
**QUIRK CREEK POPULATION ESTIMATES AND ONE-PASS
ELECTROFISHING REMOVAL OF BROOK TROUT,
2005 and 2006**



**Alberta Sustainable Resource Development
Fish and Wildlife Division
Cochrane, Alberta**

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2005 and 2006**

Prepared by

Jennifer E. Earle, Andrew J. Paul and Jim D. Stelfox

**Alberta Sustainable Resource Development
Fish and Wildlife Division
Cochrane, Alberta**

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For information about this report, please contact:

Alberta Sustainable Resource Development
Fish and Wildlife Division
Box 1420, #228, 213-1 Street West
Cochrane, Alberta T4C 1B4, Canada

Telephone: (403) 932-2388

Cover photo: Lower blocking net at lower population estimate site on Quirk Creek.

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1.0 INTRODUCTION

1.1 Project Overview

Quirk Creek, a tributary to the Elbow River, had its fish populations surveyed in 1978 (Tripp et al. 1979), 1987 (Stelfox, J., Fish and Wildlife Division, unpublished data) and again in 1995 (Paul and Post 1996). Paul and Post (1996) noted that the brook trout (*Salvelinus fontinalis*) population in Quirk Creek increased from less than 25% of the electrofishing catch in 1978 and 1987 to greater than 90% of the catch in 1995. This prompted concern over the well being of the two native species in Quirk Creek, cutthroat trout (*Oncorhynchus clarkii*) and bull trout (*S. confluentus*). Electrofishing surveys of Quirk Creek continued in 1996 with the addition of two more sampling sites; however, results were similar to 1995 in that brook trout comprised greater than 90% of the total catch (Paul and Post 1997).

In an effort to protect the remaining bull and cutthroat trout populations, an experimental brook trout suppression project was initiated by the Fish and Wildlife Division and Trout Unlimited in 1998 (Stelfox et al. 2001). The project was designed to test the efficacy of anglers in removing brook trout from Quirk Creek by selectively harvesting this species. Quite simply, anglers who passed a detailed fish identification test were allowed to harvest all brook trout they captured in the upper half of Quirk Creek. All other species were released and any brook trout angled in the lower half of the creek were also released. In 2000, the project was expanded to allow the selective harvest of brook trout throughout Quirk Creek. Because removal of brook trout by angling had not produced the desired reduction in brook trout by 2003 (Paul et al. 2003; Paul 2004), electrofishing was used in addition to angling to selectively remove brook trout above Mac Creek in 2004. Since 1998, a comprehensive creel record was kept and all harvested brook trout were counted and measured for length and weight (Stelfox et al. 2001; Stelfox et al. 2004).

As part of the brook trout suppression project and a project looking at bull trout population dynamics throughout Alberta (Paul and Post 1996, 1997), electrofishing surveys in Quirk Creek continued from 1997 to 2006 (Paul et al. 2001; Paul 2003; Paul 2004; Dormer and Paul 2005). The following report summarizes electrofishing data collected from 1995 to 2004 and presents new data collected in 2005 and 2006.

1.2 Study Area

Quirk Creek is a tributary to the Elbow River within the Bow River Watershed. The fish community of Quirk Creek consists of brook, cutthroat and bull trout (Tripp et al. 1979; Paul and Post 1996). Brook trout were introduced into the Elbow River and have established populations in Quirk Creek and several other tributaries (Tripp et al. 1979; Stelfox and Konyonenbelt 1980). From 1987 to 1997, the entire length of Quirk Creek was open to angling under the general sportfishing regulations for Alberta's eastern slopes. In 1987, minimum-size limits of 25 cm for cutthroat trout and 40 cm for bull trout were implemented. In 1995, the harvest of bull trout was prohibited. A summary of prior fishing regulations for Quirk Creek can be found in Stelfox et al. (2001).

In 1998, Quirk Creek was designated a catch-and-release stream. However, anglers who had passed a fish identification test and were participating in an outing supervised by a volunteer

coordinator were permitted to harvest all brook trout they caught in Quirk Creek upstream of the bridge near Mac Creek (Figure 1; Stelfox et al. 2001). In 2000, the area of brook trout harvest was extended to include all of Quirk Creek (Stelfox et al. 2001). A detailed air photo of the study area is provided in Paul et al. (1999).

2.0 METHODS

2.1 Sampling Sites

Two sites on Quirk Creek were used for population estimates from 1995 to 2000 and again in 2002 to 2006 (Table 1). No population estimates were conducted at either site in 2001, as access to the creek was prohibited during late summer because of an extreme forest-fire hazard. The lower site was sampled in all 11 years and is located about 2.0 km downstream of the Mac Creek bridge. The length of this site was usually 500 m, but was shortened in 1998, 1999 and 2000 because of beaver dams. The upper site, located 2.2 km upstream from the Mac Creek bridge, was sampled from 1998 to 2006 and has consistently been 380 m in length.

In 2004, fish were captured by one-pass electrofishing 100-m sections of the upper reach, starting at the Mac Creek bridge and working 6.6 km upstream. In 2005 and 2006, one-pass electrofishing was conducted in sections 2.6 to 4.7 of the upper reach, and in a 70-m section at the lowermost end of Howard Creek. This section of Quirk Creek was selected because the 2004 data indicated it contained the highest proportion of brook trout. A second one-pass electrofishing run (recapture run) was conducted in 2006 in sections 2.2 to 4.7 and the Howard Creek section on 9 September. All brook trout captured during the one-pass electrofishing from 2004 to 2006 were removed as part of the suppression program, as were the brook trout captured from the upper population estimate site in 2005 and 2006 and from the lower site in 2004.

All sampling for fish was conducted by electrofishing. In 2005, population estimates were conducted at the upper and lower sites on 27 and 29 August, respectively, and one-pass electrofishing of the 100-m sections was conducted on 30 August. In 2006, population estimates were conducted at the upper and lower sites on 25 and 24 August, respectively, and one-pass electrofishing occurred on 26 August and 9 September. All cutthroat and bull trout captured on 26 August were marked using an adipose clip, so as to facilitate a mark-recapture population estimate when the recapture run was conducted on 9 September. One-pass electrofishing was also conducted on 19 July 2006 over a 1.4 km section of Quirk Creek near the Mac Creek bridge (1.1 km upstream and 0.3 km downstream) to obtain tissue samples from cutthroat trout for genetic analysis; all brook trout captured were removed.

2.2 Electrofishing

Fish were captured by electrofishing using a Model 15-C generator-powered or Model 12-B backpack electrofisher (Smith-Root Inc., Vancouver, WA.). The electrofishing unit was operated at 300 V continuous DC in 1995. However, given poor capture efficiency and generator overload, all electrofishing conducted after 1995 was done using pulsed DC with a frequency of 30 Hz and pulse duration of four milliseconds. During each electrofishing pass, a crew of at least three people covered as much of the site as possible and endeavoured to maintain identical spatial coverage among passes for depletion estimates. Captured fish were identified, enumerated, measured (fork length to the nearest 1 mm) and weighed (nearest 1 g) after each electrofishing pass. In 2000, such a large number of young-of-year (YOY) fish were encountered that only a sub-sample were measured and none were weighed. The sub-sample was used as a key to divide the remaining YOY fish into 10-mm size groups, assuming their size distribution was normal. The mean length from this sub-sample was converted to mean weight using a standard length-weight regression of:

$$weight = 10^{-5} \bullet length^3 .$$

This estimated mean weight was then used during the calculation of biomass. In remaining years, weights for fish < 70 mm were not generally taken and were extrapolated using the length and a condition factor of one. Weights were collected from fish captured during the one-pass electrofishing when time and resources permitted. Where this was not possible, these data were derived using length-class-specific condition factors from fish captured during the population estimates. In 2006, the average condition factor data were based on combining the 2005 and 2006 population estimate data from both upper and lower sites. In 2005, the average condition factor was based on data from both population estimate sites in that same year.

Effort was made to capture YOY of all species in the upper and lower population estimate sites and during the one-pass electrofishing in 2004, but not during the one-pass electrofishing in 2005 and 2006.

2.2.1 Efficiency

Electrofishing efficiency was estimated for the population estimate sites, as well as the one-pass electrofishing. At the lower and upper population estimate sites, efficiency was calculated by dividing the number of fish of each species caught during the first pass by the population estimate for the site. Only fish >70 mm were used in the determination of efficiency.

For the one-pass electrofishing, efficiency was calculated for several size classes of cutthroat trout as the number initially caught and marked divided by the population estimate. Because population estimate data were not available for brook trout (i.e., all brook trout were removed), the cutthroat trout efficiency data was applied to brook trout, on the basis of similar efficiencies encountered at the upper and lower population estimate sites. The efficiencies then allowed calculation of a population estimate for brook trout by dividing the number caught on the marking run by the efficiency for that size class. This also permitted us to determine the proportion of the brook trout population removed on the second one-pass run, by comparing the number caught on the second run to the estimated number of brook trout remaining following the first run.

2.2.2 Capture Probability Modelling

Closed-population capture probability models were fit to the cutthroat trout mark-recapture data collected from Quirk Creek on 26 August and 9 September, 2006. Data were split into three size categories: small (S, 71–150 mm); medium (M, 151–200 mm) and large (L, >200 mm). Capture probabilities ($p_{i,j}$) were dependent on size (i , three sizes) or time (j , two occasions). A series of six different capture models were fit using MARK (<http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm>). The best fitting model has the lowest corrected Akaike Information Criteria (AIC_c) score.

2.3 Population Estimates

Abundance estimates were determined by removal-depletion methods at the upper and lower sites. Each site was isolated at its upstream and downstream ends with blocking nets (12 mm stretch diagonal) to close the population. Once nets were in place, a minimum of three electrofishing passes were completed on each site. Total abundance was determined using the generalized removal model of Otis et al. (1978). Ninety-five percent confidence intervals for these estimates were based on the log-likelihood profile assuming a binomial distribution of captured fish (Otis et al. 1978). Calculations were done using computer programs written to analyze the 2004 data (Dormer and Paul 2005) for the statistical environment R (Ihaka and Gentleman 1996).

A mark-recapture population estimate was conducted for cutthroat and bull trout in 2006 on the one-pass electrofishing section. No blocking nets were used and the marking and recapture runs were conducted within a two-week period. Where a sufficient number (i.e., 7) of recaptures occurred, population estimates were calculated according to size range. Estimates were determined using Chapman's modification of the Petersen formula (Chapman 1951). Ninety-five percent confidence intervals for these estimates were based on the normal approximation. Chapman's formula is:

$$N^* = \frac{(n_1+1)(n_2+1)}{(m_2+1)}$$

where N is the true population size; N^* is the estimate of the true population size; n_1 is the number of fish marked; n_2 is the number of fish in the recapture sample (marked plus unmarked); and m_2 is the number of marked fish in the recapture sample.

Brook trout x bull trout hybrids were counted as brook trout in the analyses of population estimate and one-pass electrofishing data.

2.4 One-Pass Electrofishing

Most of the sections sampled during one-pass electrofishing were 100 m in length; however, there were several exceptions. Because the flag separating sections 3.8 and 3.9 was placed in the wrong location in 2005, the data for these two sections was combined and then equal numbers of fish were assigned to each section. Section 4.3 was only 40 m in length and was sampled in both 2004 and 2005. The numbers for this section were reported as number of fish per 40 m and were not extrapolated to number per 100 m. In 2005, sections 4.4 to 4.7, plus an additional 30 m, were electrofished as one continuous unit. For purposes of reporting, these data were divided by the total distance sampled and reported as number of fish per 100 m.

2.5 Hybrid Identification

Since 1999 in the upper site and 2002 in the lower site, brook trout x bull trout hybrids captured by electrofishing were identified by Jim Stelfox. Since the same individual did not identify hybrids in all years, data on hybrids have not been summarized for years prior to those indicated above. Genetic analyses conducted on 61 suspected hybrids collected from Quirk Creek during the 1998–2002 period confirmed that they were all hybrids (Ryan Popowich personal communication). Hybrids were identified in the field based primarily on the presence of pale spots or faint black markings on the dorsal fin and faint worm-like vermiculations on the dorsal surface.

2.6 Abundance and Biomass

To understand the spatial distribution of fish within Quirk Creek, catch rates for the three species in each 100-m electrofishing section (starting at Mac Creek and proceeding upstream) were used as an index of density. Catch rates were expressed as fish captured per section (usually 100 m in length). Data were also presented as percent species composition per section.

Weight data were used to examine differences in biomass between sections. These data were presented in terms of species-specific weight per section.

2.7 Habitat

Measurements of wetted width were recorded every 20 m for the entire creek in 2004 and every 10 m from section 2.1 to 3.9 of the upper reach in 2006.

3.0 RESULTS AND DISCUSSION

3.1 Population Estimates

3.1.1 Size Distribution

Brook Trout

In 2005 and 2006, large (>200 mm) brook trout continued to be very scarce in the lower and upper population estimate sites relative to during the 1997–2000 period (Figures 2 and 3). This decline was first evident in the 2002 data. The scarcity of large brook trout in the last few years may be a result of angler harvest in both reaches and the removal of brook trout by electrofishing in the upper reach. Using model simulations, Paul et al. (2003) predicted large brook trout would be substantially reduced in number following the start of the brook trout suppression program.

The recruitment of YOY brook trout continued within Quirk Creek in 2005, as YOYs (<70 mm) were captured in both the lower and upper sites. Relatively fewer YOY were captured in 2005 than in 2004 in the upper site, whereas the opposite was true in the lower site. In 2006, YOY were not captured in the upper site and were almost absent from the lower site. Paul et al. (2003) hypothesized that recruitment would occur regardless of the suppression program, as brook trout become sexually mature at sizes that are relatively invulnerable to angling. However, the suppression program may reduce YOY recruitment sufficiently to allow native fishes a competitive advantage (Peterson et al. 2004).

Cutthroat Trout

In the lower site, the proportion of large (>200 mm) cutthroat trout increased in 2006 relative to 2005, primarily due to a decline in the number of small cutthroat trout (Figure 4). In the upper site, large (>200 mm) cutthroat trout, while still not numerous, accounted for a greater proportion of the catch in 2005 and 2006 than they have since 2000 (Figure 5).

In 2005, no YOY cutthroat trout were captured in the lower site and this life stage was virtually absent from the upper site. YOY were more abundant at both sites in 2006, but were still well below densities recorded in 2003. The strong cohort of YOY cutthroat trout at both sites in 2003 carried over to a strong age-1 cohort in 2004, but was not as prominent in 2005. Based on the 2003 data, it was speculated that cutthroat trout recruitment had benefited from brook trout suppression (Paul 2004). Peterson et al. (2004) reported higher survival rates for YOY cutthroat trout when brook trout had been removed from stream channels. However, given the data from the last three years, it is not possible to validate this hypothesis.

Presumed age-1 cutthroat (80–105 mm) were relatively abundant at both sites in 2005, indicating that the YOY class of the previous year was stronger than the 2004 length-frequency data suggested. This was probably due to late emergence of YOY cutthroat trout in 2004. In 2006, numbers of presumed age-1 cutthroat were low at both sites. However, their presence indicates that some successful reproduction occurred in 2005, despite the occurrence of several severe floods in June 2005.

Bull Trout

Presumed adult (>250 mm) bull trout have been scarce or absent at both sites since 2000, but bull trout >200 mm have increased in proportion in 2005 and 2006 relative to the previous two years (Figures 6 and 7). For the first time during this study, an abundance of YOY bull trout was captured in the upper site in 2005. Unfortunately, this strong year class was not evident in 2006, since no bull trout smaller than 150 mm were captured. However, an abundance of age-1 brook trout x bull trout hybrids in the 108–149 mm size range were captured at the upper site in 2006, which suggests that the YOY bull trout captured in 2005 were actually hybrids that were too small to be readily identifiable as hybrids.

3.1.2 Composition

The decline in relative abundance of brook trout, which began at both sites in 2003, continued at the upper site in 2005 but not 2006 (Table 2). At the lower site, the percent composition of brook trout increased for the third consecutive year. Simultaneously, the cutthroat trout composition at the lower site continued to decline from a high of 63% in 2003 to 18% in 2006.

The percent composition of bull trout has remained small relative to the other two species. Out of the eight years of data for the upper site, it was highest in 2005, suggesting that bull trout abundance was increasing. Unfortunately, it appears that the increase in bull trout in 2005 was due to misidentification of YOY hybrids as bull trout. Since YOY comprised about half of the bull trout catch in 2005, there should have been numerous age-1 bull trout in the catch in 2006. Although, no bull trout in the age-1 size range were caught in the upper site in 2006 (Figure 7), about three times as many hybrids as bull trout were caught and all 22 hybrids were age-1 fish in the 108–149 mm size range. Hybrid data are further discussed in Section 3.4. At the lower site, bull trout abundance in 2005 and 2006 was slightly higher than in most years, but lower than the high of 9% recorded in 2004.

3.1.3 Abundance and Biomass

Densities of large (>150 mm) brook trout at both sites in 2005 and 2006 changed little relative to the two previous years and were well below the highs recorded during the 1998–2000 period (Figure 8 and Tables 3 to 5). Although the density of YOY (< 70 mm) brook trout increased at the lower site in 2005, densities of YOY at both sites in 2006 were among the lowest recorded since the study started. In contrast, the density of brook trout in the 71–150 mm size range at the upper site in 2006 approached the high recorded in 2000, and was about twice the density recorded in the lower site.

In 2005 and 2006, densities of cutthroat trout >70 mm declined substantially at both sites relative to the highs recorded in 2004 (Figure 9 and Tables 4 and 5). Similarly, YOY (< 70 mm) cutthroat trout were absent from the lower site and very scarce at the upper site in 2005, likely reflecting poor survival due to the severe June floods and/or late emergence due to the cold summer. Although there was only a modest increase in the density of YOY cutthroat trout in the upper site in 2006, this was still very encouraging, given that no YOY brook trout were captured at this site for the first time since this study began (Figures 3 and 8 and Table 4).

A strong year class of YOY cutthroat trout in 2000 did not translate into increased densities or a shift in size distribution for subsequent years (Dormer and Paul 2005). This infers that the 2000 cutthroat trout year class was subject to high mortality in subsequent years. The 2000 cutthroat trout year class coincided with high densities of brook trout of all size classes. Therefore, high mortality for this cutthroat trout year class may have occurred through predation or competition with abundant brook trout (Peterson et al. 2004). In contrast, the strong 2003 cutthroat trout year class was subjected to a smaller brook trout population and experienced good survival, based on the increase in large (>70 mm) cutthroat trout in 2004. These results are consistent with patterns in survival observed by Peterson et al. (2004). However, the decline in abundance of large (>70 mm) cutthroat trout suggests poor recruitment in subsequent years.

At the lower site, the biomass of brook trout >150 mm was considerably lower in 2005 and 2006 than during the 1997 to 2002 period (Tables 4, 6 and 7). At the upper site, the biomass of brook trout >150 mm was higher than at the lower site during the 2004 to 2006 period, but was still considerably lower than during the 1998 to 2000 period.

The biomass of cutthroat trout was calculated for only two size classes due to lower numbers of fish overall (Tables 4 and 7). Since 1997 at the lower site, the biomass of cutthroat trout >70 mm has ranged from 6.0 kg/km in 2000 to 2.8 kg/km in 2002, but has remained similar in the last three years. Despite the substantial decline in density since 2004 (Figure 9), biomass of cutthroat trout has remained near 5 kg/km at the lower site, reflecting an increase in large cutthroat trout at this site (Figure 4).

Similarly, at the upper site, the substantial decline in density since 2004 has not been accompanied by a similar decline in biomass of cutthroat trout >70 mm. Instead, biomass of cutthroat trout >70 mm reached a high of 9.8 kg/km in 2005, reflecting an increase in large cutthroat trout at this site (Figure 5). Although the biomass was slightly lower in 2006, it was still high in comparison to the low of 0.4 kg/km in 2002.

3.1.4 Electrofishing Efficiency

Between 1998 and 2006, the average electrofishing efficiencies on the first pass for brook trout (0.59) and cutthroat trout (0.61) were very similar at the lower site (Table 8). At the upper site, the average proportion of cutthroat trout caught on the first pass (0.72) was higher than that for brook trout (0.63). A possible explanation for the difference at the upper site could be related to the larger average size of cutthroat trout in the last few years (see Section 3.2.1). Differences in efficiency exist between size groups; larger fish have higher catch efficiencies than smaller fish (see Sections 3.2.5 and 3.2.6). This could account for the electrofishing efficiency for cutthroat trout being lower than for brook trout in 2004, but higher than for brook trout in 2005 and 2006.

3.2 One-Pass Electrofishing

3.2.1 Size Distribution

The absence of small (YOY) fish captured during the one-pass electrofishing of 100-m sections of upper Quirk Creek after 2004 should not be interpreted to mean that recruitment has been poor since then (Figures 10 to 12). Rather, it reflects the lack of effort to capture YOY fish after 2004. Furthermore, it should be noted that the one-pass electrofishing in 2004 covered roughly three times more distance, which accounts for the greater number of fish caught in 2004.

Brook Trout

In all years, brook trout in the 90 mm to 200 mm size range — presumed age-1 and age-2 fish (Table 9) — have dominated the catch, while the abundance of large (>200 mm) brook trout has declined (Figure 10). This is also evident by a decline in the mean length of >70 mm brook trout, from 146 mm in 2005 to 119 mm in September 2006 (Table 10).

Cutthroat Trout

Presumed age-1 (60–100 mm) cutthroat trout declined in relative abundance after 2004 (Figure 11), mirroring the data from the upper population estimate site (Figure 5) and suggesting that there has been little successful recruitment to this age class since then. The scarcity of fish in this size class, in conjunction with relatively good survival of larger cutthroat trout, has resulted in the mean length of >70 cutthroat trout increasing substantially since 2004 (Table 10) and remaining well above that of brook trout.

Bull Trout

In all years, the proportion of bull trout <120 mm captured during the one-pass electrofishing (Figure 12) was much lower than for the other two species. This likely reflects the greater tendency of small bull trout to use the interstitial spaces in the substrate for cover, thus making them less likely to be captured during electrofishing. Partially due to the absence of these smaller fish, the mean length of bull trout captured was greater than that of the other two species in all years (Table 10). Although slightly fewer bull trout were captured during the one-pass electrofishing in 2005 and August 2006 than in 2004, the number caught in the last two years is encouraging, considering that the distance shocked in 2004 was roughly three times longer. The decline in mean length and number of bull trout between the August and September surveys in 2006 was unexpected. To some extent, this may have been due to large bull trout rapidly migrating downstream after spawning in this section of Quirk Creek, which is known to be the main spawning area for bull trout. However, there was also a decline in the abundance of sub-adult (<210 mm) bull trout captured in September.

3.2.2 Composition

Despite removing all brook trout captured by one-pass electrofishing from 2004 to 2006, as well as within the upper population estimate site in 2005 and 2006, the percentage of brook trout in the catch in sections 2.6 to 4.7 has changed relatively little (Table 11 and Figure 13). Even after removing 821 brook trout from sections 2.2 to 4.7 on 25 and 26 August 2006 (Table 5), the percentage of brook trout in the catch on 9 September in sections 2.6 to 4.7 only declined to 66%, from 76% two weeks earlier (Table 11). When the entire upper reach was electrofished in

2004, brook trout in sections 2.6 to 4.7 comprised 71% of the fish population, which was higher than in the other portions of the creek (Table 11).

With the exception of the 9 September 2006 catch, the percentage of brook trout in the one-pass electrofishing catch during the 2004–2006 period (Table 11) has been consistently higher than in the upper population estimate site (Table 2), while the percentage of cutthroat trout has been consistently lower. Other than these differences, the trends observed in the species composition of the one-pass electrofishing catch roughly parallel those of the upper population estimate site.

Interestingly, the species composition of the one-pass electrofishing catch near the Mac Creek bridge on 19 July 2006 was also virtually identical to that recorded during the one-pass electrofishing further upstream on 26 August 2006 (Table 11). However, within the 1.4 km section electrofished in July, there was a relatively large difference in the percent of cutthroat trout in the catch; cutthroat trout comprised 25% of the catch in the 0.3 km section immediately downstream of the bridge, but only 12% of the catch in the 1.1 km section immediately upstream of the bridge. This may reflect the higher gradient and lower silt levels evident in the section below the bridge.

3.2.3 Abundance and Biomass

From 2004 to 2006, a total of 3131 brook trout, with a combined weight of 114.4 kg, were removed from Quirk Creek by electrofishing (Tables 5, 7 and 12). In all three years, the only area of Quirk Creek in which one-pass electrofishing has been consistently conducted to remove brook trout is sections 2.6 to 4.7. This area had a much higher density and biomass of brook trout in 2004 than the other portions of the upper reach (Table 12, Figures 14 and 15), which is why it was selected for one-pass electrofishing removal of brook trout after 2004. Despite removing all brook trout captured by electrofishing in sections 2.6 to 4.7 since 2004, the number and biomass of brook trout captured in 2005 and August 2006 within this area was relatively similar to what was captured in 2004 (Table 12). However, the effect of removing 691 brook trout only two weeks earlier was evident on 9 September 2006, when only about half of the number and a third of the biomass of brook trout were captured in the same area.

Densities of brook trout in each 100 m section varied considerably within and between years (Figure 14). However, the consistently high density and biomass of brook trout in some sections (e.g., section 3.0) suggests that they provide better quality habitat.

The upper population estimate site—sections 2.2 to 2.5—had a density of 13 brook trout/100 m in 2004 (Table 12). This is relatively similar to the overall density of 16 brook trout/100 m recorded for the entire upper reach in 2004 and suggests that the upper population estimate site is fairly representative of the fish community in the upper reach.

In 2004, the high density but relatively low biomass of cutthroat trout in sections 2.5 to 3.0 was primarily due to an abundance of YOY (Figures 16 and 17). In the following years, the density of cutthroat trout in sections 2.6 to 4.7 was lower, but the biomass—especially in the upper sections—was higher, reflecting a decline in small fish and an increase in the number of large cutthroat trout in this area. A similar trend was evident for the upper population estimate site during the same time period (Table 4). However, caution should be exercised when comparing

the numbers of fish (especially YOY) caught in 2004 with subsequent years, since no attempt was made to capture YOY during one-pass electrofishing after 2004.

Although the abundance of bull trout was relatively low, it is encouraging that almost as many bull trout were captured in 2005 and August 2006 as in 2004, even though a much larger area was sampled in 2004 (Table 5, Figure 18). Sections 4.0 to 4.3 appear to be an important spawning area, based on the relatively high density and biomass of bull trout captured in 2005 and August 2006 (Figures 18 and 19) and the capture of several ripe bull trout within this section in late August and early September. The substantially lower number and biomass of bull trout captured within these sections on 9 September 2006 may be partially due to spent fish emigrating to overwintering areas.

Howard Creek flows into Quirk Creek approximately 2 km upstream of the upper population estimate site. In 2005 and 2006, the lowermost 70 m of Howard Creek was sampled and the results were extrapolated to 100 m and incorporated into Tables 5, 7 and 12. Brook trout and cutthroat trout were relatively abundant in this section of Howard Creek when compared to the other sections of Quirk Creek. During the second pass in September 2006, however, only brook trout were captured. No bull trout were captured in this section of Howard Creek in either year.

During the one-pass electrofishing conducted on 19 July 2006 near the Mac Creek bridge, brook trout densities were almost 2.5-fold greater in the 300 m section immediately downstream of the bridge than in the 1100 m section immediately upstream of the bridge (Table 12). Interestingly, despite the higher density of brook trout in the section downstream of the bridge, the density of cutthroat trout in this section was 6-fold greater than in the 1100 section upstream of the bridge (Table 5). As a result, cutthroat trout comprised 25% of the catch in the section downstream of the bridge. Similarly, bull trout densities were also greater (2-fold) below the bridge, although they only comprised about 4% of the catch in both areas (Table 5). One possible explanation for the higher densities in the 300 m section immediately downstream of the Mac Creek bridge is that the gradient and amount of gravel was observed to be greater than in the 1100 m section upstream.

3.2.4 Mark-Recapture Population Estimate

A population estimate was conducted in the one-pass electrofishing site (sections 2.6–4.7) using mark-recapture methodology. Sufficient numbers of cutthroat trout were recaptured to permit a calculation of estimates for several size ranges (Table 13). Based on the population estimates, the density of cutthroat trout was highest for the 71–150 mm size range (8 fish/100 m) and was 14 fish/100 m for all cutthroat >70 mm. The combined biomass for all cutthroat trout >70 mm was 845 g/100 m.

In contrast, cutthroat trout density and biomass for fish >70 mm were lower at the upper population estimate site in 2006 (8 fish/100 m and 756 g/100 m, derived from Tables 5 and 7). Since we are regarding the upper population estimate site as representative of the upper reach, it is important to compare the available data to determine whether this is a valid assumption. While a difference was observed in the density and biomass of cutthroat trout between the two sites, a possible explanation could be related to the use of two population estimate techniques (i.e., removal-depletion versus mark-recapture). For example, in their study of rainbow trout in

small mountain streams, Rosenberger and Dunham (2005) showed that decreasing sampling efficiencies over removal passes resulted in underestimated population sizes. Alternatively, mark-recapture estimates can overestimate population sizes if significant immigration of unmarked fish into the area and marked fish out of the area occurs. The reduced number of large >200 mm cutthroat trout captured in the mark-recapture section on the recapture run (Table 13) suggests that significant emigration of large fish may have occurred.

Based on the above, it appears that the estimates from the upper population site may underestimate the true population size, while data from the mark-recapture site may overestimate the density and biomass of cutthroat trout in the upper reach. As a result, it is possible that the differences in density and biomass of cutthroat trout in the upper population estimate site and in the mark-recapture section of the creek primarily reflect the inherent biases associated with these two population estimation methods, rather than actual differences in cutthroat trout density and biomass between these two sites.

An insufficient number of bull trout were recaptured to permit calculation of a population estimate.

3.2.5 Electrofishing Efficiency

Based on the proportion of marked cutthroat trout caught during the one-pass (recapture) electrofishing run on 9 September 2006, electrofishing efficiencies were calculated for several size classes of cutthroat trout (Table 13). Not surprisingly, the data indicated that larger fish were more effectively caught during the electrofishing than smaller fish.

Since all brook trout captured during the one-pass electrofishing were removed from the creek, it was not possible to directly determine the one-pass electrofishing efficiency for brook trout. However, based on the similarity in electrofishing efficiencies for brook and cutthroat trout caught at the population estimate sites (Table 8), the efficiency data for cutthroat trout captured during the one-pass electrofishing was applied to brook trout in order to generate size-specific population estimates. This allowed an estimation of the proportion of the brook trout population removed during the one-pass electrofishing.

Of the estimated 1870 brook trout >70 mm present on 26 August 2006 in the one-pass electrofishing section, 677 were removed on 26 August (Table 14). This suggests that only 36% of this estimated brook trout population >70 mm was captured during the one-pass electrofishing on 26 August, compared to 55% of the cutthroat trout >70 mm. The lower efficiency for brook trout primarily reflects their smaller average size relative to cutthroat trout (Table 10). This difference was even more pronounced for the 9 September catch, when only 368 (31%) of the estimated 1193 remaining brook trout >70 mm were captured, which was much lower than the estimated 54% efficiency for cutthroat trout >70 mm on 9 September. The decline in electrofishing efficiency for brook trout on 9 September likely reflects the 10-mm decline in the mean length of brook trout caught relative to 14 days earlier.

Although only 56% of the estimated brook trout >70 mm were cumulatively removed by one-pass electrofishing in August and September 2006, it is estimated that 89% of the brook trout >150 mm were removed. Based on the size-maturity relationship (see Section 3.3), this means

that almost 89% of the mature females were removed from this section of Quirk Creek by the one-pass electrofishing in August and September 2006. Similarly, it is estimated that 72% and 97% of the estimated biomass of brook trout >70 mm and 150 mm, respectively, were removed by the one-pass electrofishing in August and September 2006. However, these estimates should be treated with caution, since the average size of brook trout >200 mm was smaller than for cutthroat trout >200 mm, and electrofishing efficiency is lower for smaller fish. Therefore, it is possible that the application of the electrofishing efficiency for cutthroat trout >200 mm to brook trout resulted in an underestimation of the number of brook trout present in this area and an overestimation of the proportion harvested.

3.2.6 Capture Probability Modelling

The best fitting closed-population capture model fit to the size-categorised cutthroat trout data included varying capture probabilities by size and time for only the small and large size categories (i.e., there was no time effect for medium-sized individuals). However, a more parsimonious model (with one less parameter) differed from the best-fit model by only 3.8 ΔAIC_c units. Models with ΔAIC_c values <7 are supported by the data and should not be rejected (Burnham and Anderson 2001; Richards 2005). As this latter model (#3 in Table 15) is more parsimonious, it was selected as the best-fit to the data. Capture probabilities in model #3 differed by size, but only by time for the largest individuals. Parameter estimates for model #3 are provided in Table 16. All other more parsimonious models were not supported by the data as they had $\Delta AIC_c > 10$.

The capture probability for large cutthroat trout declined significantly from the first to second capture occasions (Tables 15 and 16). For fall spawning brook trout and bull trout, this decline would mostly likely be explained through the movement of fish to (or from) their spawning grounds that would have occurred between electrofishing occasions. However, as cutthroat trout are a spring-spawning species, this was not the case. Regardless, we hypothesize that the decline in capture probabilities for large cutthroat trout (>200 mm) resulted from marked cutthroat trout moving out of the study section between capture occasions, perhaps to overwintering areas. Movement of large cutthroat trout out of the study area would violate assumptions of the closed-population capture models. Therefore, estimates of capture probability and population size for these large cutthroat trout (Table 16) should be treated with caution. Finally, movement of large cutthroat trout that occurred outside of their spawning season suggests movement patterns for trout may be size-dependent. Thus, size may be an important factor in movement studies for at least cutthroat trout that span the sizes observed in this study (approximately 70–300 mm).

Although calculated in a different way, the population estimates presented here (Table 16) are in close agreement with those determined using the Chapman-modification of the Petersen estimate (Section 3.2.4). The slight difference between estimates results from two factors. First, the population estimates from Table 16 are maximum-likelihood estimates (asymptotically unbiased) and do not incorporate the '+ 1' correction term of the Chapman modification. Second, for mark-recapture models with a single capture probability (i.e., Petersen model and its modifications) there is only one degree of freedom in the model (i.e., once capture probability is estimated, population size is fixed). However, for models with more than one capture probability,

the degrees of freedom are greater than one and additional parameters in the model must also be estimated.

3.3 Length-at-Age and Maturity

In 2004, 517 brook trout (>120 mm) harvested by electrofishing between 19 August and 10 September were examined for maturity. Of these fish, 237 were female and 280 male, resulting in a female:male sex ratio of 0.85. From the 517 fish, 41% of females and 61% of males were mature (i.e., would have spawned in 2004). None of the female brook trout were spent, indicating brook trout removal occurred prior to egg deposition in 2004. The smallest mature male and female brook trout were 121 mm and 133 mm, respectively. The largest immature male and female were 223 mm and 194 mm, respectively.

The size-dependent rate at which brook trout mature differs between sexes. Male brook trout reach 50% maturity at a smaller size than females (148 mm and 172 mm, respectively); however, at 95% maturity, male and female brook trout are 200 mm and 201 mm, respectively (Figure 20). Only about 10% of females were mature by 150 mm compared to 50% of males; however, virtually all brook trout were mature by about 200 mm. On average, most male brook trout were mature by age 2, whereas most female brook trout did not mature until age 3 (Table 9).

Brook Trout Reproductive Potential After One-pass Electrofishing in 2006

If 89% of the brook trout >150 mm were removed by the one-pass electrofishing conducted in August and September 2006 (Table 14), then there would have been about 30 brook trout >150 mm left in the 2.2-km electrofishing section (sections 2.6–4.7). If 45% of these fish were females, 60% were mature and the mean length of the mature females was 190 mm, then they may have been capable of producing a total of 4050 eggs, based on an average fecundity of 500 eggs/brook trout of this size (Tripp et al. 1979). Assuming 50% survival of the eggs and annual mortality rates of 60%, there would still be 52 brook trout reaching age-4 potentially allowing the population to maintain itself in this 2.2-km section, despite removing over 90% of the mature fish in 2006.

3.4 Hybrids

Since 1998, anglers have reported catching hybrid brook trout x bull trout in Quirk Creek, with field identification based on the presence of pale spots and absence of black markings on the dorsal fin (Stelfox et al. 2001). Electrophoretic analysis of tissue samples from 61 presumed hybrids subsequently confirmed that they were all hybrids (Ryan Popowich, personal communication).

Initially, no records were kept of presumed hybrids captured while electrofishing in Quirk Creek. However, since 1999 and 2002, records have been kept of the number of hybrids captured during electrofishing in the upper and lower reaches, respectively. Although hybrids have been lumped in with brook trout for the purposes of recording species composition and size distribution of the electrofishing catch, the number of hybrids captured during electrofishing is reported in Table 17.

Hybrids have generally comprised less than 1.0% of the electrofishing catch and are usually most abundant in the upper reach, where bull trout are known to spawn. In 2003, hybrids were relatively abundant, comprising 4.5% of the catch in the upper population estimate site and 3.4% of the catch in the one-pass electrofishing section (sections 3.8–4.3) (Table 17). However, in 2006, hybrids were especially prevalent, comprising 12.4% of the catch in the upper population estimate site, where they were more than three times as abundant as bull trout. This increase in hybrid abundance was confirmed during the one-pass electrofishing conducted in August and September, when hybrids comprised 6.6% and 4.0% of the catch, respectively, and again outnumbered bull trout. Most (97%) of the hybrids in 2006 were in the 81–150 mm size range (Figure 21) and were likely age-1 fish, since an aged subset of 22 hybrids in the 108 to 149 length range were all age 1.

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Personal Communication

Ryan Popowich. Fisheries Biologist. Applied Aquatic Research Ltd. Calgary, Alberta.

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5.0 COLLECTION OF FIGURES

Figure 1 – Location of sampling sites on Quirk Creek.

Figure 2 – Length frequencies for brook trout in the lower population estimate site of Quirk Creek.

The length-frequency plot for 1995 includes both data collected during the population estimates and additional data collected on 17 August 1995 within the lower site and immediately adjacent to this site (total sample size is 73). All other years include data collected only during the population estimates (sample sizes can be determined from Table 2). Each bar represents a 5-mm size group. The 50-55 mm group for 2000 extends beyond the upper limit of the y axis and represents 61 individuals.

Figure 3 – Length frequencies for brook trout in the upper population estimate site of Quirk Creek.

All years include data collected only during the population estimates (sample sizes can be determined from Table 2). Each bar represents a 5-mm size group. The 50-55 mm group for 2000 extends beyond the upper limit of the y-axis and represents 55 individuals.

Figure 4 – Length frequencies for cutthroat trout in the lower population estimate site of Quirk Creek.

The length-frequency plot for 1995 includes both data collected during the population estimates and additional data collected on 17 August 1995 within the lower site and immediately adjacent to this site (total sample size is 4). All other years include data collected only during the population estimates (sample sizes can be determined from Table 2). Each bar represents a 5-mm size group.

Figure 5 – Length frequencies for cutthroat trout in the upper population estimate site of Quirk Creek.

All years include data collected only during the population estimates (sample sizes can be determined from Table 2). Each bar represents a 5-mm size group.

Figure 6 – Length frequencies for bull trout in the lower population estimate site of Quirk Creek.

The length-frequency plot for 1995 includes both data collected during the population estimates and additional data collected on 17 August 1995 within the lower reach and immediately adjacent to this site (total sample size is 2). All other years include data collected only during the population estimates (sample sizes can be determined from Table 2). Each bar represents a 5-mm size group.

Figure 7 – Length frequencies for bull trout in the upper population estimate site of Quirk Creek.

All years include data collected only during the population estimates (sample sizes can be determined from Table 2). Each bar represents a 5-mm size group.

Figure 8 – Linear density of brook trout in the lower and upper sites of Quirk Creek.

No data was collected in 2001. Error bars are the 95% confidence intervals. Arrows represent incalculable upper confidence intervals.

Figure 9 - Linear density of cutthroat trout in the lower and upper sites of Quirk Creek.

No data was collected in 2001. Error bars are the 95% confidence intervals. Arrows represent incalculable upper confidence intervals.

Figure 10 – Length frequencies for brook trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 11 – Length frequencies for cutthroat trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 12 – Length frequencies for bull trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 13 – Species percent composition of brook, bull, and cutthroat trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 14 - Number of brook trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 15 - Biomass of brook trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 16 - Number of cutthroat trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 17 - Biomass of cutthroat trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 18 - Number of bull trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 19 - Biomass of bull trout captured during one-pass electrofishing in 100-m sections of Quirk Creek upstream of the Mac Creek bridge, 2004–2006.

Figure 20 – Proportion of mature female and male brook trout harvested in the 100-m electrofishing sections of Quirk Creek upstream of the Mac Creek bridge in 2004.

Figure 21 – Length frequency for brook trout x bull trout hybrids captured in Quirk Creek upstream of the Mac Creek bridge, 2006.

6.0 COLLECTION OF TABLES

Table 1 – Physical description, years sampled and electrofishing effort for each of the sites sampled in Quirk Creek.

Table 2 – Species composition for fish captured by electrofishing in Quirk Creek.

Table 3 – Density (number/km) of brook trout >150 mm FL in the lower and upper sites of Quirk Creek.

The 95% confidence intervals for density are shown in brackets. Population estimates were recalculated based on all brook trout >150 mm FL rather than summing values from Table 4.

Table 4 – Capture statistics and population estimates for all electrofishing conducted on sites of Quirk Creek since 1995.

Size refers to the fork length of the indicated species and mass is the mean for the size category. The sites are: LW lower site and UP upper site.

Table 5 – Number of fish captured by electrofishing in Quirk and Howard creeks.

Table 6 – Biomass (kg/km) of brook trout >150 mm FL in the lower and upper sites of Quirk Creek.

Biomass was recalculated based on all brook trout >150 mm FL rather than summing values from Table 4.

Table 7 – Biomass (g) of fish captured by electrofishing in Quirk and Howard creeks.

Table 8 – Electrofishing efficiency of brook trout and cutthroat trout >70 mm caught on the first pass of electrofishing in the lower and upper population estimate sites, 1998–2006.

Table 9 – Length-at-age and maturity of brook trout captured in Quirk Creek.

Table 10 – Mean length of fish >70 mm caught during one-pass electrofishing in the upper reach of Quirk Creek.

Table 11 – Species composition for fish >70 mm captured by one-pass electrofishing in Quirk Creek.

Table 12 – Number and biomass of all brook trout removed from Quirk Creek by one-pass electrofishing.

Table 13 – Electrofishing efficiency, population estimates and associated number and biomass for cutthroat trout within the one-pass electrofishing section, based on the mark-recapture method, 2006.

Table 14 – Estimated percentage of brook trout removed in 2006 within sections 2.6 to 4.7.

Table 15 – Closed-population capture probability models fit to the cutthroat trout mark-recapture data collected from Quirk Creek on 26 August and 9 September, 2006.

Data were split into three size categories: small (S, 71-150mm FL); medium (M, 151-200mm FL) and large (L, >200mm FL). Capture probabilities ($p_{i,j}$) were dependent on size (i, three sizes) or time (j, two occasions). A series of six different capture models were fit using MARK (<http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm>). The best fitting model has the lowest corrected Akaike Information Criteria (AICc) score; increasing AICc scores are reflected through the $\Delta AICc$. Parameter number reflects the number of different capture probabilities (shown under the Model column) plus three additional parameters for size-dependent population estimates.

#	Model	AIC _c	ΔAIC_c	Parameters
1	$p_{S,1}$ $p_{S,2}$ $p_{M,1} = p_{M,2}$ $p_{L,1}$ $p_{L,2}$	-1106.97	0	8
2	$p_{S,1}$ $p_{S,2}$ $p_{M,1}$ $p_{M,2}$ $p_{L,1}$ $p_{L,2}$ (full model)	-1105.34	1.623	9
3	$p_{S,1} = p_{S,2}$ $p_{M,1} = p_{M,2}$ $p_{L,1}$ $p_{L,2}$	-1103.17	3.802	7
4	$p_{S,1} = p_{S,2}$ $p_{M,1} = p_{M,2}$ $p_{L,1} = p_{L,2}$	-1086.83	20.14	6
5	$p_{S,1} = p_{M,1} = p_{L,1} = p_{S,2} = p_{M,2} = p_{L,2}$	-1064.47	42.5	4
6	$p_{S,1} = p_{M,1} = p_{L,1}$ $p_{S,2} = p_{M,2} = p_{L,2}$	-1062.45	44.516	5

Table 16 – Parameter estimates for the cutthroat trout mark-recapture data fit to model #3 from Table 15 (selected as the most parsimonious model supported by the data).

The confidence intervals (lower and upper) are based on the profile likelihood. Capture probabilities ($p_{i,j}$) are broken into size categories (small, medium or large) and sampling times based on Table 15. Population estimates (N_i) are also broken into the three size categories.

Parameter	Size category (mm)	Estimate	Lower	Upper
$p_{S,1} = p_{S,2}$		0.36	0.26	0.47
$p_{M,1} = p_{M,2}$		0.60	0.47	0.71
$p_{L,1}$		0.94	0.84	0.99
$p_{L,2}$		0.63	0.51	0.75
N_S	71 150	181	141	301
N_M	151 200	73	65	92
N_L	>200	65	64	68

Table 17 – Number and relative abundance of brook trout x bull trout hybrids captured by electrofishing in Quirk Creek.