-year pilot study evaluating the potential for bull trout stock assessment in tributaries to the ALR was initiated in 2004-2006 (Decker and Hagen 2007). During the study, we identified six major drainages in the Arrow Lakes Reservoir (ALR) that support populations of adfluvial bull trout, and assessed the abundance of juvenile and adult bull trout in these streams using night snorkel counts and redd counts, respectively. While juvenile abundance data were useful for identifying factors that limit bull trout rearing distributions and production, redd counts represented a direct index of the status of the adult spawner stock in the ALR, and could in future be related to the annual creel survey to assess exploitation rates and provide conservation targets. We found that redd counts were an effective tool for assessing bull trout spawner
abundance in ALR tributaries, and that under good conditions, all core spawning reaches in the ALR, including glacially-influenced streams, could readily be surveyed. A near complete count of redds in the study reaches in 2006 provided, for the first time, an estimate of the total size of the spawning population and of the relative contribution of individual tributaries. Based on these results, we recommended that annual redd counts be conducted in identified non-glacial tributaries supporting bull trout populations, and that glacial tributaries should also be surveyed in years when conditions are suitable (Decker and Hagen 2007). In 2007, we were able to resurvey all reaches included in the 2006 study. This report summarizes redd count data for 2007 together with previously reported redd count data from 2004-2006.

2.0 METHODS

2.1 Study area

Latham (2002) provides a review of the geology and ecology of the ALR and of recent anthropogenic disturbances in the basin. He also details the evolutionary history and current genetic diversity of bull trout in the reservoir and its tributaries. Briefly, the ALR is situated between the Monashee and Selkirk Mountains in the southern interior of British Columbia and is located on the mainstem of the Canadian portion of the Columbia River. The reservoir and its tributaries lie mainly within the Interior Cedar-Hemlock biogeoclimatic zone (Krajina 1959), with upper tributary reaches extending into the Engelmann Spruce-Subalpine Fir and Alpine Tundra zones. Summers are typically cool with moderate rainfall, while winters are cold with substantial snowfall. Tributary hydrographs are snowmelt driven, with peak flows during the June freshet followed by low summer and winter flows. Summer flows are elevated by modest runoff from permanent snowfields in many tributaries, and by considerable runoff from glaciers in several larger, northern tributaries (Illecillewaet, Incomappleaux, Jordan).

The landscape adjacent to the ALR is steep and rugged. Glacial erosion has resulted in hanging valleys evidenced by waterfalls that are present in most tributaries (Latham 2002). Southern tributaries (Kuskanax, MacDonald, Caribou, Burton, Snow,
Taite) tend to be short with waterfall barriers near their mouths. These tributaries are relatively steep and have highly confined channels with step-riffle-pool morphology, and predominately riffle and cascade morphology. Larger tributaries draining into what was historically Upper Arrow Lake (Halfway, Incomappleaux, Illecillewaet) are generally lower in gradient, have alluvial channels with riffle-pool morphology, and have waterfall barriers further from the reservoir.

In the Illecillewaet and Halfway rivers, migration barriers (one human-made and one natural, respectively) were altered to allow fish from the reservoir access to upstream habitat. This was done in an attempt to compensate for tributary habitat flooded by dam construction and the raising of the Arrow Lakes. In the Illecillewaet River, fish migration was blocked by the construction of a hydroelectric dam on that river in 1898, in a canyon located 2.3 km from the mouth (McBurney and Udell 1977). Prior to this, adfluvial bull trout from the reservoir likely had access to about 39 km of mainstem habitat upstream of the canyon, but from 1898 until dam removal in 1977 bull trout persisted in the upper river in a resident fluvial form only (Northern Natural Resources Services 1976). Stocking of adfluvial bull trout in Illecillewaet River and other tributaries occurred sporadically from the 1970’s until the termination of the bull trout hatchery program after 2000. In the Halfway River, a natural barrier located 10.8 km upstream of the reservoir was altered with explosives in 1990. This allowed adfluvial bull trout to access the upper river, which had historically supported the resident life-history form only (Latham 2002).

Previous work (Decker and Hagen 2007) has suggested that other migratory species from the reservoir, including rainbow trout (Oncorhynchus mykiss), kokanee (O. nerka), and mountain whitefish (Prosopium williamsoni), are unable to ascend what are now major obstructions at the sites of the former barriers in these streams (resident mountain whitefish are present in the Illecillewaet River above Box Canyon).

Fish assemblages below barriers may include adfluvial bull trout, rainbow trout (resident or adfluvial), kokanee, mountain whitefish, longnose dace (Rhinichthys cataractae) and sculpin (Cottus spp.) (Latham 2002). Above barriers in southern tributaries, fish communities are composed almost exclusively of introduced rainbow
trout and eastern brook trout (*Salvelinus fontinalis*). In northern tributaries, fish communities below barriers are similar, but above barriers, resident bull trout and slimy sculpin (*Cottus cognatus*) are more likely to be present than introduced species (Latham 2002). Native westslope cutthroat trout are present upstream of barriers in the Jordan and Akolkolex River systems.

Surveys in 2006 and 2007 included most ALR tributaries known to support significant adfluvial bull trout populations (Table 1 summarizes mean channel width, barrier locations, and accessible stream length for all tributaries and sub-tributaries surveyed). MacDonald and Caribou Creeks are located on the east shore of the reservoir south of the town of Nakusp (Figure 1). Kuskanax Creek is located on the east shore at Nakusp, and Halfway River is located on the east shore to the north of Nakusp (Figure 1). The Illecillewaet River enters the reservoir near Revelstoke, and has Greely, Albert, West Twin, and Woolsey creeks, and Tangier River as major tributaries below its barrier (Figures 2,3). The Incomappleaux River enters the reservoir on its east shore at the head of Beaton Arm near the Shelter Bay Ferry Terminal, and has numerous tributaries below its barrier (Pool, Menhinick, Sable, Boyd, Kelly, McDougal, Battle Brook, Lexington; Figures 3,4). Migration barriers delineating the accessible lengths of these streams have been identified during previous study (Decker and Hagen 2007).

In addition to barriers, several of the tributaries (Caribou, Illecillewaet, Incomappleaux, Halfway) have obstructions (partial barriers) downstream of the actual barrier, which appear to block the upstream migration of adfluvial rainbow trout and other species, but not adfluvial bull trout (Decker and Hagen 2007). Decker and Hagen (2007) found that in non-glacial tributaries with obstructions (Caribou and Halfway) or sections of difficult passage (MacDonald), juvenile bull trout production occurred mainly above the obstruction, despite some spawning below the obstruction, and that habitats downstream of the obstruction were dominated by juvenile rainbow trout. For each tributary, stream length accessible to bull trout spawners (below the barrier) has been estimated using BC Terrain Resource Information Management (TRIM) data (Decker and Hagen 2007). Additional tributaries that appear to support populations that we were
unable to survey include Snow, Burton and Hill/McKenzie Creeks, and the Jordan River (Bray and Mylechreest 1999; Sebastian et al. 2000).

2.2 Redd counts

To index adult adfluvial bull trout escapement we employed the widely used method of visual counts of redds, or excavations in the substrate associated with spawning activity and egg deposition (Rieman and McIntyre 1996; Rieman and Myers 1997; Dunham et al. 2001). Redd counts are one of the least expensive and least invasive of adult population assessment methods, and can be reliable indicators of abundance (Dunham et al. 2001), yet there are a number of considerations for their application. Rieman and Myers (1997) reviewed times series of redd count data from Idaho and Montana and found that variation in redd counts among observers/surveys made the detection of trends in individual streams unlikely over limited time scales. Dunham et al. (2001) found that although redd count data were strongly correlated with actual abundance, inter-observer variability was nonetheless a significant source of error in redd count accuracy and precision. It should be noted, however, that Muhlfeld et al. (2006) documented substantially lower levels of observer variability when experienced observers were used. As part of a long-term bull trout monitoring program in Thutade Lake watershed in north central British Columbia, Bustard (2004) made a substantive effort to reduce inter-observer variability in redd counts by establishing detailed criteria for redd identification and providing training to new crew members at the beginning of each annual survey. In order to reduce variability in redd count accuracy among observers, we also established criteria for discriminating redds (see below), and used experienced field crew to conduct the surveys. Lacking prior information about the distribution of spawning in the study tributaries, redd surveys proceeded downstream from migration barriers to the stream mouth, or until the redd encounter rate had diminished to negligible levels.

Redd surveys were conducted by two observers wearing waders and polarized sunglasses. Observers walked downstream parallel to one another on either side of the stream, or offshore in order to gain the best view of potential spawning locations.
highly confined canyon reaches (lower Halfway, Kuskanax, Caribou), one observer wore a drysuit, mask and snorkel, so that he could investigate deeper or more turbulent areas. To reduce the likelihood of underestimating total redd numbers, surveyors recorded observations of live females that were not associated with a redd (i.e., no redd was observed within 50 m of the female). We assumed these were unspawned females that would construct redds after the survey was completed. Females that have already spawned leave for downstream lacustrine or fluvial habitats shortly after the completion of spawning activities (McPhail and Murray 1979; Oliver 1979). In estimating the number of redds in each tributary, we counted each unspawned female as one redd. Crews also recorded numbers of live females associated with redds and live males.

Redds were identified as approximately dish-shaped excavations in the bed material, often of brighter appearance than surrounding substrates, accompanied by a deposit beginning in the excavated pit and spilling out of it in a downstream direction. Disturbances in the bed material caused by fish were discriminated from natural scour by: i) the presence of tail stroke marks; ii) an over-steepened (as opposed to smooth) pit wall often accompanied by perched substrate that could be easily dislodged down into the pit, and often demarcated by sand deposited in the velocity break caused by the front wall; iii) excavation marks alongside the front portion of the deposit demarcating the pit (bull trout can deposit eggs in more than one event as the redd is built in an upstream direction; Leggett 1980); and iv) a highly characteristic overall shape that included a ‘backstop’ of gravel deposited onto the unexcavated substrates, a deposit made up of gravels continuous with this backstop and continuing upstream into the pit, and a pit typically broader than the deposit and of a circular shape resulting from the sweeping of gravels from all sides to cover the eggs (in a portion of redds gravels are swept into the pit from only one side, often a shallow gravel bar on the shore side).

A second important determination was whether fish had actually spawned at a location where an excavation had been started. ‘Test digs’ were considered to be pits, often small, accompanied by substrate mounded up on the unexcavated bed material downstream but with no substrate swept into the pit itself, which would denote at least one egg deposition
event. Redds can be small, as female bull trout can spawn in more than one redd if the substrate conditions at the first location are not optimal (Leggett 1980). In the case of a ‘test dig’ determination the mound of gravels would typically be short and narrow around the downstream side of a relatively small pit. In the Thutade watershed gravel deposits associated with test digs of this description have been excavated and few have been found to contain eggs (J. Hagen and D. Bustard, personal observation).

In areas of limited gravel or high redd abundance, or where spawning site selection is highly specific, superimposition of redds upon one another can occur (Baxter and McPhail 1996). When superimposed redds were encountered, we based our counts on a subjective evaluation, with the most recent complete redd(s) counted and the disturbed remains of prior redds being estimated in relation to it. For example, if the length of the deposit was greatly extended (subjectively evaluated to be at least twice the length of a ‘typical’ deposit length), the observer would consider whether other females had made use of the pit created by a first to construct additional redds. Block (1955) observed one male bull trout spawn with three females in succession at a single redd location, which expanded with each spawning event. Fortunately, such cases usually represent a small proportion of the total number of redds present. All redd locations were recorded using hand-held GPS units (provided in a spreadsheet as a separate deliverable).

During the pilot study, Decker and Hagen (2007) found that non-glacial tributaries in the ALR were well suited to redd surveys, and providing that no high flow events preceded the survey, redds retained their original shape and were readily identified. We attempted to conduct redd surveys at the end of the spawning period or shortly thereafter (i.e., late September-early October) in order to minimize undercounting as a result of new redds being constructed after the survey, and also to minimize the risk of redds being obscured by bedload movement during a high-flow event. However, this was not possible in glacial ALR streams (Illecillewaet and Incomappleaux Rivers and most of their tributaries) because glacial runoff continues past the end of spawning resulting in excessive turbidity for observing redds. In late October 2006, when nighttime temperatures began dropping below 0°C in the ALR basin and glacial runoff had
subsided, we conducted aerial (helicopter) surveys of the mainstems of the Illecillewaet and Incomappleaux Rivers to identify the distribution of spawning activity. Foot surveys in these mainstem sections and in tributary reaches below barriers were conducted during late-October/early November 2006 and during late October 2007. Some stream sections that were observed from the air to have no redds were also included in foot surveys in 2006, as part of ground-truthing aerial observations.

The feasibility of conducting redd surveys in ALR streams in fall depends on the absence of high flow events in the span of time between spawning and the timing of the survey, and it therefore is not possible to conduct redd surveys in some years in these systems. Because of the necessary delay between spawning and redd surveys in glacial tributaries to the ALR, the likelihood that redd surveys cannot be completed each year is greater. Continuous flow hydrographs from the past are available for Kuskanax Creek (Water Survey of Canada, station 08NE006) and Illecillewaet River (WSC, station 08ND013), and we used these as indices of seasonal flows in non-glacial and glacial ALR tributaries streams, respectively, in order to estimate the likelihood that redd surveys could be completed in a given future field survey.

3.0 RESULTS

3.1 Survey conditions

During 2004 and 2005 unusually high precipitation resulted in ALR tributaries experiencing frequent periods of elevated discharge during the normal redd survey period (Table 2). Despite repeated attempts to conduct surveys in other reaches, in 2004 high discharge and turbidity limited successful redd surveys to Halfway River and Greely Creek (see Decker et al. 2005). In 2005, a redd survey was completed in MacDonald Creek during Sept 16-17. We surveyed MacDonald Creek on these relatively early dates because previous visits indicated the timing of spawning activity was earlier in MacDonald Creek compared to other ALR tributaries. A large storm event (> 80 mm rainfall in 24 hours) on September 29, 2005 increased streamflows in ALR tributaries several-fold (3 to 22 m³/s in Kuskanax Creek, Table 2). Following this storm, continued rainfall prolonged high flows in the non-glacial tributaries until the end of the survey.
window (October 15), precluding redd surveys in other tributaries. In 2004 and 2005, redd surveys in glacial streams (Illecillewaet and Incomappleaux Rivers and their tributaries) were precluded by high peak flows during the intervening period between spawning and the subsiding of glacial runoff (70 m$^3$/s and 142 m$^3$/s in 2004 and 2005, respectively, in Illecillewaet River; Table 2). A road closure also prevented access to the Incomappleaux River during the entire late fall period in 2005.

In 2006 stream flows in ALR tributaries remained low from the end of the spawning period in early October until early November (Table 2), resulting in ideal survey conditions, even several weeks after spawning had been completed. We were able to complete redd surveys in nearly all reaches where we had previously identified adfluvial bull trout populations, including the large mainstems of the Illecillewaet and Incomappleaux rivers.

In 2007 we were able to resurvey all of the streams included in the 2006 survey. Flows remained low in 2007 from the end of spawning until the completion of redd surveys in the non-glacial streams, but then increased moderately prior to the completion of surveys in the glacial streams (peak flow: 49 m$^3$/s in Illecillewaet River on September 28, Table 2). Additionally, during the 2007 survey, flows in the Illecillewaet River were about two-fold higher compared to 2006 (30 m$^3$/s versus 17 m$^3$/s, Table 2). Based on survey conditions and the appearance of redds observed, the survey crews judged that less than ideal survey conditions likely resulted in minor undercounting of redds in the Illecillewaet River mainstem and more substantial undercounting in the Incomappleaux River mainstem where redds were noticeably more scoured and difficult to identify. In tributaries of the Illecillewaet and Incomappleaux Rivers, only minor redd scour was observed. The 2004-2007 survey dates are summarized for individual streams in Table 3.
3.2 Distribution of redds within individual tributaries

In this report we have included maps (Figures 1-9) reproduced from Decker and Hagen (2007) that show survey reach boundaries and individual redd locations during surveys prior to 2007. However, because survey reach boundaries in 2007 were essentially the same as in 2006, as were general spatial patterns in redd abundance, these maps were not updated to include new information from 2007.

Redd surveys generally encompassed the entire accessible portion of each study stream, but there were several exceptions. In 2004, 2.4 km and 3.2 km long sections of the upper reach and a 9.0 km section of the lower reach of the Halfway River were not surveyed due to elevated discharge and time constraints (Figure 6). In all years, we did not survey the lowermost 2.4 km of the Halfway River because redd densities had declined to zero upstream of this, and the suitability of this unstable stream section for bull trout spawning appeared to be low. In 2007, we extended the upstream survey boundary in the north headwater fork of the Halfway River by 2.3 km (Figure 6; labelled Section 4.5 in Table 3) and found four redds below a series of substrate/debris migration barriers in this section. In the Incomappleaux River mainstem, only the upper 13.3 km of the accessible length was surveyed (Table 3; Figures 4 and 5) because this large, unstable mainstem section was deemed to have low suitability for bull trout spawning, and no redds were observed there during a helicopter survey in 2006 and associated ground-truthing (see Decker and Hagen 2007). In 2007, the survey section was reduced to the upper 11.6 km of the Incomappleaux mainstem due to poor survey conditions and low spawning potential in the section between Kelly Creek and the Mountain Hostel Resort (no redds were observed in this section in 2006 under excellent survey conditions). In the Illecillewaet River mainstem, we omitted the lowermost 10.7 km and a 7.5 km long section upstream of Clachnacdainn Creek from the survey because no redds were observed during an aerial survey of these sections in 2006 (Figures 2 and 3), and because they were dominated by large substrates and appeared to possess low spawning potential. Ground-truthing during the 2006 study suggested that helicopter surveys underestimated redd numbers in the Illecillewaet and Incomappleaux mainstems substantially (aerial redd counts represented 34% and 11% of foot survey counts, in the two streams, respectively;
Table 3), but appeared to be reliable indicators of the distribution of spawning – no redds were observed on foot in sections where redds had not been observed from the air (Decker and Hagen 2007).

Highest redd densities occurred in reaches separated from the reservoir either by major obstructions or lengthy sections of high gradient channel. Nearly all redds found in MacDonald Creek during surveys in 2005-2007 (87%-100%) were located in the upper reach (Table 3, Figure 7). The upper several kilometers of MacDonald Creek are relatively high gradient, narrow (< 15 m channel width) and contain abundant large woody debris. During 2005-2007 we observed changes in the location of the migration barrier in MacDonald Creek as a result of movements of logjams during spring freshet. Given the further increase in gradient and narrowing of the stream channel in the two headwater forks (Figure 7), however, it is unlikely that spawners would migrate much further upstream than the confluence of these forks regardless of logjam locations. For MacDonald Creek as a whole, redd numbers varied from 112 to 167 during three years of surveys (2005-2007).

The total number of redds in Halfway River in 2007 was 50% lower than in 2006 (73 versus 141 redds, Table 3), the only other year when a complete survey occurred (110 redds were counted during a partial survey in 2004). The proportion of redds downstream of the obstruction in Halfway River was also higher in 2007 (37% of the total redd count) compared to previous years (≈ 25%), suggesting that the prolonged low discharge conditions that occurred during the migration period in August-September, 2007 may have prevented some fish from successfully migrating past the obstruction and spawning in the upper reach. However, flows were relatively low in 2006 as well. The clustering of redds in the section immediately below the obstruction in all survey years (Figure 6) suggests that it constitutes a migration barrier for some fish even in years of normal flows. We assume that more bull trout would spawn above the falls if possible because juvenile rearing in the lower Halfway River appears to be strongly dominated by rainbow trout (Decker and Hagen 2007), and the reproductive fitness of bull trout spawning below the falls would be low. Near the upstream end of the spawning
distribution, we observed low numbers of resident adult bull trout spawning in the same areas as adfluvial adults. Residents were visually estimated to be of 200 to 250 mm fork length, and the redds they constructed averaged 0.3 m$^2$ compared to 2.4 m$^2$ for larger adfluvial fish (Decker and Hagen 2007).

We conducted a partial redd survey in Kuskanax Creek in 2006 that encompassed a 1.4 km section immediately below the migration barrier, and found 37 redds (Table 3, Figure 8), confirming the continued presence of an adfluvial bull trout population in this tributary. In 2007, we attempted to conduct a complete survey of the 5.0 km canyon section of this tributary downstream of the barrier (the remaining 3.5 km between the canyon and the stream mouth appears to be dominated by rainbow trout; Decker and Hagen 2007), but we were forced to abort the final 1.1 km of the survey in the canyon because of the sheer rock walls and excessive stream depths encountered. In future years, the entire canyon section could likely be surveyed if both crew members were equipped with dry suits. The total count in 2007 was 38 redds, which was likely only a small underestimate of the total number of redds considering that only two redds were counted in the lower 2 km of the surveyed portion of the canyon compared to 36 redds in the upper 1.9 km.

In Caribou Creek during July 2005, forestry personnel observed 30-40 dead adfluvial adult bull trout that had unsuccessfully attempted to ascend the obstruction at 4.1 km from the stream mouth. These fish had fallen into a small isolated pool where they succumbed to oxygen deprivation (J. Burrows, Ministry of Environment, pers. comm.). Why adults encountered difficulty in ascending these falls in 2005 is unclear, but low flows or a change in the morphology of the falls may have been contributing factors. Prior to the 2006 spawning migration, local resource agency personnel and volunteers collaborated to fill the isolated pool with concrete. We did not observe any dead adults at the obstruction during fall redd surveys in 2006 and 2007. However during the 2006 survey we observed the majority of adult bull trout and redds (31 of 49 redds and 56 of 67 adults; Table 3, Figure 9) in the lower reach below the obstruction. During the survey on September 28, 2006, redds located in the upper reach were mostly complete and few (11)
adults were still present, whereas almost all redds located downstream of the obstruction were still under construction. Moreover, redds observed in the lower reach were all clumped within the first few hundred meters immediately downstream of the obstruction. In contrast, on September 27, 2007, only 13 of the 93 redds and 23 of the 74 adults we observed in Caribou Creek were downstream of the obstruction, and spawning was largely complete. This suggests that many fish were unable to ascend the obstruction in 2006, and delayed spawning timing while attempting to navigate the falls. This obstruction is greater than 3 m in height at lower flows, and there is likely only a narrow range in flow over which bull trout are able to ascend.

The total redd count in the Incomappleaux River system was moderately lower in 2007 compared to 2006 (128 versus 165 redds, Table 3), but this can be attributed at least partly to poor survey conditions in 2007 (see section 3.1). In both years, the majority of bull trout spawning in the Incomappleaux River system took place in the upper reach of the mainstem (123 of 165 redds in 2006 and 88 of 128 redds in 2007; Table 3, Figures 4,5), with the remainder in tributary reaches. The lowest redds observed in the Incomappleaux River mainstem in 2006 and 2007 were 1.4 km and 1.0 km upstream of the Kelly Creek confluence, respectively (about 28 km upstream of the reservoir). Redd numbers in Incomappleaux River tributaries were low and similar between years (Table 3). The low number of redds observed in tributary reaches is noteworthy. Access to Lexington Creek (0 redds in 2006) appeared to be cut off at the mouth, and an unstable debris jam that re-routed Sable Creek (1 redd in 2006) across a logging road and into a drainage ditch in 2005-2006 may have diverted fish away from this otherwise suitable-looking stream. By fall 2007, the entire lower section of Sable Creek was flowing in the former bed of the logging road, and the natural channel was completely dry. High turbidity prevented us from conducting a redd survey in Sable Creek in 2007. Juvenile bull trout densities in Sable were high relative to other Incomappleaux tributaries (Decker and Hagen 2007), suggesting greater spawner numbers in years prior to the destabilization of the lower stream channel. Menhinick, Boyd and Kelly creeks all exhibited evidence of substantial channel instability, to which previous streamside forest harvesting appeared to have been a contributing factor.
Total redd counts in the Illecillewaet River system in 2006 and 2007 were fairly similar (449 and 385 redds, respectively; Table 3). As was the case in the Incomappleaux system, the majority of spawning activity in the Illecillewaet River took place in the upper reach of the mainstem above the obstruction (66% and 68%, respectively, in 2006 and 2007, Table 3), with the remainder in tributary reaches. However, above the obstruction, spawning activity in the Illecillewaet River mainstem was distributed more broadly compared to the Incomappleaux mainstem (Figures 2-5). The helicopter survey in 2006 indicated that redds were absent (or nearly so) in two highly confined sections of the Illecillewaet River mainstem, an 8.4 km section located with West Twin Creek roughly in its center, and a 4.5 km section immediately upstream of the obstruction at 4.9 km from the reservoir (Figures 2 and 3), where the channel was highly confined and dominated by bedrock and boulders.

During 2006 and 2007, Albert Creek was the most important spawning tributary in the Illecillewaet River system (69-87 redds, Table 3, Figure 2), followed by Greely Creek (42-48 redds, Figure 3) and Woolsey Creek (12-18 redds, Figure 2). In 2007, we surveyed the lower 900 m of Tangier River below the barrier (Figure 2), and found no redds. We did not survey the short section of West Twin Creek that is accessible to bull trout spawners. However, this section appears to contain little spawning habitat. The 2006 and 2007 redd counts in Greely Creek greatly exceeded the count of 14 redds in 2004 (14 redds). This may be partly due to the break-up of a debris jam that was located 400-500 m below the barrier in 2004, above which redds were abundant in 2006 and 2007. The lower section of Greely Creek near its confluence with the Illecillewaet River contains multiple braids and it is also possible that redds were missed by the survey crew in 2004, as not all braids were surveyed.

3.3 Relative abundance of bull trout among ALR tributaries

It is likely that the redd surveys conducted in ALR tributaries in 2006 and 2007 included the large majority of spawning areas utilized by adfluvial bull trout populations.
Thus, the results of these surveys provide a useful index of the relative importance of each major spawning tributary. In 2006 and 2007, there were 953 and 846 redds counted respectively, in the six drainages surveyed (Table 4). The relative contribution of each was similar between years, although, in 2007, the relative abundance of redds in the Halfway River declined, while the number of redds in Caribou Creek increased. The relative abundance of bull trout redds in the six drainages was roughly matched by the relative abundance of juvenile bull trout as estimated by snorkel surveys in 2006 (see Decker and Hagen 2007). The Illecillewaet River system is clearly the most important bull trout spawning and rearing tributary in the ALR system, with nearly half of the total number of redds in both years (47% and 46% in 2006 and 2007, respectively; Table 4). When redd numbers are combined for the Illecillewaet and Incomappleaux Rivers (614 and 513 redds in 2006 and 2007, respectively), these two relatively large, glacial systems and their tributaries accounted for 64% and 61% of the total number of redds counted in the ALR system in 2006 and 2007, respectively.

The average relative contributions of the remaining, non-glacial tributaries in 2006 and 2007 were 14% for MacDonald Creek, 12% for Halfway River, 8% for Caribou Creek, and 4% for Kuskanax Creek (Table 4). The ‘southern’ genotypic stock in the ALR (Latham 2002), as represented by MacDonald and Caribou Creeks, contributed an average of 22% of the redds counted in the ALR during 2006-2007, but this value is an underestimate because Burton and Snow creeks, which were not included in the survey, also appear to support populations of the southern stock (Bray and Mylechreest 1999). Numbers of bull trout juveniles were negligible at juvenile sampling sites in Taite Creek and Jordan River (Decker and Hagen 2007), but small adfluvial populations in these tributaries may exist as well. A small number of bull trout are known to spawn in Hill Creek (Porto and Arndt 2006), following the construction of a diversion that transfers some of McKenzie Creek into the Hill Creek system, and some adults may still spawn in McKenzie Creek as well. Prior to the diversion, Hill Creek had a very minor population of bull trout (Lindsay 1977b), and a population of approximately 60 spawners was enumerated by McPhail and Murray (1979) in McKenzie Creek. Blanket Creek was surveyed in the 1970s and found to have a very small-to-negligible run of bull trout
spawners as well (Lindsay 1977b). The contribution of these tributaries to the overall ALR population today probably remains relatively minor. Therefore, the missing redd count data from these small streams likely would not affect the above proportions greatly.

4.0 DISCUSSION

4.1 Usefulness of redd counts for estimating bull trout escapement

Redd counts have been the primary stock assessment tool for adfluvial bull trout, and as such have provided population status information for use in a number of important contexts, ranging from evaluation of population spatial structure and extinction risks (e.g. Rieman and McIntyre 1996), to evaluation of management experiments and system state changes (Chirico and Westover 1998; Bustard 2004), to identification of important natal tributaries and habitat use patterns (Bustard and Schell 2002; Pillipow and Williamson 2004). Despite the widespread application of redd counts, their reliability has only rarely been evaluated quantitatively. Redd counts within watersheds were highly correlated with independent estimates of population size for Dunham et al. (2001) and Al-Chokhachy et al. (2005). However, errors in redd counts must be reasonably low to allow relatively rapid, sensitive detections of changes in the population state (Korman and Higgins 1997; Ham and Pearsons 2000). Errors in redd counts can come from such factors as variability among observers, variation in detection rate among streams, and timing of surveys.

Dunham et al. (2001) found high levels of inter-observer variability in redd counts within particular stream sections that received replicate counts, although Muhlfeld et al. (2006) found that redd detection probability was high and inter-observer variability could be reduced to statistically insignificant levels when all observers were highly experienced. Our study protocols were designed to address this issue. All observers had redd counting experience from other studies, and the entire crew surveyed a reach together at the start of the field study each year to help standardize their observations. However, budget constraints to date have prevented us from conducting replicate counts, with the exception of stream sections that were also surveyed from the air. Comparison
of helicopter and foot surveys showed that the former greatly underestimated redd numbers, but were reliable for determining the general distribution of spawning in mainstem reaches.

In other studies spatial variability in the ratio of redd counts to independent estimates of spawner abundance has been evident. Spawner to redd ratios for the Wigwam River, British Columbia (two years’ data; Westover and Conroy 1997; Chirico and Westover 1998), Trestle Creek and East Fork Lightning Creek, Idaho (Dunham et al. 2001), and the Kaslo River, British Columbia (McCubbing and Andrusak 2006) ranged from 1.2 to 2.8 spawners per redd, averaging 2.2 spawners per redd. Our crew conducted the redd counts for the latter study, in which a resistivity counter provided an escapement estimate for comparison with the redd number resulting in an estimate of 2.2 spawners per redd. For the purpose of spawning population estimation in the ALR system, therefore, an expansion factor of two times the redd count is probably reasonable. The deployment of a resistivity counter in each of the core ALR bull trout spawning tributaries, which would take many years unless more than one counter is available, may allow a direct investigation of redd count accuracy in the ALR system. Although resistivity counters provide a promising methodology for spawning population estimation, it should be noted that their reliability has yet to be evaluated for bull trout.

Redd surveys in the glacial Illecillewaet and Incomappleaux systems likely occurred about four weeks after the completion of spawning. Earlier surveys in these tributaries are not possible due to glacial run-off, except during unseasonably cold, dry spells. The number of missed redds may have been higher in the glacial tributaries relative to the non-glacial ones tributaries that were surveyed at approximately the completion of spawning. In 2006, low flow conditions persisted from the beginning of the spawning period in September to the completion of our surveys in early November, which resulted in redds in the glacial tributaries remaining relatively clean and easy to identify. However, in 2007, flows were higher during the interim period between spawning and surveys, and also during the surveys, compared to 2005, and as a result redds were more difficult to identify, and a greater proportion were likely missed.
If redd counts are to be used to monitor the state of the ALR bull trout population, it is important that environmental conditions allow for the completion of surveys in most years. In 2004 and 2005 high flows prevented us from completing surveys in the majority of the study tributaries. However, an analysis of historical streamflow data for Kuskanax Creek (Water Survey of Canada, station 08NE006), a stream which is representative of medium-sized, non-glacial bull trout spawning tributaries in the ALR, suggested that discharge was unusually high in ALR tributaries in fall 2004 and 2005, and that the poor survey conditions we encountered were not representative of most years (Decker et. al 2006). The analysis suggested that high flow conditions could jeopardize the success of redd surveys in 20% of years. Given the inherent difficulty in conducting stream surveys in a high rainfall area, this projected failure rate is probably acceptable.

The frequency of missed surveys in glacial reaches would be higher because redd surveys must be delayed for roughly three-to-four weeks following the completion of spawning in early October to allow air temperature to drop and glacial run-off to subside. In the West Kootenay Region, fall storms and resultant high streamflows are much more common in October than in September (Decker et al. 2006), and this will increase the probability of reds becoming obscured by substrate movement before surveys can occur in glacial reaches.

### 4.2 Distribution of bull trout spawners in ALR tributaries

In general, the distribution of bull trout reds among the study tributaries in 2006 and 2007 followed the distribution of juvenile abundance in 2006 (the only year in which basin-wide juvenile abundance estimates were possible; Decker and Hagen 2007). In both glacial and non-glacial streams, redd densities were highest in the upper reaches that supported relatively high juvenile densities. In reaches below obstructions where juveniles were absent or nearly so, reds, if present at all, were found only in the immediate vicinity of the obstruction. With respect to the contribution of major drainages to overall bull trout abundance in the ALR, absolute numbers and the relative proportions of reds counted in six drainages in 2007 were similar to those in 2006, with
the two largest, glacial systems (Illecillewaet and Incomappleaux Rivers) contributing almost two-thirds of the total redd count. However, highest redd densities (redds/km) occurred in relatively small, non-glacial streams (Caribou, MacDonald, and Greely Creeks; Table 3), or tributaries to the larger glacial streams (Albert Creek). Our work to date suggests that the amount of spawning and rearing habitat for adfluvial bull trout in the upper reaches of these and other non-glacial ALR tributaries is limited. These streams are highly vulnerable to temperature increases resulting from forest harvesting activities or climate change. Temperature changes of even 1-2°C may shift habitat suitability within key bull trout rearing areas in the Arrow Lakes Reservoir basin in favour of rainbow trout (Decker and Hagen 2007), suggesting that extirpations are possible even in watersheds managed according to Forest Practices Code guidelines.

The upper reaches of MacDonald and Caribou Creeks, despite their limited accessible length (6.3 km and 1.8 km, respectively), probably support the majority of natural production for the southern genotypic stock, although this stock may also be present in Burton and Snow Creeks as well (underscoring the need to conduct reconnaissance surveys for southern-type stocks in Burton and Snow Creeks). Preserving water quality and cool temperatures in core bull trout rearing areas should be considered utmost priorities for conservation and management of all bull trout populations inhabiting non-glacial streams, and in particular populations of the southern genotype. Noting that the threshold of maximum temperature for bull trout dominance is approximately 13-14°C, the deployment of thermographs to all identified rearing reaches may be warranted as part of efforts to monitor conservation status for these populations. To facilitate special conservation actions, management steps may also include the designation of the reach as a Temperature Sensitive Stream (BC Wildlife Act, Section 15) or Fisheries Sensitive Watershed (BC Forest Practices and Range Act, Section 14). Forest harvesting in drainages containing bull trout should proceed only if increased stream temperatures can be avoided through no-harvest zones in riparian corridors and retention of mature age classes over a substantial portion of the drainage at any one time. The number of stream crossings should also be minimized to reduce the risk of landslides in these steep streams, and to limit access for those seeking to illegally harvest adults as they return to spawn.
We observed the formation or break-up of large debris jams in several ALR tributaries (MacDonald, Greely, Sable) during the course of the study. In smaller ALR tributaries, which are typically steep and highly confined, debris jams appear to form easily and can become obstructions or even barriers to upstream migration. In Greely and MacDonald creeks, the break up and formation of debris jams, respectively, resulted in markedly different spawning distributions from one year to the next. Streamflows during spawning migration can also affect whether obstructions are passable. In 2005, a large portion of the adult bull trout spawning population in Caribou Creek expired while trying to ascend a waterfall to gain access to prime spawning and rearing habitat (see section 3.1). The following year the obstruction was modified to reduce the risk of fish mortality, but late arriving fish were still unable to ascend falls due to low flows and most were forced to spawn downstream in a reach that does not appear to be used by juvenile bull trout. In 2007, under more favourable flow conditions, nearly 90% of spawning in Caribou Creek occurred above the obstruction. These observations demonstrate the vulnerability of bull trout in ALR tributaries to disturbances to the stream channel, particularly disturbances at points of difficult passage. In November 2006, a major rockslide buried the main logging road into the Incomappleaux River Valley within a canyon gorge that creates a major obstruction to fish passage; the road remained blocked in 2007. The large volume of material deposited on the road could have a significant effect on the hydraulics of the obstruction if it were cleared from the road directly into the river. The canyon is only 5 km from the reservoir, and virtually all bull trout production occurs upstream of this point. Therefore, utmost care should be taken when repairing the road, including a review of the work plan and on-site monitoring by a professional biologist. Proposals for small run-of-the-river hydroelectric projects in ALR tributaries should also be carefully reviewed by fisheries managers. Sites proposed for such projects are usually located in steep canyons where waterfalls occur. Migration obstructions and barriers for bull trout often occur at these same locations. It is common for a large proportion of a bull trout spawning population to stage for several weeks at the base of an obstruction or barrier. For example, all 59 adults observed in Caribou Creek during a pre-spawning survey on September 15, 2006 (see Decker and Hagen 2007) were within 100 m of either the barrier
or the major obstruction downstream. The construction of diversion tunnels, head pools and penstocks in canyon sections used as staging areas by adult bull trout may affect their spawning distribution and eventual reproductive success. Latham (2002) concluded that deliberate manipulation of barriers to improve passage for adfluvial bull trout may negatively impact isolated resident bull trout populations. Likewise, improving fish passage at existing obstructions may allow adfluvial rainbow trout to access upper reaches that are currently used only by adfluvial bull trout.

4.3 Footprint impacts of dam construction

Footprint impacts are the irreversible effects on a fish population(s) of dam construction and associated flooding. With respect to the lacustrine environment of bull trout populations, estimating footprint impacts of dam construction requires that footprint impacts on their primary prey species, kokanee salmon, also be taken into account. By the mid-1990’s, kokanee stocks in the ALR were substantially reduced from historic levels, likely due to nutrient retention in upstream reservoirs following construction of the Mica and Revelstoke dams (Schindler et al. 2006). Experimental fertilization between 1999-2004, likely in combination with artificial production at the Hill Creek spawning channel, appeared successful in restoring kokanee abundance to pre-impoundment levels (Schindler et al. 2006), although it should be noted that recent spawner returns since 2004 have been lower (Arndt 2008). Bull trout growth and survival conditions following reservoir fertilization also also appeared to have been enhanced (Arndt 2004), suggesting that the program has the potential to successfully mitigate footprint impacts for bull trout in the lacustrine phase of their life cycle.

This study indicated that in ALR tributaries, bull trout rearing was distributed well above the reservoir full pool line, suggesting that footprint impacts from Keenleyside Dam construction on ALR bull trout use of tributary habitats for spawning and rearing have been minimal. In contrast, we found that the lower reaches of accessible ALR tributaries were intensively utilized by adfluvial rainbow trout populations, suggesting
that the inundation of streams after the creation of the ALR resulted in footprint impacts to this species instead.

Historically, bull trout stocks in the Arrow Lakes Reservoir spawned and reared in Columbia River tributaries upstream of Revelstoke Dam (Martin 1976; Lindsay 1977; Sebastian et al. 2000), which are now tributaries to Revelstoke Reservoir. The Revelstoke Reservoir probably did inundate important bull trout spawning and rearing habitats (Martin 1976; Triton 1992; Hagen 2008). The lower reaches of most accessible streams probably contained bull trout populations, based on the influence of glaciers and permanent snowfields within tributary basins and the widespread occurrence of the species in post-impoundment sampling (Triton 1992). A recent analysis by FWCP (Hagen 2008) estimated that 29 km of potential bull trout spawning and rearing habitat would have been inundated by Revelstoke Reservoir. A further 125 km of accessible spawning and rearing habitat remains above the full pool elevation of the Revelstoke Reservoir (Triton 1992) but is now cut-off from the ALR. Thus, bull trout stocks in the ALR have experienced an estimated loss of 154 km of accessible spawning and rearing habitat.

Hagen (2008) used the estimated overall bull trout redd density in ALR tributaries in 2006 as a biostandard for estimating potential bull trout production from rearing tributaries lost to the ALR, expressed in terms of the number of spawners annually. The 2006 observations were utilized because ideal viewing conditions were present during redd surveys of all streams, particularly the glacial Illecillewaet and Incomappleaux systems, and underestimation bias was therefore as low as possible. Mean redd density in surveyed tributaries (total number divided by total accessible length, summed over all tributaries) was 6.3 redds/km (derived from Tables 1 and 3), resulting in a biostandard of 12.6 spawners/km based on an expansion factor of 2.0 spawners per redd (Section 4.1). While this biostandard was developed from ALR tributary data only, it is probably representative of potential production in the glacial tributaries to Revelstoke Reservoir because 61% of the spawning stream length and 64% of the redds counted in the ALR were associated with the glacial Incomappleaux and Illecillewaet systems (Tables 1
and 3). Interestingly, the ALR biostandard proposed by Hagen (2008) is very close to the biostandard of 13 spawners/km presented in Lindsay (1977) based on more limited sampling.

Application of the 12.6 spawners/km biostandard to the estimated 154 km of lost tributary habitat results in an estimate of 1,950 spawners annually that were lost to the ALR (this value would be less if resident (fluvial) bull trout stocks historically accounted for a portion of tributary production). In 2006, production from approximately 60 km of habitat in the Illecillewaet and Halfway Rivers above artificially-removed barriers was 558 redds (Table 3) or approximately 1,120 spawners, pointing to the significance of these compensation measures. The maximum estimated net loss to ALR bull trout production from spawning stream losses is therefore approximately 830 spawners annually (less if pre-impoundment fluvial populations are accounted for). This figure is substantially less than compensation target of 4000 adult bull trout set for the now defunct hatchery program (Sebastian et al. 2000). While changes in angler behaviour or capture efficiency have been suggested as explanations for the unexpectedly small decrease in bull trout catch rate during and after the construction of the Revelstoke Dam in the 1980s difference (from 0.067 fish/hr 1976-1979 to 0.051 fish/hr 1980-1989 and 0.059 fish/hr 1990-1997; Sebastian et al. 2000), the possibility that the actual net loss in production from ALR tributaries as a result of dam construction has been much lower than the original prediction should be given consideration as well.

5.0 RECOMMENDATIONS

1. Results from 2006 and 2007 demonstrated that tributaries in the ALR that support adfluvial bull trout populations can be readily surveyed for redds under favourable flow conditions. Redd counts are relatively cost-effective, can cover numerous reaches without the need for sub-sampling, and can be applied broadly, even in drainages with poor road access. For management purposes, redd counts, when combined with creel survey data, provide a direct index of the state of the adult spawner stock in the ALR, and are therefore an important
means of addressing several key issues with respect to lacustrine mitigation measures. Current effort in assessing adult bull trout stocks in portions of the upper Columbia Basin outside of the East Kootenay region, are inadequate for assessing the relationship between lacustrine conditions and production of adult bull trout. This paucity of information limits our ability to detect potential benefits of reservoir fertilization and to evaluate the role of piscivory in top-down regulation of lower trophic levels. Given the feasibility of monitoring adult bull trout abundance using redd counts, we recommend conducting surveys of all known spawning reaches in the ALR basin on an annual basis, streamflow conditions permitting.

2. Although the large majority of bull trout spawning and rearing areas in the ALR system were likely included in the 2006 and 2007 surveys, new surveys should be conducted in previously unsurveyed tributaries that may currently support adfluvial populations, in particular Jordan River and Taite, Burton, Snow, Hill, McKenzie, and Blanket Creeks. Because bull trout distribution is often patchy within a basin, and it appears to be within ALR tributaries, the distribution of bull trout must be verified prior to designing and conducting mitigation measures. Specific prescriptions for mitigation measures, or conservation actions in the case of highly vulnerable populations, may follow from this initial step. The identification of the total distribution of bull trout within the watershed and an estimate of the total spawning population size will also allow refinement of the footprint impact estimate, as the proportion of the total productive capacity that was impacted can be estimated.

3. Redd counts as a population assessment methodology should also be investigated in tributaries of the Revelstoke and Kinbasket reservoirs and of Kootenay Lake. Information about bull trout population states from other lake and reservoir tributaries will greatly improve our ability to learn about factors affecting production in lacustrine environments, the relative roles of stream and reservoir environments in population regulation, the role of piscivore abundance
in regulating kokanee production, and factors affecting bull trout distribution and production in tributary environments. A better understanding of these relationships is essential for designing effective compensation for footprint impacts of BC Hydro dams in the upper Columbia Basin, and for ensuring that benefits resulting from compensation measures are not outweighed by lost production in areas where bull trout populations are most vulnerable.

6.0 ACKNOWLEDGMENTS

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7.0 REFERENCES


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**Table 1.** Description of biophysical characteristics for 16 tributaries and sub-tributaries (21 reaches) in the Arrow Lakes Reservoir where bull trout redd surveys were conducted during 2004-2007. Upstream boundaries of ‘lower’ reaches are defined by migration obstructions; upstream boundaries for all other reaches are defined by migration barriers.

<table>
<thead>
<tr>
<th>Stream or reach</th>
<th>Accessible stream length (km)</th>
<th>Mean wetted width (m)</th>
<th>Mean channel width (m)</th>
<th>Mean annual discharge (m³/s)</th>
<th>Mean Aug-Sept discharge (m³/s)</th>
<th>Upstream barrier or obstruction</th>
<th>UTM Easting</th>
<th>UTM Northing</th>
<th>Distance from stream mouth (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribou (lower)</td>
<td>4.1</td>
<td>16.2</td>
<td>22.8</td>
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<td>-</td>
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<td>-</td>
<td>441088</td>
<td>5539384</td>
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<td>-</td>
<td>443832</td>
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<td>17.6</td>
<td>29.8</td>
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<td>-</td>
<td>na</td>
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<td>na</td>
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<td>Illecillewaet (lower)</td>
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<td>64.2</td>
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<tr>
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<td>21.1</td>
<td>62.4</td>
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<td>-</td>
<td>441574</td>
<td>5666259</td>
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<td>Albert (Illec trib)</td>
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<td>11.5</td>
<td>24</td>
<td>no stn.</td>
<td>-</td>
<td>-</td>
<td>439242</td>
<td>5663531</td>
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<tr>
<td>Greely (Illec trib)</td>
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<td>13.8</td>
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<td>-</td>
<td>425802</td>
<td>5651225</td>
<td>1.8</td>
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<tr>
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<td>-</td>
<td>440734</td>
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1 Barrier was not located, but accessible stream length is likely a close approximation of actual spawner distribution during the study.
**Table 2.** Summary of peak flows occurring between the fall spawning period (September 15-October 1) and potential survey windows for bull trout redd counts, and mean flows during actual surveys for two streams representing relative flow conditions in glacial (Illecillewaet River, WSC, station 08ND013) and non-glacial (Kuskanax Creek, WSC, station 08NE006) tributaries in the Arrow Lakes Reservoir during 2004-2007.

<table>
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<tr>
<th>Streams with available hydrograph data</th>
<th>Peak flow (m³/s) between spawning and survey window</th>
<th>Mean discharge during redd surveys (m³/s)</th>
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¹ Halfway River was the only non-glacial tributary surveyed in 2004.

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<th>Tributary or reach</th>
<th>Section</th>
<th>Year</th>
<th>Survey dates</th>
<th>Length (km)²</th>
<th>Redds observed</th>
<th>Redd density (redds/km)</th>
<th>Live spawners obs.</th>
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¹ Sections ordered in a downstream to upstream direction
² Numbers in brackets in ‘length surveyed’ column are actual distances surveyed
³,4 Surveys did not include all potential spawning areas within the reach
Table 3. Continued.

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</tbody>
</table>
Table 4. Estimated bull trout parr standing stocks (averaged for tributaries with more than one years’ data) and total redd numbers for six major drainages supporting adfluvial bull trout populations in the Arrow Lakes Reservoir. Also shown are the relative contributions of each tributary to total parr standing stock and redds in a given year. Values for the Illecillewaet and Incomappleaux rivers include numbers from sub-tributaries.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tributary</th>
<th>Parr standing stock</th>
<th>Proportion of standing stock</th>
<th>Redd count</th>
<th>Proportion of redd count</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Illecillewaet</td>
<td>23,276</td>
<td>48.8%</td>
<td>449</td>
<td>47.1%</td>
</tr>
<tr>
<td>2006</td>
<td>Incomappleaux</td>
<td>12,524</td>
<td>26.4%</td>
<td>165</td>
<td>17.3%</td>
</tr>
<tr>
<td>2006</td>
<td>Halfway</td>
<td>6,376</td>
<td>13.5%</td>
<td>141</td>
<td>14.8%</td>
</tr>
<tr>
<td>2006</td>
<td>MacDonald</td>
<td>3,256</td>
<td>6.9%</td>
<td>112</td>
<td>11.8%</td>
</tr>
<tr>
<td>2006</td>
<td>Caribou</td>
<td>2,089</td>
<td>4.5%</td>
<td>49</td>
<td>5.1%</td>
</tr>
<tr>
<td>2006</td>
<td>Kuskanax</td>
<td>183</td>
<td>na</td>
<td>37</td>
<td>3.9%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>47,704</td>
<td>100.0%</td>
<td>953</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Tributary</th>
<th>Parr standing stock</th>
<th>Proportion of standing stock</th>
<th>Redd count</th>
<th>Proportion of redd count</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Illecillewaet</td>
<td>na</td>
<td>-</td>
<td>385</td>
<td>45.5%</td>
</tr>
<tr>
<td>2007</td>
<td>Incomappleaux</td>
<td>na</td>
<td>-</td>
<td>128</td>
<td>15.1%</td>
</tr>
<tr>
<td>2007</td>
<td>Halfway</td>
<td>na</td>
<td>-</td>
<td>73</td>
<td>8.6%</td>
</tr>
<tr>
<td>2007</td>
<td>MacDonald</td>
<td>na</td>
<td>-</td>
<td>129</td>
<td>15.2%</td>
</tr>
<tr>
<td>2007</td>
<td>Caribou</td>
<td>na</td>
<td>-</td>
<td>93</td>
<td>11.0%</td>
</tr>
<tr>
<td>2007</td>
<td>Kuskanax</td>
<td>na</td>
<td>-</td>
<td>38</td>
<td>4.5%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>na</td>
<td>-</td>
<td>846</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Figure 1. Overview of the Arrow Lakes Reservoir showing major tributaries included in the study.
The following Figures have been removed as per FWCP policy on sensitive habitats of listed species

**Figure 2.** Upper Illecillewaet River and tributaries with aerial and foot redd survey sections and bull trout redd locations shown (2006 survey only).

**Figure 3.** Lower Illecillewaet River and tributaries with aerial and foot redd survey sections and bull trout redd locations shown (2006 survey only).

**Figure 4.** Upper Incomappleaux River and tributaries with aerial and foot redd survey sections and bull trout redd locations shown (2006 only). Aerial survey included the entire section of the mainstem from the barrier downstream to the obstruction 5 km above the reservoir (see also Figure 5).

**Figure 5.** Lower Incomappleaux River and tributaries with aerial and foot redd survey sections and bull trout redd locations shown (2006 only). Aerial survey included the portion of the mainstem extending downstream from the barrier to the obstruction 5 km above the reservoir.

**Figure 6.** Halfway River with foot redd survey sections and bull trout redd locations in 2004 and 2006 shown. A major obstruction to migration divides upper and lower study reaches in Halfway River.

**Figure 7.** MacDonald Creek with foot redd survey sections and bull trout redd locations shown (2005 and 2006 surveys only).

**Figure 8.** Kuskanax Creek with foot redd survey sections and bull trout redd locations shown (2006 survey only).

**Figure 9.** Caribou Creek with foot redd survey sections and bull trout redd locations shown (2006 survey only).