# SPORTFISH POPULATION DYNAMICS IN AN INTENSIVELY MANAGED RIVER SYSTEM

by

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# ABSTRACT

The Elk River valley is intensively utilized by various resource industries including a recreational fishery that predominates in the river section between Sparwood and Elko. Most angling comes from fly-fishers in drift boats who mainly target westslope cutthroat trout (WCT) *Oncorhynchus clarkii lewisi* in the summer, but also secondarily catch bull trout (BT) *Salvelinus confluentus*. Non-native rainbow trout (RB) *Oncorhynchus mykiss* and Eastern brook trout (EB) *Salvelinus fontinalis* have also been introduced to the system. The river's trout and char populations have never been directly examined in response to fishing regulations. In 2006 and 2007, I used ecological survey methods to determine WCT growth, mortality, and abundance in a series of catch-and-release and catch-and-keep regulation zones of the lower mainstem Elk River. I assessed the angling effort response to WCT and BT densities in the lower mainstem and systematically determined the relative recruitment capability of the two drainage basins in the tributary system.

I estimated 10,050 WCT inhabited the lower mainstem in 2006 with 16,200 WCT in 2007, indicating an annual recruitment of 5,753 fish into the mainstem. Growth was inversely related to fish density, particularly in the first fractal plane of the tributary system. Effects on mortality due to fishing pressure could not be directly determined from effort, but mortality rates were slightly higher in the harvest zones in 2007, especially in the first fractal division of tributaries. Angling effort showed a linear increase with WCT densities. In the tributary system, the highest WCT densities were found in the Michel drainage, whereas BT recruitment appeared largely restricted to the Upper Elk drainage. A strong EB presence in the upper Michel drainage coupled by an absence of BT suggests that EB have displaced BT in warmer streams in this river system, which may even lead to improved WCT densities. This initial investigation indicates that active monitoring of the Elk River sportfish populations can feasibly be integrated into a system-wide adaptive management strategy.

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# DEDICATION

This thesis is dedicated to C.S. Holling and his words of advice:

“Set a goal that is impossible to achieve and then be hard-nosed about the first step in accomplishing it.”

- UBC AERL, 25.1.8

# 1 INTRODUCTION

Many forms of resource development erode the very environment upon which they are based and a realization has come to pass in governments and institutions that there is no conceivable way to separate the issues of economic development with those of the natural environment (World Commission on Environment and Development 1987). Developing industries in the Elk Valley in the late 1800s led to population growth, hydroelectric dam construction on existing and adjacent river systems, and an expanding development footprint, all of which have altered the ecology of many streams and local landscapes in the valley. Concomitant to this has been an increase in pressure on the local sportfish populations, both for subsistence and recreational purposes, that has led to a understanding that some form of management must be instituted to ensure against overexploitation.

## 1.1 The Summer Fishery

In the most recent decades, the summer fishery, particularly recreational fly fishing, has become the dominant fishing practice on the Elk River. It is also a key factor driving the summer tourist economy, which generates a substantial amount of revenue for local businesses in the valley. Heidt (2003) estimated the Elk River fishery contributed $1.4 million CDN to the local economy in 2002. Anglers mainly target westslope cutthroat trout *Oncorhynchus clarkii lewisi* (WCT) and to lesser degree bull trout (char) *Salvelinus confluentus* (BT). Part of the total revenue has also been appropriated by the provincial government through guide rod day fees, angling and classified waters licenses, and daily non-resident user fees totalling up to $250,000 annually in the East Kootenay region (MOE 2003). The Province has taken measures to track fishing effort in the form of creel surveys to determine how the user base has grown and changed over time. This form of monitoring has been ongoing since the early 1980s (see Martin 1983; Westover 1993 and 1994; MOE 2003), but direct monitoring of the fish populations has been minimal to non-existent.

### 1.2 Other Industries

Early life stages of WCT and BT are affected by a variety of land-use activities. Large-scale coal, natural gas, and timber extraction industries cause disturbances in tributary habitats where spawning occurs. Recruitment of young fish into the fishery depends on a sufficient number of spawning adults, which itself is also a function of overall fishing pressure (Ricker 1954). The industries are required by the Ministry of Environment to make expenditures on scientific monitoring programs that use standardized methods to track abundance, monitor stream chemistry, and reclaim and enhance local fish habitats (e.g. see Allan 1987).

### 1. 3 Policies and Management

The recreational fishing industry does not have a suitable program to track spatial and temporal changes in abundance of fish stocks. The Ministry of Environment has tended to respond to concerns raised by public and commercial users of the fishery, rather than focusing on routine monitoring. Today, drift boats are highly concentrated around the communities of Sparwood, Fernie, and Elko in the lower part of the system (see Figure 1.1; Heidt 2005). Most of the current fishing pressure on the Elk River results from catch-and-release activity (Heidt 2002). The science underlying this type of fishing activity is still in its infancy (Cooke and Schram 2007) and questions remain about the effects of repeated capture on growth and survival of fish.

In the Upper Elk River, where the fish populations are locked in by both natural and anthropogenic barriers, it is especially critical to take measures to understand how exploitation spatially affects the stock structure. The fish are physically and genetically isolated by the hydro-electric dam at Elko. A series of waterfalls directly below the dam has also isolated these populations at least since the last glacial period. As a result, Elk River WCT and BT do not naturally interact with adjacent systems that could otherwise help to replenish numbers when they become depleted.

The Elk River is also a useful system to test the efficacy of alternative fisheries management practices. Such tests include direct examination of catch-and-release policy on fish behaviour (Askey *et al.* 2006) and mortality (Schill *et al.* 1986; Pine *et al.* 2008) and fishing behaviour in the context of predator-prey theory (Gillis and Peterman 1998; Cox and Walters 2002; Gillis 2003). A new era is emerging in fisheries management that relies less on trend extrapolation from indicators like catch or catch per effort (Walters and Martell 2004). There is a movement toward an experimental or adaptive approach to management (Walters and Hilborn 1976; Walters 1986), in which management necessarily involves some quantitative field comparisons of policy options and can deal more directly with the uncertainty of each option (Hilborn and Walters 1992).

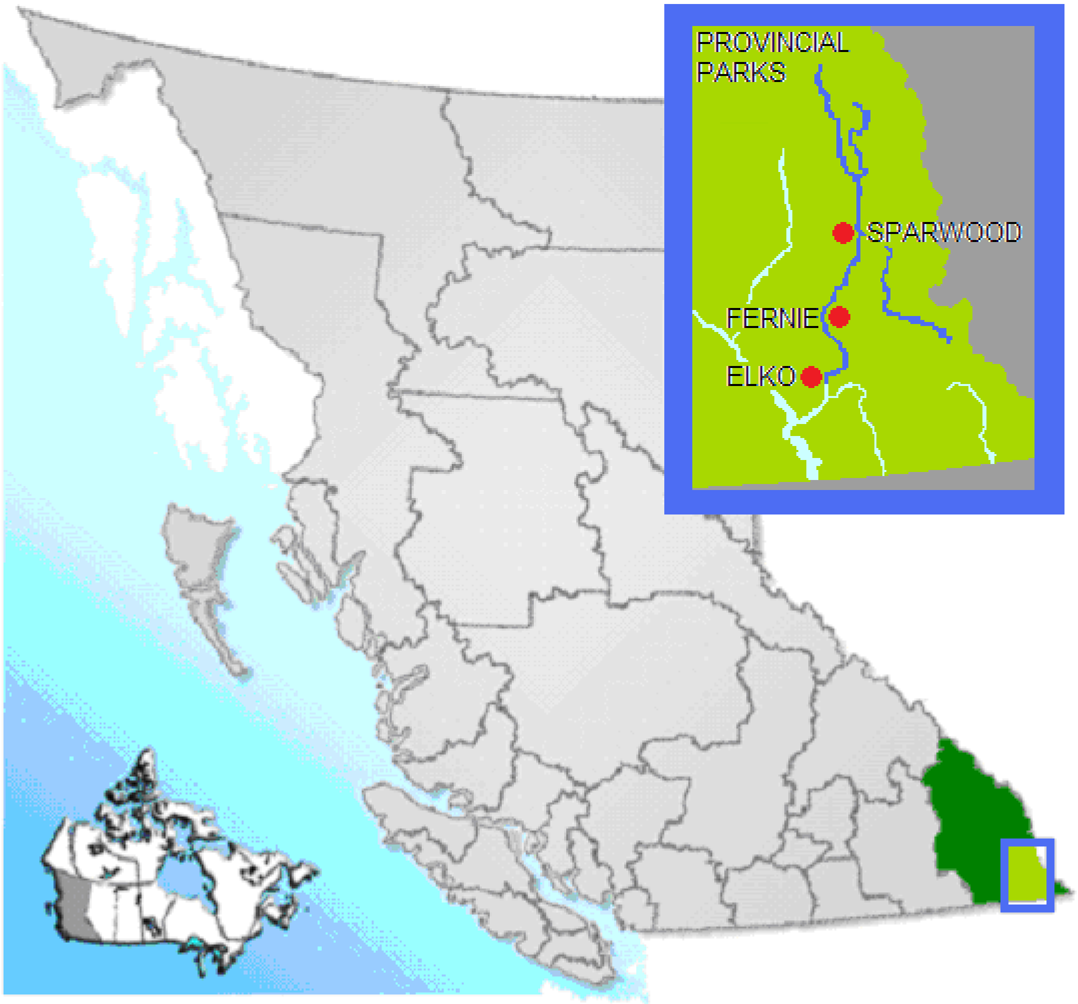

**Figure 1.1 Geographic location of the Elk River and key tributaries (inset) above the hydroelectric dam at Elko (outlined in blue) within the Regional District of the East Kootenay, BC (bottom right corner).**

### 1.4 Elk River Fishery Management Background

Martin (1983) cites an anonymous creel census conducted on the Elk River by the Provincial Fish and Wildlife Branch in 1968. This appears to be the first of such surveys on the Elk River fishery, and subsequent reports were also cited (see Andrusek *et al.* 1970; Hooton *et al.* 1971). In 1980, Andrusek and Brown (1983) reported an estimated total of 67,000 angler days with a harvest of 77,000 fish from the Elk and Flathead watersheds. Martin (1983) investigated effects of the fishery for WCT and BT in the section of the Elk River above the hydroelectric dam at Elko; this study involved a creel census from April 1, 1982 to February 28, 1983 examining angler effort and the distribution of catch. It also included an analysis of age and size structure from scale and otolith samples. Martin (1983) estimated total effort over the entire year at 60,000 angler hours with a harvest removal of 80,000 fish, mostly mountain whitefish *Prosopium williamsoni* (MW) harvested during the winter fishery. The remainder of the total harvest consisted of 14% WCT and 6% BT. 79% of all angling was conducted by B.C. residents, followed by 20% non-resident Canadians (mostly Albertans), and 1% non-resident aliens, primarily from the US. The summer trout/char fishery supported an estimated 29,000 angler hours with a harvest of 16,000 fish, 66% of which were WCT and 23% were BT. Martin (1983) reported that the Elk River WCT size and age distribution was indicative of a heavily exploited population.

The hydroelectric dam on the Upper Kootenay River at Libby, MT created a large reservoir extending north past the Elk River confluence and eliminated a considerable amount the stream angling on the Kootenay River in the early 1970s. Martin (1983) suggested that many anglers from this section of the Kootenay River likely moved to the Elk River. Industrial expansion, particularly coal extraction, led to population growth in Elk Valley during the second half of the last century. Angling was the primary outdoor activity for 61% of local residents surveyed in the Elk and adjacent Flathead watersheds (Bailey and Nessman 1982) and at least 17% of total angling in the Kootenay region came from non-residents (Stone 1982).

Reports from long-term residents of reduced catch rates and sizes of fish in the Elk River were treated as indicative of overharvesting, and Martin (1983) recommended the implementation of regulations to reduce harvest and hooking mortality rates. Following his report, a number of restrictions were implemented in 1984 (Westover 1993) including:

- A size limit of 30 cm for both trout and char to stimulate recruitment by enhancing the spawning capability of the population.
- A bait ban from June 15 to October 31 to reduce incidental mortality of smaller fish.
- A reduced daily limit of 2 each for trout and char to prevent overharvesting (reduced from 4 and 8 respectively).
- Catch-and-release only for trout and char during the winter and spring. This was meant to avoid any harvesting and disturbance to overwintering and spawning populations.

Westover (1993) conducted a six-week long follow-up creel survey from August 1 to September 15, 1991 between Lladner Creek (south of Sparwood) and Elko, noting that more fish were caught by fewer anglers in a shorter time period (i.e. increased overall CPUE). Only a proportion of the total catch was harvested. The overall catch composition (including both harvested and released fish) was 63% WCT, 9% BT and 28% MW. The majority of fishing effort and harvests took place in sections of river on either side of the town of Fernie, the central community in the Elk Valley. The mean length of cutthroat trout captured had increased from 26 cm in 1982 to 33.6 cm in 1991, suggesting that the imposed regulations had been effective for WCT (Westover 1993). However, Westover (1993) also noted that scale data indicated the fish to be the same mean age despite the size increase, which he speculated to have resulted from an error in aging between the two surveys. A drop in BT catch was attributed to the imposed bait ban.

In a second follow-up creel survey conducted during the winter on the Elk River from January 27 to March 31, 1992 between Fernie and Elko, Westover (1994) reported an overall increase in WCT in the species composition data (9% in 1992 compared to 1% in 1983). BT catch remained unchanged at 1%. Westover (1994) attributed this WCT increase to the imposed regulations of 1984/85, but noted difficulty in comparing two surveys given that they took place in a shorter time span and over a markedly reduced stream distance. The following new regulations came into effect in 1992:

- No fishing between April 1 and June 15 (this replaced the previously instated “trout/char release only” regulation during the winter whitefish fishery). The new regulation was meant to protect spawning cutthroat trout.
- Single hook restriction to reduce post-hooking mortalities.
- Two sections of the river were restricted to catch-and-release only (Lladner Creek to Hosmer and Morrissey to Elko), and were meant to act as refuges for mature fish.

Although the follow-up creel surveys were informative, neither was as extensive in scope as Martin’s initial survey in 1983/84. Westover (1994) suggested that the original survey methods be repeated to best measure the response to regulations. The new regulations remained in effect until 1995 when a severe flooding event in early June devastated spawning WCT. In response, the Elk River and its tributaries were closed to harvest and the Province instated a catch-and-release fishery in order to replenish stocks (Heidt 2002).

Harvest zones were re-established on the Elk River in 1998, alternating between catch-and-release and catch-and-keep zones with the daily limit reduced from 2 trout/char to a single fish in catch-and-keep zones. These regulations have persisted up to the present day, and other fishing regulations on the Elk River have been implemented in response to local concerns and the growing pressure, particularly from guides and non-resident anglers. In 1999 the single hook restriction was changed to single barbless hook (Heidt 2002).

Fishing effort on the Elk River has increased in the last decade as the number of guides and assistant guides increased from 5 in 1994 to 52 in 2002 and the number of guided angler days increased from 81 to 1575 in these respective years (Figure 1.2; MOE 2003). The percentage of non-resident anglers in the Elk River has increased (Table 1.1) with a rise in the proportion of American and Albertan anglers (Heidt 2002).

Martin (1983) noted that overall effort for the WCT and BT fisheries was actually lowest in the area between Sparwood and Elko and highest in the uppermost section between Elkford and the Cadorna Creek confluence, which received 47% of total effort and 60% of total harvest. Bank fishers still use the upper sections of the Elk River, but the growth in popularity of guided fly fishing and consequent change angler behaviour over the years has led to a predominance of drift angling in the more accessible lower mainstem near the larger communities of Fernie and Sparwood (Heidt 2002).

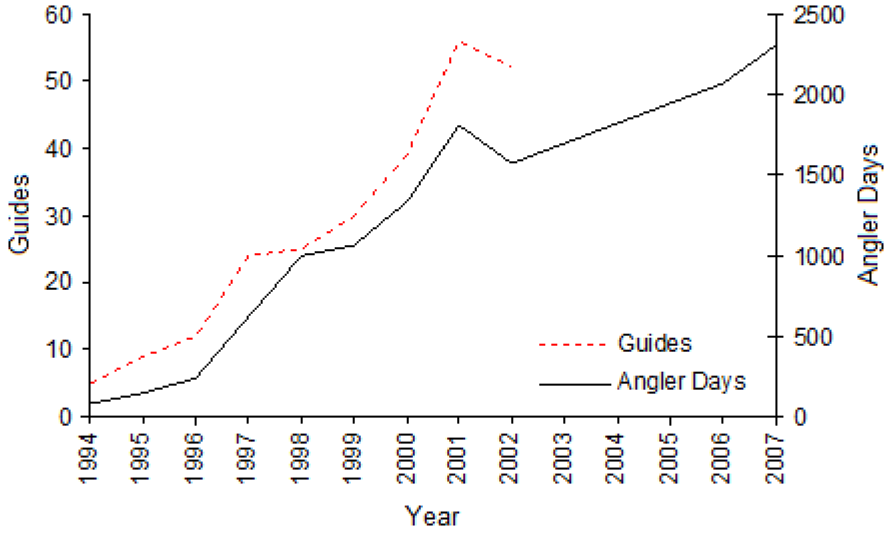

**Figure 1.2 Growth in guided fishing activity on the Elk River (2002 numbers are incomplete; MOE 2003) with angler day updates from Tepper (personal communication).**

**Table 1.1 Place of origin of anglers interviewed in Elk River creel surveys conducted by Martin (1983) and Heidt (2002, 2004, and 2005) with updates from Tepper (personal communication).**

| Year | BC Resident | Non-resident Canadian | Non-resident Alien | Total Non-resident |
|---|---|---|---|---|
| 1982 | 79% | 20% | 1% | 21% |
| 2002 | 20% | 30% | 50% | 80% |
| 2004 | 6% | 29% | 65% | 94% |
| 2005 | 36% | 21% | 43% | 64% |
| 2006 | 4% | 17% | 79% | 96% |
| 2007 | 3% | 21% | 76% | 97% |

The river section between Sparwood and Elko now receives so much effort that it is used as a benchmark for comparing relative fishing effort across the 9 major river sections in the entire upper Kootenay drainage basin. All other sections receive only a fraction of that effort and the section above Sparwood receives about 25% (MOE 2003). Heidt (2002) estimated a total of 66,025 angler hours on the section below Sparwood during the summer over 3 months, compared to 29,000 reported by Martin (1983) on the entire river up to Cadorna Creek.

The Elk River's ability to set such high angler effort is related to a pronounced trend in catch-and-release activity. In contrast to an estimated total harvest of 79,944 fish (Martin 1983), 99.8% of the estimated 98,031 fish landed in 2002 and 100% of the fish caught in the 2004 and 2005 surveys were reported released upon capture (Heidt 2002, 2004, and 2005). However, these figures have likely been inflated, as Prince and Morris (2003) reported a harvest rate of 17.5% of the 40 adult WCT that were radio-tagged as part of an independent telemetry study from 2000-2002.

The 2002 creel survey, along with a vociferous local guiding constituent in the Elk Valley, has led to a re-evaluation of management guidelines for the Elk River. To restrain the growth in angling activity, an 18-month angling guide moratorium was established by the Province in 2003 on the Elk River along with six other streams in the Upper Kootenay drainage (MOE 2003). The moratorium suspended any new guide licenses in anticipation of the proposed East Kootenay Angling Management Plan (EKAMP). The EKAMP identified a number of concerns held by the different interest groups (MOE 2003) including:

- Conservation issues (including hybridization effects)
- Angler crowding and associated problems
- Regulation non-compliance and enforcement
- Business environment for guides and access to guiding
- Sharing the water

Several new regulations have been instated for the Elk River as of 2005, including its designation as Class II Classified Waters, whereby all anglers are required to purchase a separate watershed-specific classified license for the Elk River and tributaries. In addition, non-resident anglers are each required to pay a user fee of $20.00 per day. Using two conservation officers, the Ministry of Environment established a means to monitor the effects of the new regulations through the River Guardians Program. Revenue from the license and user fees has funded this initiative. Through funding from the Habitat Conservation Trust Fund (HCTF), annual creel surveys and angler-use monitoring has continued. Despite a large amount of funding allocated for the program, virtually no information is available about actual fish densities, health status of the fish, or allocation of effort among the different regulations zones of lower mainstem.

The catch and effort data collected have never been used to assess the status of the resource. Although biases exist in relying solely on catch and effort data for stock assessments (Harley *et al.* 2001; Walters and Martell 2004), the data could still be used to indicate the efficacy of competing management options, especially in a river system that is subdivided into a number of equally-accessible management zones (e.g. see Cox *et al.* 2003). Difficulties necessarily arise and assumptions must be made about fishing mortality if all fish are released upon capture, as reported by Heidt (2004 and 2005).

## 1.5 Thesis Objectives

The purpose of this thesis is to better understand the current state of the Upper Elk River system in terms of the distribution and abundance of its sportfish populations. This understanding can then lead to the development of an adaptive management strategy for the Elk River WCT and BT populations. The thesis develops sampling methods to systematically gather data on fish densities across spatial and temporal units over the system.

The main interest of the thesis is the recreational fishery from Sparwood to Elko (Figure 1.3). The two main tributary systems in the upper watershed have also been investigated to address recruitment and the role of two exotic sportfish species: rainbow trout (RB) *Oncorhynchus mykiss* and Eastern brook trout (EB) *Salvelinus fontinalis*. Other resource management activities will likely also affect the tributary system and are discussed to a limited degree with respect to the fishery. The tributaries are located within and around existing open-pit coal mine operations, also with areas under exploration for coal-bed methane extraction, timber extraction areas, and agricultural land use areas (range cattle permits).

Five key objectives comprise this thesis, which is also a management strategy (ranked in order of immediate to long-term):

1.5.1 Assess WCT population dynamics across the fishery management zones in the mainstem and Elk River's and lower-most tributary sections:

  - Growth
  - Mortality
  - Movement
  - Total abundance and adult fish density across zones
  - Annual recruitment

1.5.2 Effort and sportfish dynamics in the lower mainstem Elk River;

1.5.3 Spatial assessment of WCT and BT recruitment capability from the upper tributary system based on juvenile fish densities;

1.5.4 The role of exotic RB and EB in terms of WCT introgression and BT displacement in tributaries, respectively;

1.5.5 Proposal for an adaptive management strategy for the Elk River's sportfish populations.

### 1.5.1 Mainstem Recreational Fishery

The Elk River is divided into a series of catch-and-keep and catch-and-release zones (Figure 1.3). The four zones between Sparwood and Elko are considered to be the most heavily fished and this is where the majority of drift boat guiding takes place (MOE 2003). Drift boat guiding is markedly reduced in the Elk River between Line Creek and Sparwood due to limited accessibility. The main confluence of the river system is located at Sparwood where the Upper Elk meets the lowermost section of Michel, which is also a designated catch-and-keep zone. It is parallel to Highway 3 and highly accessible to bank fishers, but flows are too low in the summer for drifting. These two uppermost zones comprise the first and lower-most sections (1st fractal division) of the upper tributary system and are considered as lightly fished compared to the four zones south of Sparwood. A total of six management zones have been included in the lower mainstem investigation (Table 1.2).

Catch-and-release activity is preferred in conservation-oriented fisheries because it avoids direct removal through harvest (Askey *et al.* 2006). There has been evidence in other sport fisheries for reduced catchability of previously captured sportfish due to learning (Young and Hayes 2004; Askey *et al.* 2006). The opposite effect has also been reported, where previously caught and released fish are more likely to be recaptured (Tsuboi and Morita 2004). If a management objective is to uphold angling quality, hook-avoidance can be problematic to a release fishery; however, if fish are repeatedly captured, angling pressure may have a more subtle effect and growth, mortality, and recruitment. Assessment of angling quality has been a major component of the River Guardian Program, and adverse effects to the angling experience have been reported as minimal (Heidt 2002, 2004, and 2005).

**Table 1.2 Stratified sampling protocol for mainstem mark-recapture and visual snorkel surveys.**

| Block | River Section | Regulation |
|---|---|---|
| A | Elko to Morrissey Bridge | Catch-and-Release |
| B | Morrissey Bridge to North Fernie Bridge | Catch-and-Keep |
| C | North Fernie Bridge to Hosmer Bridge | Catch-and-Release |
| D | Hosmer Bridge to Sparwood | Catch-and-Keep |
| E | Sparwood to Line Creek Bridge* | Catch-and-Release |
| F | Sparwood to Hwy. 3 Bridge* | Catch-and-Keep |

*Lower-most stream section of the upper tributary drainage basin.

In this study, I examined growth parameters of WCT across the river system in conjunction with the catch and age information from tagged fish to determine a more precise estimate of mortality across individual management zones. If users of the Elk River fishery are compliant to the existing regulations, fishing mortality should be highest in catch-and-keep zones. The tagging program was also used in conjunction with visual (snorkel) surveys to develop mark-recapture estimates of abundance.

I used the growth and mortality information along with mark-recapture data from the visual swim surveys to determine the total abundance of WCT and compared WCT densities across the six management zones. I also utilized limited information provided by local participants as a means to assess WCT movement and potentially serve as part of a fishery-dependent survey in an annual monitoring program. The information consisted of a combination of angler survey data and reports to the UBC Fisheries Centre and the Fisheries Branch of the Ministry of Environment, along with reports in 2007 to an internet-based catch database: www.elkriverfishtracker.com.

### 1.5.2 Effort Dynamics

Drift boat fishing between Sparwood and Elko has become the dominant form of angling, especially for the non-resident guided fishery. There are five main runs, three of which each correspond to the lower management zones (Blocks A, B, and C) with two runs in Block D (see Figure 1.3) at the upper end of the mainstem. Guides have an obvious incentive to ensure angler satisfaction with high catch rates. I examined spatial effort and patterns to see whether: a) anglers exhibit a numerical response to fish densities, b) fishing effects can influence total mortality, and c) catch rates are a suitable indicator of abundance.

### 1.5.3 Tributary System

In addition to the mainstem, I examined juvenile fish densities to spatially assess recruitment capability across the two upper tributary drainages. This evaluation assumed that juvenile fish migrate into the mainstem as they age. I surveyed multiple sites for each tributary to estimate juvenile fish abundances and densities. Understanding the species composition and spatial variation in fish abundance in the tributary system was useful to determine which tributaries are most important for recruitment into the mainstem fishery.

### 1.5.4 Exotic Species

Lake stocking programs of RB undertaken by the Ministry of Environment have led to the movement of this species into river systems, where it has been shown to interbreed with WCT (Hitt *et al.* 2003; Rubidge and Taylor 2004). Hybridization is a primary conservation threat to existing populations of WCT (Allendorf and Leary 1988). British Columbia WCT populations are peripheral to populations at the centre of its range in Montana and Idaho, and WCT may be at greater demographic risk in these marginal environments (Lesica and Allendorf 1995). Elk River WCT has been further isolated by natural and anthropogenic barriers, and was probably post-glacially colonized by few individuals, rendering a gene pool with reduced heterozygosity (Taylor *et al.* 2003).

Westslope cutthroat/rainbow trout hybrids have been detected in the Elk River in previous studies from specimens collected in tributaries, but to date few samples from the Elk River mainstem have been assayed. Rubidge (2002) conducted a genetic analysis of 20 radio-tagged WCT from the mainstem Elk, none of which showed evidence of RB introgression. Rubidge and Taylor (2005) reported an overall total of 3.56% of allospecific (i.e. RB) alleles in a sample of 168 WCT throughout the Elk River system (excluding the Fording River above Josephine

Falls), with the highest concentration of such alleles (13.2%, n=30) located in Michel Creek. The State of Montana through Montana Fish, Wildlife, and Parks (MFWP) has generously conducted a genetic analysis of a subsample of the tissues collected from WCT that I tagged in the entire lower mainstem Elk River as well as numerous juvenile voucher specimens collected in several tributaries of the Michel drainage during the electrofishing program. This genetic information is important to better understand and monitor the spread of hybridization between native WCT and previously stocked RB throughout the Elk River.

Eastern brook trout (EB) is a second exotic salmonid in the Elk River that was intentionally introduced by members of the Fernie Rod and Gun Club in the early part of the last century (Rocca 2006). EB have persisted in the Elk River and have moved into a number of its tributaries. In previous studies on other systems, EB had size and growth advantages over BT at warm temperatures, but BT did not appear to gain a similar advantage over brook trout at low temperatures (McMahon *et al. 2007*; Rodtka and Volpe 2007). Hybridization between EB and BT has also been observed on other systems (Leary *et al.* 1983; Kanda *et al.* 2002), but has never been examined in the Elk River system.

I compared densities of WCT, BT, and EB throughout the Elk River's upper tributary system. I also explored the potential for BT displacement by EB in the upper tributaries of the Elk River based on the recorded stream temperature and relative abundance of each species across tributary sampling sites.

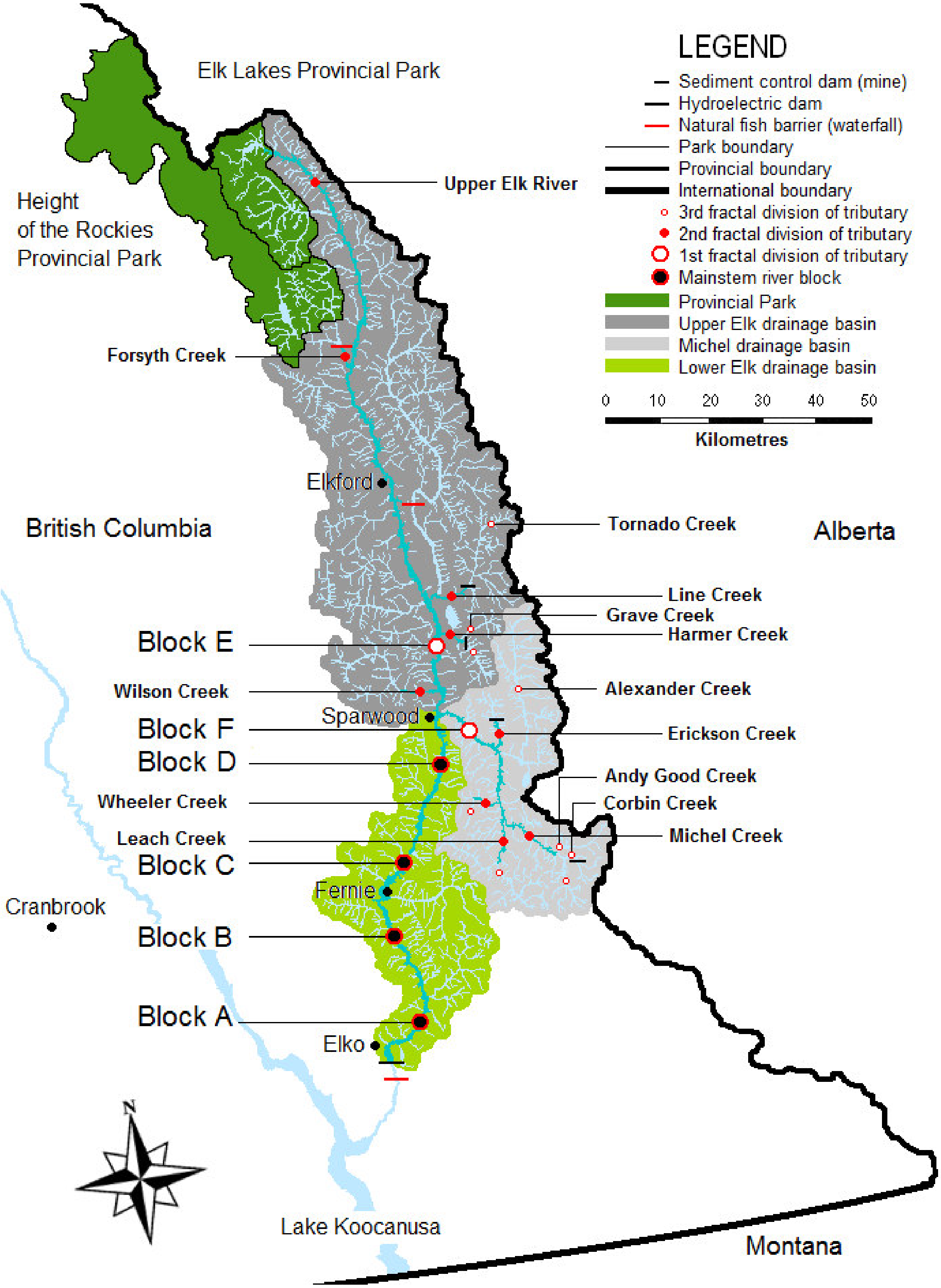

**Figure 1.3 Map of the Upper Elk River drainage basin in the southeast corner of British Columbia. The six habitat blocks of the lower mainstem and the upper tributaries have been included in the study.**

### 1.5.5 Adaptive Management of the Elk River

The final objective of this thesis has attempted to integrate the results obtained into a comprehensive adaptive management strategy for the Elk River system. There are two key components to the proposed management strategy. The first is to continue an experimentally-based research program that follows from the initial results, which are coupled by an appropriate modeling scheme. Prolonged experimentation will then help to reveal the important underlying processes influencing WCT and BT population dynamics. The second component is a cost-effective monitoring program that can be used to determine how WCT and BT populations within the system respond to exploratory management policies that would best reveal how both species can be sustainably managed.

# 2 METHODS I

For the Elk River sport fishery, no previous monitoring activity has ever attempted to determine fish abundance. Any form of stock assessment has been replaced by intermittent estimation of fishing effort resulting from creel census data (Martin 1983; Westover 1993 and 1994), which has only been used to estimate total harvest. Cox and Walters (2002) note how few detailed analyses exist to quantify fishing mortality and have argued that the methods underlying recreational fisheries policy do not adequately ensure a sustainable harvest. Walters and Martell (2004) have emphasized the need for more direct estimates of fishing mortality through tagging experiments.

I investigated WCT in the Elk River lower mainstem using a mark-recapture methodology. This river section is divided into fishery management zones that alternate between catch-and-release and catch-and-keep regulations (Table 1.2). In the latter zones, daily harvest is limited to a single WCT of at least 30cm total length. The primary data that I gathered in the lower mainstem include:

- tagging information to assess WCT age structure, growth, and abundance
- snorkel information to estimate WCT abundance and densities
- drift boat counts to examine angler distribution in relation to fish densities
- catch and effort information by tagging, angler surveys, and reports

Tributary surveys of juvenile fish provide additional information on recruitment potential throughout the system. I have included the genetic information from the laboratory assays conducted by Montana Fish Wildlife and Parks (MFWP) on tissue samples I collected from tagged fish (fin tissues) and voucher specimens of juvenile WCT in order to show the spatial extent to which WCT/RB introgression exists in the Elk River drainage. I have also spatially mapped the distribution of WCT, BT, and EB, which has invaded and persisted in the upper tributaries since its initial introduction.

## 2.1 Mainstem Field Methods

The mark-recapture abundance estimation required that I first administer visible tags early in the summer with the assistance of local angling guides and volunteer anglers. At the end of each summer, I returned to these river sections and snorkel-counted all visible fish, including both tagged and untagged fish. The fieldwork continued over two summers, the first of which took place from June 29 to September 30, 2006. The second field season went from July 1 until August 24, 2007. Although the basic methods are the same for both summers, I made slight modifications in 2007.

I held two meetings in Fernie and one in Sparwood in May 2006 to inform local anglers of the study and call for assistance. Many local anglers attended the meetings, but no guides were present even though I contacted a number of guide outfits from the Kootenay Angling Guide Association (KAGA). Members of local organizations, including the Fernie Rod and Gun Club and Sparwood Fish and Wildlife, attended one or more meetings. Other attendees included Fernie Mayor Randall McNair, representatives from Tembec Industries and Elk Valley Coal Corporation (EVCC), local fisheries consultants, and conservation organizations including Wildsight and Trout Unlimited Canada. There was an enthusiastic response overall, and several people committed a number of days to help tag fish in the following months.

### 2.1.1 Tagging Program

The lack of attendance by angling guides at the meetings was a concern, so I visited several guide outfits in Fernie during the following weeks and spoke with the outfitters and a few of their guides. Everyone seemed interested in the research and agreed to help with tagging by providing guided assistance to capture fish using drift boats. It was still quite difficult for me to get many guides to help. Consequently, much of the 2006 assistance came from a few local guides together with several local anglers. The 2006 tagging program included a combination of drifting and walk-and-wade access. I accomplished all tagging in 16 days throughout July to include all four blocks in the lower mainstem and one day of drifting in Block E north of Sparwood to the Fording River confluence at EVCC’s Line Creek Operations. July 23 was the last tagging day in 2006.

In 2007, I began tagging fish on July 3 and continued over 17 days until August 7. I decided to focus exclusively on tagging via drift boats in the lower 4 zones (Blocks A-D) that correspond to the river sections that are most commonly run by both guided and non-guided boats. The 2007 tagging activity on Block E north of Sparwood included both drift and bank fishing and I extended tagging into the catch-and-keep zone of the lower section of Michel Creek (Block F). Drift boats are absent in this block due to low flows, so I tagged fish here with the assistance of bank fishers. All of Block F is accessible to bank fishers because of its proximity to Highway 3. Tagging activity is summarized in Table 2.1.

**Table 2.1 Summary of tagging activity over both field seasons.**

| Block | Location | 2006 sampling | 2007 sampling |
|---|---|---|---|
| A | Elko to Morrissey | Bank and drift | Drift only |
| B | Morrissey to Fernie | Bank and drift | Drift only |
| C | Fernie bridge to Hosmer | Bank and drift | Drift only |
| D | Hosmer to Sparwood | Bank and drift | Drift only |
| E | Sparwood to Line Creek | Drift only | Bank and drift |
| F | Lower Michel Creek | Not sampled | Bank only |

### 2.1.2 Tagging Procedure

I tagged all fish with a tagging gun and numbered anchor tags provided by Floy© Ltd. in Seattle, Washington, USA. I used variety of gear to capture fish, but the majority of fish were landed on fly rods using dry flies or nymphs with single barbless hooks. I immediately anaesthetized all fish landed by placing a damp cloth with several drops of clove oil over the nostrils for several seconds. Once subdued, I recorded the fork length (FL) and quickly inserted a tag below the anterior half of the dorsal fin on the left side of each fish. The “T” on the end of each tag anchored through the dorsal musculature and behind underlying pterygiophores of the dorsal fin with a numbered length of yellow plastic “spaghetti” trailing out (Figure 2.1). I administered regular size tags to all fish over 300-mm FL, and fish under 300-mm FL were administered fine fabric tags with a smaller needle.

A secondary mark was applied to allow an estimation of tag loss rate. I clipped the leading three fin rays at the base of a pelvic fin with a Leatherman Micra® tool.

I also plucked several scales from the lateral line region between the pelvic fins and the leading edge of the dorsal fin, which contain the most complete age information (Shepard *et al.* 1984). I placed the fins and scales in small Ziploc® bags and froze them in 2006, but I was unable to successfully retrieve the scales. In 2007, I placed the scales and fins into small envelopes and dried them out instead. To distinguish fish tagged in different years, I clipped the left pelvic fin in 2006 and the right pelvic fin in 2007. I also observed a percentage of fish captured to possess some degree of mouth damage (Figure 2.2), previously reported by Prince and Morris (2003).

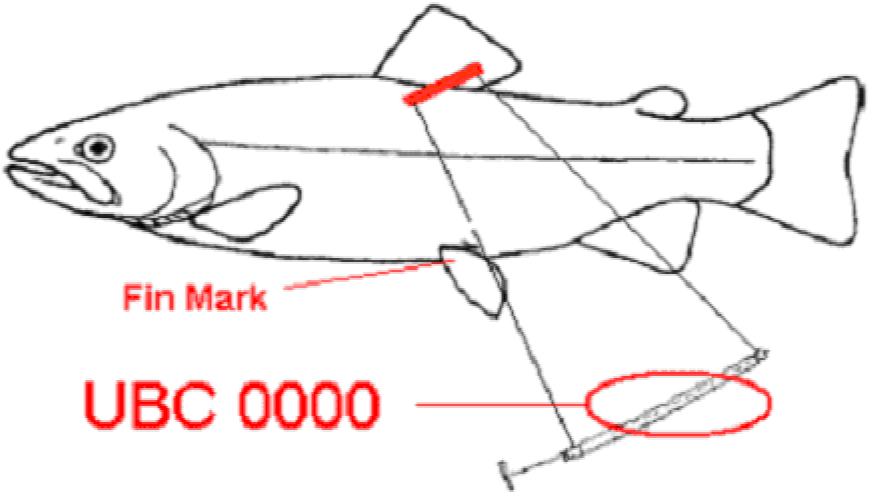

**Figure 2.1 Location of anchor tag and secondary pelvic fin mark on captured fish.**

Once each fish had been tagged and measured, I placed it in a lotic chamber submerged in the stream, where it was able to recover for up to 15 minutes and resume a holding position. Finally, I recorded the location of each fish using a hand held Garmin® GPS unit immediately following its release. The predominant use of fly-fishing gear greatly reduced the catchability of BT. Consequently, only a few small fish were captured and tagged in both years. BT densities could only be inferred from the snorkel observations.

**Figure 2.2 Mouth damage on an adult WCT with the right maxillary missing.**

### 2.1.3 Snorkelling Procedure

I was the sole observer for the snorkel survey over both summers. Night snorkelling can be a more efficient survey method for both WCT and especially BT (Thurlow *et al.* 2006), but I chose to snorkel during the day because it was more practical. I repeatedly snorkelled the same section of river on the first and second days in 2006 in order to assess variability in resights (i.e. previously tagged fish) and the total number of observed fish. In a 5.7-km section of river, I observed low (<10%) variability, and proceeded to snorkel all remaining sections.

I used hand-held tally counters to record fish observations. I saw few tagged fish, so I was able to remember the total number of tag resights from each snorkel session. The 2006 snorkel survey of Blocks A to D took place from September 19 to 28, but unfortunately I was unable to snorkel Block E above Sparwood. In 2007, I snorkelled all six blocks and was followed by a field assistant in a kayak who recorded my observations and marked the locations of tag resights with the GPS (see Appendix B for maps of individual blocks and waypoints). The GPS also kept a track record of the total distance snorkelled and allowed me to gather more precise information about distances (river km) and encounter rates (fish per km). My assistant recorded any additional catch information offered by anglers encountered along the river banks and in drift boats, including any recapture information of previously tagged fish.

I followed the main course of the river using a standard method where I moved across the channel between bends and into the deepest part of the river, usually cutbanks, where I could see the shoals opposite them. When I encountered complex sections (pools, boulder gardens, LWD/log jams, etc.) where fish aggregated, I conducted multiple passes. WCT were not alarmed by my presence and I could get quite close to them. WCT counts actually tended to increase with successive passes, likely due to improvements in my search image for particular fish locations, so I took the average of the counts for all passes. BT numbers decreased with each pass, as they tended to leave the area and respond evasively to snorkel activity. I saw few BT so it was easier to accurately count them and I used the highest count, which was usually the first pass.

Turbidity was low but somewhat variable and the low flows during mid-late summer allowed the water to be clear enough to easily spot fish within the channel. The bright yellow tags were also clearly visible. I estimated that I could spot fish up to 5m away, which was adequate to cover a high percentage of the stream channel.

### 2.1.4 Fishing Effort

In the 1980s, harvest fishing predominated and creel census takers gathered somewhat reliable catch information (Martin 1983). A trend over decades toward catch-and-release angling has made recent creel survey data exceedingly unreliable as most of the information about numbers of fish caught and released is provided by anglers, assumed to be honest. I was interested in examining the distribution of fishing effort throughout the lower mainstem and comparing the catch and effort information from various sources with my own set of observations.

Drift boat activity is the dominant form of angling in the Elk River. Charity Barkwell operates Fernie Fly Girls, the only independent boat shuttle service in the Elk Valley. All guides shuttle their boats and many of them use the Fly Girls' service, but some outfitters also shuttle boats themselves. She provided a valuable record of shuttle activity for both 2006 and 2007. This information on drift effort in lower four blocks (A through D) has been assessed along with my own independent boat count in 2007, which I compared with the Charity's shuttle service data.

I also had an assistant conduct independent angler surveys between August 9 and September 1, 2007. Each day, she was randomly assigned to a location and time period for the six blocks (A to F) during six time periods that were six hours in length (Table 2.2). She was instructed to drive along Highway 3 during the 6-hour time period and look for anglers on the river and/or vehicles located at the various access points within the assigned river block. If she observed any vehicles parked by the river, she was instructed to walk along the bank until she encountered the angler(s). I prepared a standard survey form for her to use (Appendix A).

**Table 2.2 River sections and time periods for 2007 streamside angler surveys.**

| Block | Location | 6-hour time block |
|---|---|---|
| A | Elko bridge to Morrissey bridge | 9 AM to 3 PM |
| B | Morrissey bridge to N. Fernie bridge | 10 AM to 4 PM |
| C | N. Fernie bridge to Hosmer bridge | 11 AM to 5 PM |
| D | Hosmer bridge to Sparwood CPR bridge | 12 PM to 6 PM |
| E | Sparwood CPR bridge to Line Creek bridge | 1 PM to 7 PM |
| F | Lower Michel Creek (Sparwood to Hwy. iron bridge) | 2 PM to 8 PM |

### 2.1.5 Voluntary Recapture Participation

I was interested in gathering information about fish movement. I released all tagged fish in precise known locations, so any recapture information provided by participating anglers could also address questions about fish movement throughout the mainstem over the fishing season, as well as between seasons following overwintering and annual spawning migrations. In 2006, I developed catch data sheets on Rite in the Rain® paper and distributed them to participating anglers. To ensure that anglers understood the purpose of the information, I also supplied a list of important points, which explained why each piece of information was requested (see Appendix A). I wrote an article in the Fernie Free Press and informed local anglers in the communities in the Elk Valley of the research.

In 2007, I developed a website www.elkriverfishtracker.com with a database where participants could login to record catch information. My goal was to create a straightforward and user-friendly means for anglers to understand and contribute to the project. The website outlined the purpose of the research and explained how anglers could submit their catch data each time they fished. Data sheets and maps of each habitat block could be downloaded and printed for use while fishing. Anglers could record the following information:

- number of fish caught and landed
- location of capture of each fish
- species
- tag and/or fin mark information
- approximate fork length of each fish
- gear used
- approximate time spent angling each fish
- degree of mouth scarring (based on an index provided)

I encouraged users to post blogs and I regularly contributed to a blog on the website acknowledging participation and offering encouragement to everyone to continue contributing their catch information. I advertised the website on T-shirts I made for the tagging volunteers and wrote articles in both the Fernie Free Press and the Fernie Fix, a magazine that is quite popular to local recreational and tourist anglers.

### 2.2 Tributary Field Methods

The second component of the research was a systematic sampling program for the Upper Elk River's tributary system. Part of it is beyond the scope of this thesis so I have attempted to limit the discussion of the methods to its relevance within the context of recruitment to the fishery. Knowing the spatial distribution of juveniles (i.e. fish at ages 0 to 2+) is a useful means by which to assess which parts of the tributary system are important to recruitment. Essentially, I have attempted to model the distribution of fish in a drainage basin in terms of the natural venation pattern of stream systems. Such patterns involve fractal geometry (Pelletier and Turcotte 2000) as a single mainstem stream repeatedly bifurcates into a pair of streams to include the mainstem and its tributary. This is exactly the same concept as the stream ordering system developed by developed by Strahler (1957) and Tokunaga (1978). A spatial model of the tributary system was extended onto smaller fractal divisions within the two main tributary drainage basins that converge at Sparwood (see Figure 1.3). The first fractal division consisted of Blocks E (Upper Elk River) and F (Michel Creek) above the confluence at Sparwood, but successive fractal divisions continued into the uppermost fractal division in the headwaters of either drainage basin. I used the data gathered in the second fractal division of the tributaries in assessing recruitment, based on the assumption that fish in these tributary sections are most likely to migrate into the mainstem and recruit to the fishery when mature. Such migration was previously observed through radio-telemetry (Prince as Morris 2003). I collected additional information from the third fractal division, using the same sampling methods in the uppermost stream sections, some of which are close to existing coal mines.

### 2.2.1 Tributary Sampling Design

The tributary sampling protocol involved a two-stage sampling design similar to Wyatt (2002). First, I systematically chose sites from within a stratified section of stream. Second, fish were sampled from the total pool of fish present within each site's closed sample area. Estimates of fish densities were compared within tributaries using a combination of electrofishing depletion removal and mark-recapture methods in a systematic layout of sites extending up the stream section from its confluence.

In 2006, five sites per tributary comprised a full sample set for each tributary on the second fractal plane. There were four fully-sampled tributaries in Michel and two in the Upper Elk in 2006. In 2007, the fully sampled tributaries from this fractal plane were re-examined at the confluences below the 5-site layout. The confluence of each tributary and its mainstem is a bifurcation point. I sampled the stream habitat on the tributary side of the bifurcation where I walked up from the confluence until encountering the first complex habitat that would be expected to hold fish. The Michel drainage included 4 tributaries: Erickson, Wheeler, Leach, and Upper Michel Creeks. The 5-site layout on Michel Creek that I used to compare with the second fractal plane for the previous tributaries continued just above the Leach Creek confluence (Figure 2.3).

I similarly sampled complex habitats above confluences of Line and Harmer Creeks in the Upper Elk drainage, walking upstream from the confluence of Harmer Creek and the Elk River and the confluence of Line Creek and the

Fording River. The Fording River joins the Elk River several hundred metres below this confluence, but I did not sample here because the flow is too great to effectively block off a sample area. So Line Creek’s confluence with Fording River is not the second bifurcation point, but it is more comparable with the other tributaries in terms of overall discharge. These sites correspond to those on the Michel tributaries in the second fractal division. Over both years, 6 sites comprised a fully sampled tributary on the second fractal plane (Figure 1.3).

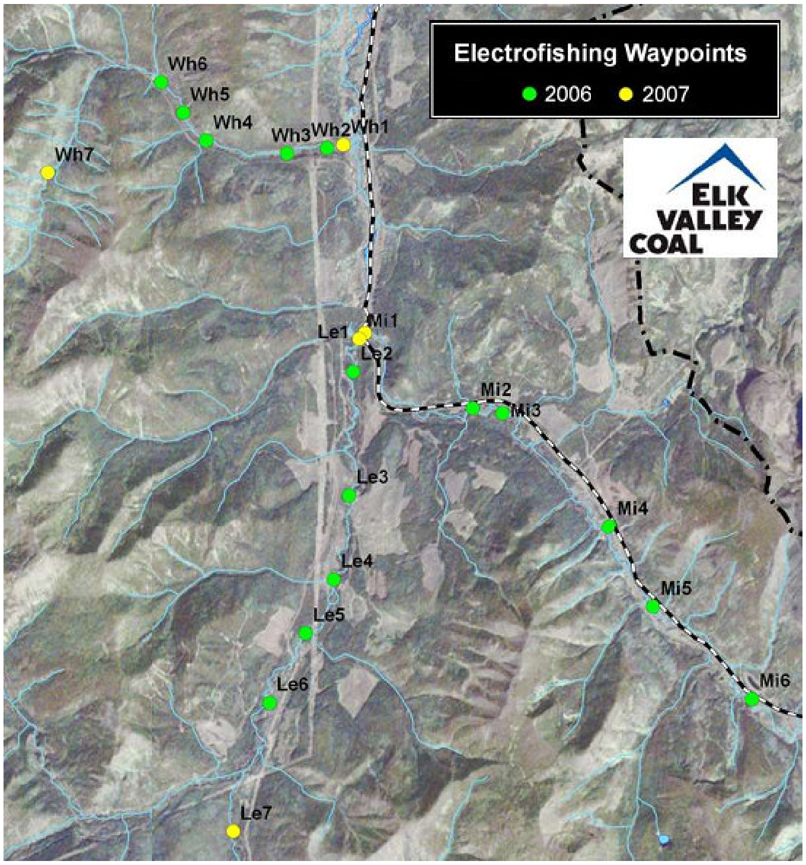

**Figure 2.3 Site layout for 3 tributaries the Michel drainage (Wheeler, Leach, and Michel Creeks). The lower six sites comprise the second fractal division. The seventh site is located in the third fractal division above the next main bifurcation point.**

I added three tributaries in the Upper Elk system in 2007: Wilson Creek, Forsyth Creek, and the upper Elk River. Wilson Creek had three sites with the lowest being the first complex habitat encountered when walking in from the Elk River confluence along with two upstream sites to correspond to the 5-site layout from 2006. Forsyth Creek had two sites with the lower site just above the Elk River confluence. Two sites on the Elk River were below the entrance to Elk Lakes Provincial Park with the lower site located in a complex habitat above the Cadorna Creek confluence, which is the final major bifurcation point in the uppermost section of the Elk River (analogous to Leach Creek). The uppermost site was located just inside the park. A total of 15 new sites within the second fractal division were added in 2007 increasing the grand total to 43 sites in the WCT tributary investigation (Table 2.3).

**Table 2.3 Summary of the tributaries that have been sampled in the second fractal division.**

| Drainage | Tributary | No. sites in 2006 | Sites added in 2007 |
|---|---|---|---|
| Michel | Michel Creek | 5 | 1 |
| Michel | Erickson Creek | 4[a] | 1 |
| Michel | Leach Creek | 5 | 1 |
| Michel | Wheeler Creek | 5 | 1 |
| Upper Elk | Harmer Creek | 5 | 1 |
| Upper Elk | Line Creek | 5[b] | 2[c] |
| Upper Elk | Wilson Creek | 0 | 3 |
| Upper Elk | Forsyth Creek | 0 | 2 |
| Upper Elk | Elk River | 0 | 3 |

[a] an upper site was not included here because Erickson Creek dewaters above the last site.
[b] data from the two sites on Line Creek have been provided by Interior Reforestation.
[c] a second site was included in upper Line Creek that corresponds with the 2006 layout.

### 2.2.2 Tributary Sampling Procedure

The 2006 methods were slightly modified in 2007, but I have employed the same standards to block off the sample area, electrofish, and describe water quality and habitat characteristics at each site. I sampled each site by first sealing off the designated sample area to a standard area swept based on the measured stream length and mean stream width within which electrofishing took place. Most sites were $200m^2$ while some were smaller. No site was smaller than $100m^2$. I used beach seines spanned across the channel. The weighted end of the seine was anchored down into the substrate with boulders to prevent movement of fish out of the sample area. The seines were also propped up out of the water to prevent fish movement over the surface. Once the sample area had been sealed off, I conducted a habitat inventory of the site based on the methods outlined by the Resource Inventory and Standards Committee (RISC 2004), which include channel, flow, stream bank, streambed, and cover characteristics (Appendix A). I also collected water quality parameters at each site. In 2006 I recorded temperature and dissolved $O_2$ using a YSI® 55 DO instrument and turbidity was recorded using an Analite® NEP160 turbidimeter from McVan Instruments Ltd. In 2007 I used a Hach® HQ40D multimeter with additional probes for measuring conductivity, dissolved $O_2$, pH, and temperature. For turbidity, I used a Hach® 2100P portable turbidimeter.

Once I calibrated the meters and recorded the readings, I began electrofishing. A person equipped with a backpack electrofisher was accompanied by a dipnetter in the stream. I used a model 12A backpack electrofisher from Smith-Root Inc. A complete pass was conducted by sweeping the area from the lower block net upstream to the upper end, then moving back downstream. I recorded the total effort in seconds for the first pass and an attempted to hold it constant for each successive pass (800s - 900s). I placed the captured fish in a holding bin on the shore where I measured the fork length and identified the species (Figure 2.4). The electrofishing procedure included a combination of single passes and multiple-pass removals in all sites (Table 2.5). I waited approximately 30 minutes between passes in multiple-pass sites to allow the fish to redistribute throughout the sample area. Most multiple-pass sites comprise three passes, but if I did not see a clear depletion signal I conducted a fourth pass.

**Figure 2.4 Fry and age-1 classes of juvenile WCT retained from an electrofishing survey.**

The results of several investigations have indicated that electrofishing depletion methods typically tend to underestimate abundance (Cross and Stott 1975; Mahon *et al.* 1979; Mahon 1980; Riley and Fausch 1992), particularly due to violations in the assumption of constant capture probability between successive passes. It is generally accepted that mean capture probability decreases over passes (Bohlin and Sundstrom 1977; Otis *et al.* 1978; Schnute 1983; Mesa and Schreck 1989). Peterson *et al.* (2004) identify factors that can affect the capture probability and lead to negatively biased estimates of WCT and BT, including habitat characteristics, size, and species of the fish. Mark-recapture methods have been shown to give unbiased estimates compared to electro-fishing depletion removal (Rosenberger and Dunham 2005). In 2007, I included a combination of trapping and releasing marked fish into the sample areas prior to electrofishing as a second method to provide abundance estimates.

I visited a percentage of the 2007 sites the night before electrofishing to set minnow traps baited with oatmeal soaked in anise seed oil within the sample area. I revisited these sites the next day and marked the trapped fish by clipping the adipose fin. Then I blocked off the sample area and released the marked fish into it. I waited an hour for fish to redistribute prior to electrofishing. The mesh of the minnow traps was size selective and did not trap fish smaller than 70-mm FL, including all fry and smaller age 1 fish; however, fish up to 410 mm were successfully trapped. The methods employed for all tributary sites are outlined in Table 2.5.

**Table 2.4 Summary of all 43 sites and respective sampling methods employed over 2006 and 2007 for the second fractal division of the Elk River tributary system. The first site within each tributary (e.g. wi1) represents the sample areas directly above a confluence.**

| System | Tributary | Site | Year | EF passes | Minnow Trap |
|---|---|---|---|---|---|
| Upper Elk | Wilson Cr. | wi1 | 2007 | 3 | No |
| Upper Elk | Wilson Cr. | wi2 | 2007 | 3 | No |
| Upper Elk | Wilson Cr. | wi3 | 2007 | 3 | Yes |
| Upper Elk | Harmer Cr. | ha1 | 2007 | 3 | Yes |
| Upper Elk | Harmer Cr. | ha2 | 2006 | 3 | No |
| Upper Elk | Harmer Cr. | ha3 | 2006 | 1 | No |
| Upper Elk | Harmer Cr. | ha4 | 2006 | 1 | No |
| Upper Elk | Harmer Cr. | ha5 | 2006 | 3 | No |
| Upper Elk | Harmer Cr. | ha6 | 2006 | 3 | No |
| Upper Elk | Line Cr. | li1 | 2007 | 3 | Yes |
| Upper Elk | Line Cr. | li2 | 2006 | 1 | No |
| Upper Elk | Line Cr. | li3 | 2006 | 1 | No |
| Upper Elk | Line Cr. | li4 | 2007 | 1 | Yes |
| Upper Elk | Line Cr. | li5 | 2006 | 3 | No |
| Upper Elk | Forsyth Cr. | fo1 | 2007 | 3 | No |
| Upper Elk | Forsyth Cr. | fo2 | 2007 | 4 | Yes |
| Upper Elk | Elk River | el1 | 2007 | 4 | Yes |
| Upper Elk | Elk River | el2 | 2007 | 1 | No |
| Upper Elk | Elk River | el3 | 2007 | 1 | No |
| Michel | Erickson Cr. | er1 | 2007 | 3 | Yes |
| Michel | Erickson Cr. | er2 | 2006 | 1 | No |
| Michel | Erickson Cr. | er3 | 2006 | 1 | No |
| Michel | Erickson Cr. | er4 | 2006 | 1 | No |
| Michel | Erickson Cr. | er5 | 2006 | 1 | No |
| Michel | Wheeler Cr. | wh1 | 2007 | 4 | Yes |
| Michel | Wheeler Cr. | wh2 | 2006 | 3 | No |
| Michel | Wheeler Cr. | wh3 | 2006 | 3 | No |
| Michel | Wheeler Cr. | wh4 | 2006 | 1 | No |
| Michel | Wheeler Cr. | wh5 | 2006 | 1 | No |
| Michel | Wheeler Cr. | wh6 | 2006 | 3 | No |
| Michel | Leach Cr. | le1 | 2007 | 3 | Yes |
| Michel | Leach Cr. | le2 | 2006 | 1 | No |
| Michel | Leach Cr. | le3 | 2006 | 4 | No |
| Michel | Leach Cr. | le4 | 2006 | 3 | No |
| Michel | Leach Cr. | le5 | 2006 | 1 | No |
| Michel | Leach Cr. | le6 | 2006 | 4 | No |
| Michel | Michel Cr. | mi1 | 2007 | 4 | Yes |
| Michel | Michel Cr. | mi2 | 2006 | 4 | No |
| Michel | Michel Cr. | mi3 | 2006 | 1 | No |
| Michel | Michel Cr. | mi4 | 2006 | 3 | No |
| Michel | Michel Cr. | mi5 | 2006 | 1 | No |
| Michel | Michel Cr. | mi6 | 2006 | 4 | No |

## 2.3 Laboratory Methods

### 2.3.1 Scale preparation

I used scales from 177 adult fish throughout all six blocks in 2007 to age fish. Erickson (1999) recommends mounting multiple scales for each fish on a microscope slide to ensure that at least one scale has the complete set of visible annuli. I lined the scales up along the short edge of the slide so that two fish could be contained on a single slide. I sandwiched the scales between two slides, taped them together in the centre of the slide, and labelled each end. The scale was placed under a microfiche reader and projected to a high enough resolution that the individual circuli were clearly visible. I mounted a digital camera on a tripod, placed it at a standard distance from the projected image and digitally catalogued a photograph of each scale (Figure 2.5).

Westslope cutthroat trout scales tend to underestimate age compared to otoliths, as some WCT fry do not lay down an annulus (Erickson 1999; Fraley and Shepard 2005). Allan (1987) compared scales and otoliths from Line Creek WCT and observed that the first annulus does not appear until after two seasons of growth. I used an algorithm developed by Downs (1995) to identify WCT scales missing the first annulus: if $C_{1\text{-}2} \leq 1 + C_{0\text{-}1}$, then add a year, where $C_{1\text{-}2}$ is the number of circuli from the first and second annulus and $C_{0\text{-}1}$ is the number of circuli up to the first annulus. Likewise if $C_{0\text{-}1} > 6$ and there is no second annulus, add a year. For older ages, growth slows considerably (Pfeifer 2005). Fewer circuli form and the annuli compact toward scale margin, making it difficult to discern among annuli in the oldest years (Figure 2.5; Erickson 1999).

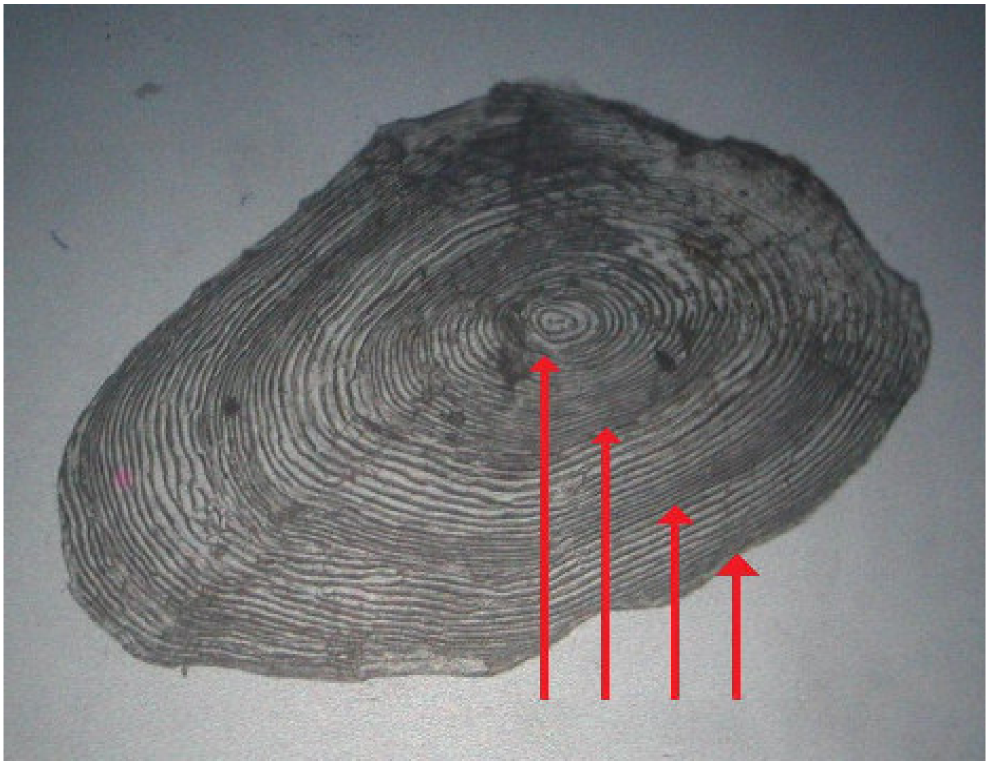

**Figure 2.5 Detecting age from an Elk River WCT scale. Four distinct annuli suggest the fish is in its 4th summer of growth (i.e. age 3). It can be difficult to discern annuli at the margin.**

### 2.3.2 Tissue preparation

To assess WCT/RB introgression, I prepared 166 tissue samples for genetic analysis by Leary *et al.* (2008) at the University of Montana Conservation Genetics Laboratory (Table 2.6). Their samples came from a random subsample that included 20 fins collected in the lower river blocks and 25 voucher specimens collected from the Michel tributary system in 2007. Fins were placed dry in 5ml test tubes and wet tissues in 5ml test tubes fixed in 100% ethanol.

### 2.3.3 Genetic Analysis

The methods for genetic analysis conducted by Leary *et al.* (2008) involved two separate techniques: the indel technique developed by Ostberg and Rodriguez

(2004) and an examination of microsatellite loci. The former technique uses pairs of synthetic DNA primers (short sequences of about 20 nucleotides) to target specific alleles on the sample DNA where deletion and/or insertion mutation events have occurred (indel sites). The primers complement the sequences at either end of the target DNA segment and bind during the polymerase chain reaction (PCR) to isolate and produce many copies of (i.e. amplify) the sample DNA using dye labelled free nucleotides. The indel events result in length differences in the region of amplified DNA due to alleles that are taxonomically characteristic of individual trout species, which are useful to examine hybridization (Ostberg *et al.* 2004). Leary *et al.* (2008) used capillary electrophoresis to separate the different alleles, which were labelled by the primers and visualized using an applied Biosystems 3130x1 genetic analyzer. The alleles were compared to synthetic fragments of DNA of known length and alleles from previously analyzed individuals.

**Table 2.5 Location of all tissue samples gathered in 2007.**

| Lower Elk drainage | Date | Species | Type | No. samples |
|---|---|---|---|---|
| Block A | 2007 | WCT | fin clip | 11 |
| Block B | 2007 | WCT | fin clip | 18 |
| Block C | 2007 | WCT | fin clip | 19 |
| Block D | 2007 | WCT | fin clip | 17 |
| Block E | 2007 | WCT | fin clip | 10 |
| Block F | 2007 | WCT | fin clip | 27 |
| Michel drainage | | | | |
| Erickson Creek | 2007 | WCT | Voucher | 2 |
| Lower Leach Creek | 2007 | WCT | Voucher | 5 |
| Michel Creek | 2007 | WCT | Voucher | 26 |
| Upper Corbin Creek | 2007 | WCT | Voucher | 8 |
| Upper Wheeler Creek | 2007 | WCT | Voucher | 7 |

Microsatellite loci are segments of DNA in which small sequences (usually two to five nucleotides) consecutively repeat (Leary *et al.* 2008). PCR methods similarly amplify the specific microsatellite loci, which are analyzed in terms of differences in the number of repeated units. The size differences among alleles are detected using the same electrophoretic and visualization procedures used to detect indel alleles.

Leary *et al.* (2008) obtained data from seven indel loci and seven microsatellite loci (Table 2.7). At 14 of these loci, WCT and RB rarely share alleles in common and are thus termed marker loci because they can be used to determine whether the sample DNA came from a hybridized population. A non-hybridized population will possess only alleles with marker loci characteristic of that taxon. In contrast, since half the DNA from $F_1$ (a first generation hybrid) comes from the parent of either species, $F_1$ individuals possess alleles characteristic of both species at all loci analyzed. Loci of later generation hybrids (post $F_1$), will vary among individuals based on the particular regions of DNA acquired from the hybrid parent or parents. Alleles detected in post $F_1$ hybrids will therefore be highly variable at the marker loci. As all genotypes are readily distinguishable, Leary *et al.* (2008) determined the proportion of alleles from either taxon.

**Table 2.6 The list of indel and microsatellite loci examined for WCT and RB, including the total number of alleles found in each species, and the number of alleles from this total that are occasionally shared.**

| Locus | | WCT alleles | | RB alleles | |
|---|---|---|---|---|---|
| Name | Origin | Total | Shared | Total | Shared |
| Occ34 | Indel | 1 | 0 | 1 | 0 |
| Occ35 | Indel | 1 | 0 | 1 | 0 |
| Occ36 | Indel | 2 | 0 | 2 | 0 |
| Occ37 | Indel | 2 | 0 | 3 | 0 |
| Occ38 | Indel | 1 | 0 | 1 | 0 |
| Occ42 | Indel | 2 | 1 | 1 | 1 |
| Om55 | Indel | 4 | 0 | 2 | 0 |
| Ssa408 | Microsatellite | 5 | 3 | 27 | 3 |
| Oki10 | Microsatellite | 19 | 13 | 14 | 13 |
| Omm1037-1 | Microsatellite | 11 | 4 | 16 | 4 |
| Omm1037-2 | Microsatellite | 3 | 1 | 3 | 1 |
| Omm1050 | Microsatellite | 9 | 1 | 65 | 1 |
| Omy0004 | Microsatellite | 2 | 0 | 27 | 0 |
| Omy1001 | Microsatellite | 24 | 0 | 28 | 0 |

# 3 METHODS II

This chapter deals with the analytical methods used in the analysis of the field data. I have attempted to construct a step-wise framework where individual research components are developed from preceding analyses so that all results culminate into an overall depiction of the population dynamics (Chapter 4).

## 3.1 Westslope Cutthroat Trout

The goal of arriving at an overall population estimate for Elk River WCT in the lower mainstem builds on the use of the von Bertalanffy growth model. In the absence of age information for 2006, I developed an age-length key based on the information collected from the 2007 tagged and aged fish in order to convert the 2006 length frequencies to proportions-at-age. In either case, I was able to estimate total mortality based on a catch curve analysis.

To estimate abundance from the tagging data, I needed to consider how total mortality and tag loss affected the marked proportion of fish over both years. Because I had snorkel information for both 2006 and 2007 in the four lower mainstem blocks, I also was able to estimate annual recruitment from the mark-recapture information using a balance model. In addition to the estimate of recruitment in the mainstem, I assessed the recruitment capability of WCT across individual tributary creeks based on electrofishing depletion surveys in the upper tributary system. Finally, I examined the recapture data from angler reports to assess WCT movement within and between both years.

### 3.1.1 Growth

The von Bertallanfy growth model has been used extensively in fisheries science. For this analysis, I used fork length for all fish captured in 2007, from which I was able to determine age using scales. Assuming constant growth between years, I then applied the estimated growth parameters from 2007 to the 2006 length data. The von Bertallanfy growth model is as follows:

(1) $$L_a = L_\infty \left(1 - e^{-K(a-a_o)}\right)$$

where $L_a$ is the predicted average fork length of fish of age $a$. Two of the growth parameters were estimated using a non-linear numerical search procedure: $L_\infty$ is the asymptotic fork length, which I constrained to be ≤ 600m, $K$ is the metabolic coefficient, and $a_o$ is the theoretical age at which fork length is zero (Hilborn and Walters 1992), which I fixed at -0.1. I fit growth curves for each individual sampling block using maximum likelihood methods. A total of three parameters were estimated ($L_\infty$, K, $CV$) where $CV$ is the coefficient of variation used to determine the age-specific standard deviation $\sigma_a$ in the set of the observed lengths $L_i$, $i = 1,\ldots,n$ for each age class:

(2) $$\sigma_a = CV \cdot L_a$$

The negative log likelihood of the data (ignoring the constraints) is given by:

(3) $$L\left(L_i \mid age_i, L_\infty, a_o, K, CV\right) = n\ln(\sigma_a) + \sum_{i=1}^{n} \frac{(L_i - L_a)^2}{2\sigma_a{}^2}$$

### 3.1.2 Mortality

Mortality can be difficult to estimate from catch data due to gear selectivity biases (Taylor *et al.* 2005) and variability in past recruits. Based on the assumption stable recruitment among cohorts, I visually examined the frequency distribution of lengths from the total number of tagged fish in both years, which suggested there to be gear selectivity for fish less than 150mm FL (Figure 3.1).

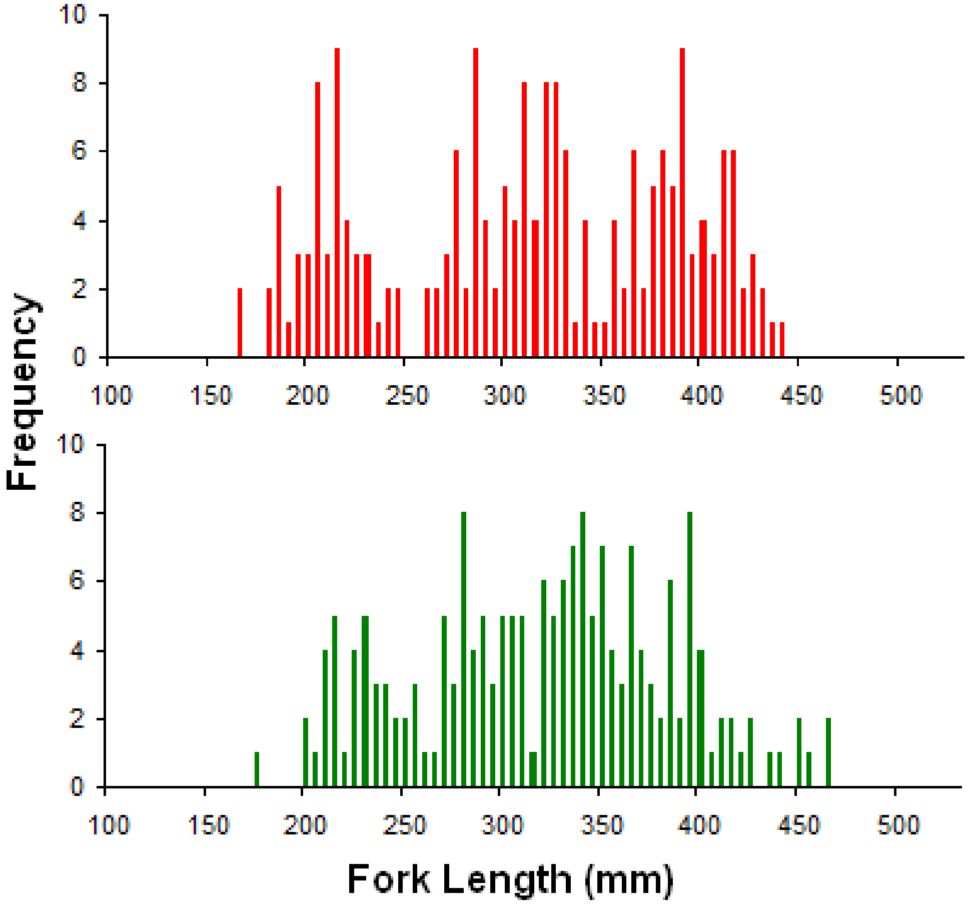

**Figure 3.1 Length distributions of adult fish caught during the 2006 (red) and 2007 (green) tagging programs. The absence of younger, invulnerable age classes indicates gear selectivity (<150mm FL).**

I determined 2007 total mortality $Z$ with the age information from the scales in an age-structured catch curve analysis (Gayanilo and Pauly 1997). This mortality estimate assumed constant recruitment over time and was calculated as a constant mortality across the group of maximally vulnerable age classes based on a fitted regression slope:

$$\ln(C_a + 1) = b - Za \tag{4}$$

where $C_a$ is the total catch at age $a$ and the intercept $b$ is the theoretical catch for the youngest age class (age 0) if it was fully vulnerable to the gear (Hilborn and Walters 1992). I added 1 to the $C_a$ term to account for cases where I did not have any fish of a certain age class in the sample. I determined the maximally vulnerable age classes based on the slope ($Z$) of the group of age classes that minimized the residuals (i.e. maximum $R^2$) in the 2007 set of tagged fish with known ages across all six blocks.

Without any scale information in 2006, I used parameter estimates from the 2007 growth models to develop a series of age-length keys for the 2006 tagging data. I considered the predicted length at age $L_a$ as determined by the von Bertalanffy model parameters for all fish caught in the lower six blocks. As these growth parameters initially come from known ages based on scale observations from the 2007 catch, I assumed the growth parameters from 2007 to be constant over both years when applying the age-length key to the 2006 tagging data.

The age-length key was an age-specific probability matrix across a range of 5mm length intervals (*x*):

(5) $$P(x \mid a) = \int_{x-2.5}^{x+2.5} \frac{1}{\sqrt{2\pi}\sigma_a} e\left( \frac{-(L_a - x)^2}{2\sigma_a{}^2} \right) dx$$

I assumed the set of observed lengths $L_i$ to be normally distributed about the mean length $L_a$ from the growth model (1) at each age class with a maximum age of 12 years, the oldest age to be observed in this study. I also admitted a degree of uncertainty in developing these age-specific probability distributions based on (2), the standard deviation in age-specific lengths $\sigma_a$.

I used this probability matrix to get the mean age at each length interval with an initial assumption about mortality *Z* as a starting value that was iteratively refined by assigning the mean age to the vector of length frequencies from the 2006 tagging data used to develop a catch curve (4). I substituted the resulting *Z* estimate from the catch curve back into the initial *Z* value and repeated the procedure until I arrived at a stable total mortality estimate. The initial starting value of *Z* was 0.250 and the mean age was determined as follows:

(6) $$\overline{a_x} = \frac{\sum_{a=1}^{A} a l_a P(x \mid a)}{\sum_{a=1}^{A} l_a P(x \mid a)}$$

Where $l_a$ is the proportion surviving at the start of each age $a$ given the mortality $Z$, weighted across individual length probabilities to the maximum age $A$, or 12 years.

Overall, I assessed the 2006 and 2007 growth and mortality information a) in the lower mainstem, b) in the six individual blocks (only five blocks in 2006), and c) between the two types of management zones (using a total of 8 age-length keys for the 2006 tagging data).

### 3.1.3 Abundance

I estimated abundance of WCT using a maximum likelihood approach with the tagging data. I assumed the probable outcome of each fish counted during the recapture snorkel survey as either tagged or untagged; I used the binomial probability distribution (e.g. see Gazey and Staley 1986):

(7) $$P(C_t, R_t \mid N_t) = \binom{C_t}{R_t} \left(\frac{M_t}{N_t}\right)^{R_t} \left(1 - \frac{M_t}{N_t}\right)^{C_t - R_t}$$

where $R_t$ represented the number of tagged fish counted during a snorkel event given some unknown abundance of fish $N_t$, of which a known number have been tagged $M_t$.

I developed a likelihood profile for the 2006 snorkel data across a range of hypothesized abundances $N$. The likelihood function considered a time-dependent decay of marked individuals in the population $M_t$. The decay rate was based on the mortality estimates from the catch-at-age analysis. Additionally, I was able to get an idea of annual tag loss during the 2007 tagging program. A total of 8 fish tagged in 2006 were recaptured in 2007. Of these eight fish, four had lost their tags, but were confirmed by examining the clipped pelvic fin, yielding an annual tag loss rate of 50%.

All tagging in 2006 took place in the first month of the study (July). From this point, the model considered a monthly decay of the total marked proportion due to the aforementioned factors. The total instantaneous mortality rate $Z_t$ over $t$ months was the sum of the mortality estimate from the catch curve $m_{est}$ and the tag loss rate $m_{tag}$:

(8)
$$Z_t = (m_{tag} + m_{est})\left({}^{t}\!/_{12}\right)$$

Given a decay in the number of tagged fish from the initial total of $M_o$, the remaining marked number $M_t$ was adjusted on a monthly basis according to the combined effects of tag loss and mortality:

(9)
$$M_t = M \mid Z_t = M_o e^{-Z_t}$$

The 2006 snorkel counts took place in September ($t = 3$) and the likelihood profile was constructed for a range of hypothesized values for $N_t$ (Equation 6). I used the likelihood profile to derive the 2006 abundance estimate for the lower mainstem and obtained upper and lower confidence limits from its cumulative probability distribution. I repeated the above procedure for the 2007 data, which included any remaining tags from 2006 and the additional tags administered in July and August of 2007 ($t = 13$ and 14 respectively). Finally, I reported the block-wise abundances in terms of fish density (WCT per kilometre). Similar to the preceding analyses, I derived the density estimates and compared them a) across individual blocks and b) between the two types of management.

Although I did not complete a full sampling protocol over both summers in Blocks E and F, I was able to use the same abundance estimation model to derive an estimate for both blocks in 2007. I only tagged fish in Block F during 2007, but the Block E estimation also included the tagged proportion from 2006 that survived into 2007 similar to the lower four blocks. I did not snorkel Block E in 2006, so there was no way of estimating abundance (or fish density) for that year. I compared the likelihood estimate of WCT density in these upper blocks with the 2007 estimates for the lower mainstem in order to assess how fish densities disperse into the main streams of the upper tributary basins.

### 3.1.4 Recruitment

The mark-recapture model factored in sources of mortality and tag loss from the 2006 tagging program, but it did not consider newly recruited fish at the beginning of the summer. Recruitment is defined as all fish large enough to be vulnerable to the angling gear (Approximately > 150mm FL). The 2006 mortality estimate used 2007 growth information to infer mean age and develop the 2006 catch curves, which must assume constant mortality and hence stable recruitment across fully vulnerable age classes, so if the population is at equilibrium, recruitment should offset mortality such that $N_{2006} \approx N_{2007}$. I determined recruitment using a balance model based on a stable mortality $Z_{\text{stable}}$ resulting from the mean Z estimates across both years, which were fairly well correlated (Figure 3.2), thereby assuming stable recruitment and abundance $N_{stable}$ (the mean of the 2006 and 2007 $N$ estimates):

(10)
$$\text{Recruits} = N_{stable}(1 - \exp^{-Z_{stable}})$$

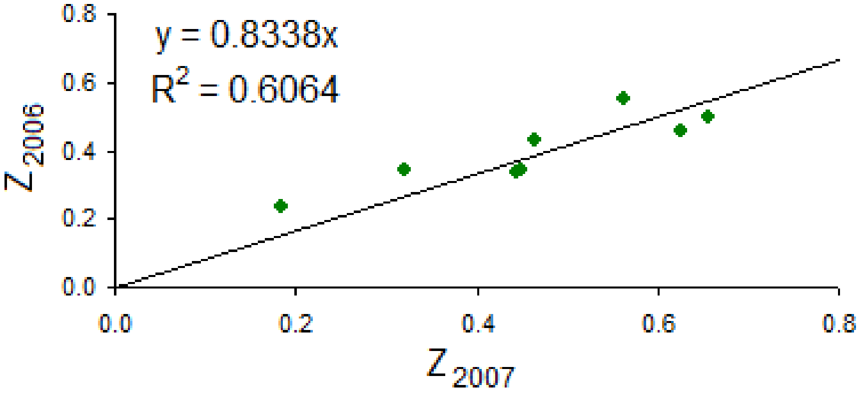

**Figure 3.2 Correlation between total mortality *Z* in 2006 and 2007.**

I reported recruitment for individual blocks in terms of densities (i.e. recruits per km) in order to compares among blocks and between management zones.

Mark-recapture estimates assume no migration in the area sampled, which is valid for the lower end of the mainstem, which is bounded by the hydro-electric dam. In the upper end, immigration is likely due to the recruitment of young fish entering from tributaries upstream, which have been accounted for in (10). However, this assumption may not be valid for abundance estimates among individual blocks and/or between the two management zones. A previous examination of fish movement in the Elk River suggested WCT exhibit a high degree of site fidelity (Prince and Morris 2003), which supports the results from other studies on cutthroat trout (Miller 1957; Heggenes *et al.* 1991; Young 1996) and other stream salmonids (Gerking 1959; Harcup *et al*. 1984; Gowan and Fausch 1996). I was able to get some idea of fish movement in this study over both years from the recapture information reported by volunteer anglers.

### 3.1.5 Movement

Although I did not get enough capture and recapture information from volunteer participants to derive a second, fishery-dependent estimate of relative abundance, I was still able to use the information I received to assess movement. The recapture data came from a combination of different sources. Actively participating anglers returned the angle-recapture data sheets I provided (see Appendix A) along with the additional reports to www.elkriverfishtracker.com, a website I created in 2007. Reports were also forwarded to me from the Ministry of Environment. Some information about tagged fish came from the angler creel surveys, and a few guides also reported tag recaptures. Finally, I collected information on movement from any tagged fish recaptured during the 2007 tagging program. I even observed one fish as it was being caught by a guided angler with a tag from the previous summer. Interestingly, this fish (UBC-0045) was still in the same location after 415 days, had previously been reported twice in the same location, and was also recaptured during the 2007 tagging program. In total, I received recapture information for 43 fish, but only 26 fish had complete information (Table 3.1).

**Table 3.1 Summary of all recapture data with complete information. All distances have been approximated based on individual reports with a minimum distance of 50 metres.**

| Tag | Capture Waypoint | | Days Between Captures | # Captures | Distance Moved (m) | Movement Rate* (m/day) | Method of Reporting |
|---|---|---|---|---|---|---|---|
| | Initial | Final | | | | | |
| UBC-0605 | B-T6 | B-T6 | 1 | 1 | <50 | - | Angle Recapture Data Sheet |
| UBC-0855 | F-T3 | F-T3 | 1 | 1 | <50 | - | Elk River Fishtracker |
| UBC-0854 | F-T3 | F-T3 | 1 | 1 | <50 | - | Elk River Fishtracker |
| UBC-0765 | F-T2 | F-T2 | 5 | 1 | <50 | - | Elk River Fishtracker |
| UBC-0184 | B-T18 | B-S3 | 9 | 1 | 1550 | - | Ministry of Environment |
| UBC-0773 | D-T21 | D-S2 | 38 | 1 | <50 | 1.32 | Observed while snorkeling |
| UBC-0775 | D-T21 | D-T21 | 43 | 1 | <50 | 1.16 | Creel survey |
| UBC-0191 | D-T1 | D-T1 | 46 | 1 | <50 | 1.09 | Guide report |
| UBC-0036 | C-T14 | C-T14 | 83 | 1 | <50 | 0.60 | Ministry of Environment |
| UBC-0046 | C-T13 | C-T13 | 83 | 1 | <50 | 0.60 | Ministry of Environment |
| UBC-0120 | E-T7 | E-T7 | 353 | 2 | <50 | 0.14 | 2007 Tagging |
| UBC-0057 | D-T12 | D-T12 | 409 | 1 | <50 | 0.12 | Guide report |
| UBC-0045 | C-T13 | C-T13 | 415 | 3 | <50 | 0.12 | Witnessed directly |
| UBC-0009 | B-T1 | B-T1 | 432 | 1 | <50 | 0.12 | Elk River Fishtracker |
| UBC-0621 | C-T8 | C-T48 | 401 | 2 | 250 | 0.62 | 2007 Tagging |
| UBC-0616 | C-T12 | C-T45 | 401 | 1 | 300 | 0.75 | 2007 Tagging |
| UBC-0181 | B-T18 | B-T20 | 63 | 1 | 950 | 15.1 | Ministry of Environment |
| UBC-0063 | D-T6 | D-T6 | 31 | 2 | <50 | 1.61 | Ministry of Environment |
| UBC-0764 | D-T36 | D-T37 | 44 | 1 | 1700 | 38.6 | Guide report |
| UBC-0121 | E-T7 | E-S1 | 84 | 1 | 2100 | 25.0 | Angle Recapture Data Sheet |
| UBC-0030 | C-T6 | C-0T11 | 57 | 1 | 2400 | 42.11 | Ministry of Environment |
| UBC-0188 | B-T1 | B-T22 | 63 | 1 | 2500 | 39.7 | Ministry of Environment |
| UBC-0052 | D-T18 | D-T38 | 414 | 3 | 2950 | 7.13 | Guide report |
| UBC-0379 | C-T48 | B-T27** | 326 | 1 | 4500 | 13.8 | Informed me directly |
| UBC-0187 | B-T1 | B-T21 | 66 | 1 | 6100 | 92.4 | Ministry of Environment |
| UBC-0192 | D-T9 | D-T16 | 45 | 1 | 16100 | 358 | Guide report |

*Only considers fish at large for more than 30 days.

**The nearest reference waypoint. The fish was recaptured at the lower end of Block C.

I only used the recapture information for the fish that had been reported more than 30 days since initially tagged in order to ensure adequate dispersion, which reduced the total number of fish to 21. I noted that all 21 fish had remained within the individual blocks where they were tagged and concluded that the assumption of no net migration between blocks had been met.

### 3.1.6 Tributaries

I was unable to determine WCT recruitment in 2007 for Blocks E and F without any snorkel observations for 2006, but these two stream sections drain from several tributaries in the next fractal division, where I conducted electrofishing surveys of juvenile fish densities using a depletion removal method. I used a two-stage sampling design similar to Wyatt (2002), which maximized the amount of sites with a combination of single- and multiple-pass removals. All sites where single passes were conducted took the capture probability provided by the pool of multiple-pass sites across the entire tributary system. I observed such high variation across multiple-pass sites both within and among tributaries that I calculated the global catchability $q$ from all sites and applied it to the catch data from the single-pass site to obtain the remaining abundance estimates.

I determined the mean density of fish in each tributary using an approach developed by Schnute (1983), which assumed constant capture probability $q$ across successive passes in each site. Schnute (1983) estimated the total number of fish within a confined area by minimizing the negative log likelihood of a two-parameter binomial model of fish capture $\theta$. Let $\theta$ denote the parameter set:

(11) $$\Theta = (N, q)$$

where $N$ is the total initial number of fish and $q$ is the capture probability. These parameters are estimated from a set of observed catches $C_1,\ldots,C_k$ across $k$ passes, from which the total cumulative catch $T_i$ up to and including each successive pass is obtained:

(12) $$T_i = \sum_{j=1}^{i} C_j, i = 1,\ldots,k$$

Several models have used the following solution derived by Moran (1951) to determine the maximum likelihood estimate of $q$ conditioned on $N$ (Zippin 1956; Otis *et al.* 1978; Schnute 1983):

(13) $$q(N) = T_k / \left( kN - \sum_{i=1}^{k-1} T_i \right)$$

This allows the likelihood to be evaluated over a range of hypothesized values for $N$. Schnute (1983) derived $N$ by minimizing the following negative log likelihood:

(14) $$-\log \mathcal{L}(\Theta) = G(\Theta) + H(\Theta) + K$$

where

(15) $$G(\Theta) = N\log(N) - T_k \log(T_k) - (N - T_k)\log(N - T_k^{pred}) - \log\binom{N}{T_k}$$

(16) $$H(\Theta) = \sum_{i=1}^{k} C_i \log(C_i / C_i^{pred})$$

(17) $$K = \sum_{i=1}^{k} \left[ \log(C_i!) - C_i \log(C_i) \right] - \log(T_k!) + T_k \log(T_k)$$

The $K$ term can be removed as it remains constant across all hypothesized values of $N$ and is only composed of the observed data. The terms $C^{\text{pred}}{}_i$ and $T^{\text{pred}}{}_k$ are the predicted catch per pass and predicted total catch respectively, which are used to assess the model fit. Schnute (1983) uses the following model equation to obtain the value of $C^{\text{pred}}{}_i$ such that the sum over $k$ passes totals to $T^{\text{pred}}{}_k$:

(18) $$C_i^{pred} = q(1-q)^{i-1} N$$

Uncertainty in the minimum negative log likelihood estimate can be determined with the likelihood ratio test (Hilborn and Mangel 1997) and evaluated in terms of the 95% confidence interval. Schnute (1983) stated that the log likelihoods for the true $N^{\text{true}}$ and hypothesized abundance $N^{est}$ follow a chi-square distribution with 1 *df* such that $2[L\ (N^{True}) - L\ (N^{est})] < 3.84$, which is equates to the following condition:

(19) $$L(N^{true}) \leq L(N^{est}) + 1.92$$

It should also be noted that, in several cases, the actual likelihood profile will not allow the calculation of an upper confidence limit when the catch data are inadequate, such that likelihood profile for a range of hypothesized values of N approaches infinity asymptotically at levels that are less than the $L(N^{est}) + 1.92$ (Schnute 1983).

It is well-supported in the literature that depletion estimates using electrofishing tend to under-estimate abundances due to reduction in catchability over successive passes (Bohlin *et al.* 1989; Peterson *et al.* 2004). By using a second mark-recapture trapping method in 2007, I attempted to reduce this bias with the assumption that trap vulnerability of an individual fish is unrelated to its susceptibility to the electrofisher. I applied the same mainstem mark-recapture binomial likelihood model to a portion tributary sites where I had trapped and released marked fish prior to electrofishing. I also could only apply the model to fish greater than 70-mm FL because the range of lengths for fish trapped in the nets across all sites was between 70 and 410 mm.

Only the fish within a particular length range were included in the mark-recapture analysis (i.e. fry and smaller age-1 WCT are excluded), so any correction factor must assume equal catchability of all fish lengths during electrofishing as well as equal catchability over the range of vulnerable lengths when trapping. The assumption of equal catchability  while electrofishing has not been supported elsewhere due to such habitat factors as % cobble substrate (Peterson *et al.* 2004), which allows the smallest fish to seek refuge in the substratum and be less susceptible to the electrofisher. I visually assessed the length-frequency distribution of fish captured across all sites and noted a high percentage of fry in the total catch (Figure 3.3), although size selectivity against the smallest fry (FL ≤25mm) would skew the distribution away from an expected length-frequency for a population the exhibits geometric decay (Krebs 1994). If anything the lack of smaller fish in the total caught when electrofishing would cause a negative bias and result in a more conservative correction factor.

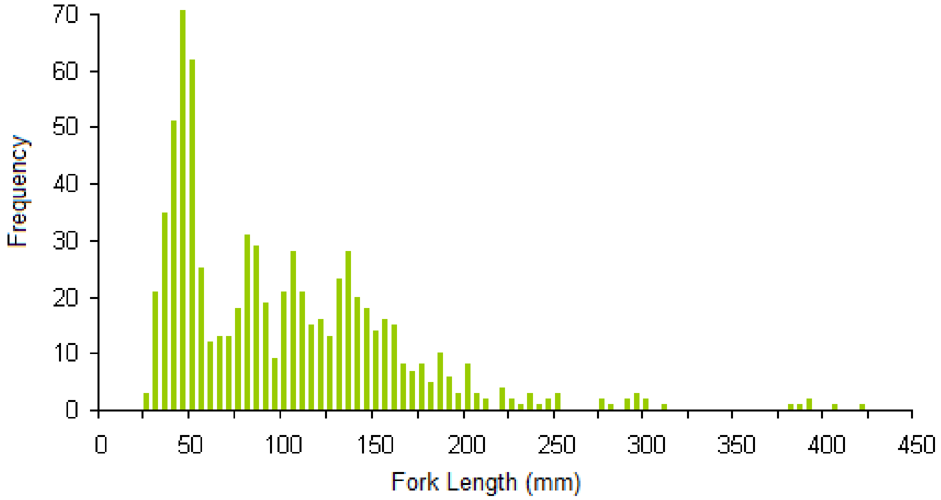

**Figure 3.3 Length distribution for WCT captured in the tributary system during electrofishing. No fish smaller than 25mm FL was captured.**

The mark-recapture likelihood profiles are determined over the range of hypothesized values of $N$ after it has been adjusted to correct for differences in size-selective vulnerability between the two methods:

$$N_{adjusted} = N_{mr}(T_{dep} / C_{dep}) \tag{20}$$

where $N_{mr}$ is the maximum likelihood estimate from the mark-recapture model, $T_{dep}$ represents the total number of fish electrofished in the sample area over multiple passes and $C_{dep}$ is the proportion of those fish that are trap-vulnerable (70mm ≤ FL). For example, I successfully trapped, marked, and released 11 fish (105mm ≤ FL ≤ 177mm) into site mi1 prior to electrofishing. After a three-pass depletion removal, I retained a total of 53 fish ($C_{dep}$ = 16; 70mm ≤ FL), two of which were marked ($R_{dep}$ = 2). The mark-recapture model only used the information from the trap-vulnerable pool to estimate abundance $N_{mr}$, which I then multiplied by the correction factor ($T_{dep}/C_{dep}$). The depletion likelihood estimated 75 WCT (95% CI: 59 - 208) and the mark-recapture model estimate showed a 298% increase to 292 WCT (95% CI: 162 – 6009). I developed this correction factor from all sites where I had previously trapped fish, but I only used the sites where I had trapped enough fish to get a reasonable mark-recapture estimate. Therefore, I only used the 6 sites where I had successfully trapped at least 10 WCT (i.e. $M \geq 10$; Table 3.2).

**Table 3.2 Sites where I trapped and released 10 or more WCT prior to electrofishing.**

| Tributary | Site | # Trapped WCT (*M*) |
|---|---|---|
| Michel | mi1 | 11 |
| Michel | mi7 | 10 |
| Michel | mi8 | 20 |
| Leach | le1 | 30 |
| Leach | le7 | 10 |
| Corbin | co2 | 61 |

The corrected likelihood estimates for all sites sampled in 2006 and 2007 used the mean % difference in the two estimates for the six sites, which I applied to all remaining sites within the second fractal division. The adjusted abundance estimates were then pooled into individual tributaries and I reported a mean density for all tributaries, expressed as WCT/m$^2$, which approximates a normal distribution according to the central limit theorem. Overall, the estimates across tributaries indicated which creeks in the upper tributary drainage basins showed the greatest potential for recruitment into the mainstem.

### 3.2 Angling Effort

In the absence of adequate catch data, I examined angler effort in terms of boat density using the information provided by Charity Barkwell of the Fernie Fly Girls shuttle service. I also used my own extrapolated estimates of angler dispersion throughout the four lower blocks based independent daily vehicle and trailer counts. Next, I examined the catch and effort data from my tagging and angler surveys in 2007 to see if CPUE is proportional to block-wise abundance estimates. Finally, I compared the total catch and angler effort from 2006 and 2007 guide reports to the corresponding mark-recapture abundance for the entire lower mainstem to see whether the change in overall abundance is reflected in the reported data.

#### 3.2.1 Effort as a Function of Fish Density

To determine whether the observed fish densities affect angler distribution throughout the lower mainstem I used the 2006 and 2007 shuttle service data log provided by Fernie Fly Girls to model boat density as a function of fish density. I conducted my own boat counts throughout the summer of 2007 based on my daily observations of boat trailers at the various put-in and take-out locations between Sparwood and Elko, which I compared with the information provided by Charity (Figure 3.4). Because most put-ins are also take-outs, I factored in the time of day when allotting an observed trailer to an appropriate block. In the morning, I would consider a trailer to be located at a put-in, but in the afternoon, when I returned from conducting electro-fishing surveys in the upper tributary system, I assumed that all trailers had been shuttled to take-out locations. This was based on what Charity told me about angler drifting habits. I compared my extrapolated boat densities with Charity and determined that my observations were sufficiently congruent with her data, so I used her data to model boat density *E* (i.e. boat per km) as a linear function of fish density over both years:

(21) $$E = aC + b$$

where *C* is my independent snorkel count from the visual surveys reported as a density (i.e. fish per km) over the corresponding distance of the block, *a* is the slope, and *b* is the intercept, from which I determined a theoretical lower limit of observed fish at which boat density would diminish to zero.

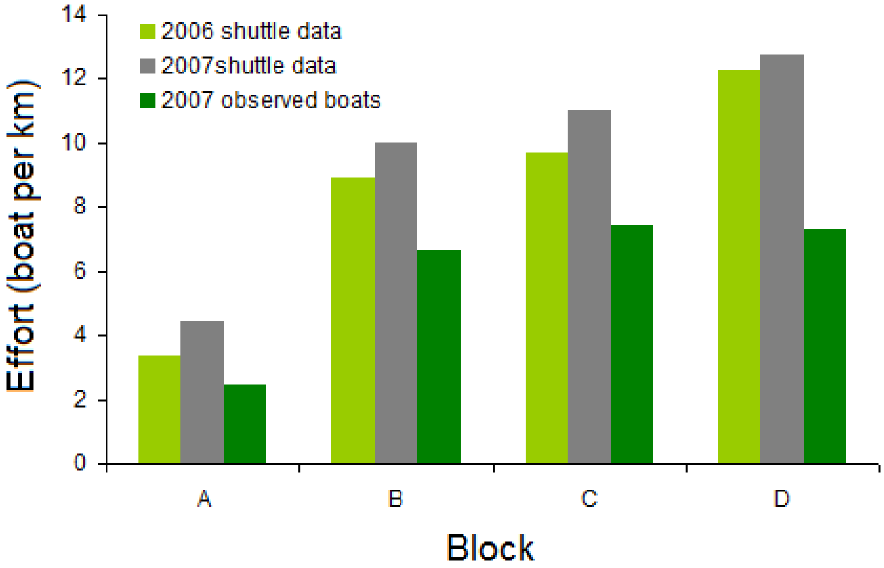

**Figure 3.4 Shuttle data for boat activity from the Fernie Fly Girls over 2006 and 2007 compared to my own observations in 2007.**

For my own 2007 effort index, I extrapolated the number of anglers from daily boat trailer and vehicle counts at put-in and take-out locations. If I saw a vehicle with no trailer, I counted it as one angler. If I saw a vehicle and a trailer, I counted it as two anglers. I used my swim counts of WCT per km (i.e. fishery-independent survey) assuming that snorkelling had been conducted in a narrow enough time frame during the each summer that factors including changes in visibility and flow patterns across individual blocks would not critically affect my ability to detect fish. A fishery-dependent survey using catch-per-unit-effort (CPUE) as an indicator of abundance would arguably possess more sources of variation, especially if these data came from a pool of anglers with varying degrees of angling skill, experience, and knowledge of the river. As the sole observer during snorkel counts, I only saw a fraction of the true fish density, but I maintain that as a standardized, fishery-independent survey across all blocks, it provides a more credible index of relative abundance.

### 3.2.2 Mortality as a Function of Effort

Although I employed a series of methods to determine total mortality $Z$ from the tagging data, I had no way of determining what portion of this total mortality resulted from angling effort (i.e. fishing mortality $F$). Boat density data give an indication of relative fishing effort among the different blocks over both years, which corresponded with the mortality estimates. If fishing effort contributes greatly to total mortality, it may be possible to determine from the relationship between $Z$ and boat density in the absence of any direct estimate of $F$. I used Charity's shuttle data to model total mortality $Z$ as a linear function of boat density $E$ similar to the preceding analysis (21):

$$Z = aE + b \tag{22}$$

### 3.2.3 Catch-per-unit-effort

Previous studies have attempted to test the validity of using CPUE as an indicator of abundance (Harley *et al.* 2001), and the dispersion fishing fleets in response to varying abundances of both fish and other vessels has been implicated as a factor that affects the utility of catch rates as an indicator of abundance (Gillis and Peterman 1998). Although a total catch has been estimated in recent Elk River creel surveys (Heidt 2002, 2004, and 2005), it has never been partitioned into the individual river sections that correspond to the popular drift runs and designated management zones in the lower mainstem. Angling guides must submit a total annual catch per species along with the number of anglers they guide per day, but they are not required differentiate the catch and effort data among the Elk River's individual management regulation zones for their annual reports (Tepper, personal communication).

I examined CPUE as an indicator of abundance across river blocks from the angler creel surveys and the tagging data. I calculated the mean CPUE for all six blocks from the reported number of WCT caught over the time spent angling in hours based on the angler surveys, which included interviews with a combination of bank and drift anglers based on the methods described in Chapter 2 (Appendix A). The second set of CPUE data across these blocks came from the number of fish caught in each tagging event over the time spent angling by volunteer anglers. Both these CPUE indices were expressed in rod hours. I calculated the mean CPUE from multiple tagging events in 2006 and 2007 and from angler interviews in 2007, which I compared to the corresponding mark-recapture abundance estimates in the four lower blocks. This spatial assessment was based on the following relationship:

(23)
$$CPUE = qN^{\beta}$$

where $q$ is the catchability coefficient and $\beta$ indicates the proportionality of CPUE and abundance $N$. Log-transformation yields a linear relationship, where $\beta$ estimated as the slope of the regression among spatial units for the two data sets:

(24)
$$\ln(CPUE) = \ln(q) + \beta\ln(N)$$

I examined how CPUE in individual blocks corresponds to abundance estimates to see whether CPUE is proportional to abundance (i.e. $\beta$ =1).

In the absence of any reported information on the spatial distribution of catch and effort, I also calculated a total CPUE from the reported catch for WCT and angler effort (expressed in angler days) from annual the angling guide reports provided by the BC Ministry of Environment.

### 3.3 Exotic Species

Rainbow trout and Eastern brook trout are the two known exotic salmonid species in the Elk River system. I received consistent, but infrequent reports of capture of RB and WCT/RB hybrids, or “cutbows”, by anglers in the mainstem and Michel Creek. Anglers also report catching EB in tributaries and beaver ponds along the mainstem. During the snorkel surveys, I only observed a single adult EB in 2006 and a single adult RB in 2007, but hybridization could not be visually determined. The presence of exotic species, especially EB, was more pronounced in the tributaries. To address the role of exotic species in the Elk River, separate analyses have been conducted for each species.

### 3.3.1 Rainbow Trout

The presence of RB and RB/WCT hybrids in the Elk River system has been reported in the findings from a genetic analysis specifically for this investigation by Leary *et al.* (2008). The proportion of alleles from different taxa in the samples was directly estimated at each diagnostic locus analyzed. When averaged over all diagnostic loci, Leary *et al.* (2008) estimated the proportion of alleles attributed to one or more taxa and reported it as an overall percentage of RB and WCT genotypes across the total sample set.

If hybridization was detected, Leary *et al.* (2008) next determined if the sample set came from a hybrid swarm within a mating population where exotic alleles are randomly distributed such that all individuals are of hybrid origin. Leary *et al.* (2008) calculated a hybrid index for each fish in the sample and determined if the allele frequencies among diagnostic loci conformed to homogeneity (i.e. the expected random distribution of alleles given some proportion of RB) using a chi-square contingency table.

### 3.3.2 Eastern Brook Trout

I noted a regular presence of EB in a number of tributaries during electrofishing. There has also been evidence that EB outcompetes BT in warmer streams elsewhere (McMahon *et al. 2007*; Rodtka and Volpe 2007). Bull trout have the lowest temperature growth optima among North American salmonids (Selong *et al.* 2001). Survival to hatching declines precipitously above 8 °C and the largest fry are produced at the lowest incubation temperatures (McPhail 2007). I estimated EB and BT density in tributaries similarly to WCT using Schnute's (1983) model and included all 43 sites within the second fractal division that were used to assess WCT recruitment potential (Table 2.4), as well as the additional sites in the third fractal division for a total of 57 sites in the upper tributaries (Table 3.3).

I used the BT and EB density estimates to assess whether stream temperature affects their relative abundances using a regression analysis. I expressed the fish densities as a proportion of EB ($x_{EB}$) relative to BT ($x_{BT}$), such that:

$$x_{EB} + x_{BT} = 1 \tag{25}$$

**Table 3.3 Fourteen additional tributary sites in the third fractal division that I included with the 43 lower tributary sites and used to determine the presence of EB relative to BT.**

| Drainage | Tributary | Sites |
|---|---|---|
| Michel | Alexander | al1 to al5 |
| | Andy Good | an1 |
| | Corbin | co2 |
| | Michel | mi8 & mi10 |
| Upper Elk | Grave | gr1 to gr5 |

# 4 RESULTS

The results have been divided into five components and reported in such a manner as to correspond with the individual analyses from the previous chapter.

## 4.1 Lower Mainstem

The first set of results came from the examination of the WCT population in the lower mainstem. I examined growth parameters and mortality rates for 2007 and used the parameter estimates from the 2007 von Bertalanffy growth models to develop the age-length keys and obtain an age composition from the length frequency observations in 2006, which I used in a catch curve to estimate total mortality for 2006. This total mortality estimate was then factored into the mark-recapture model to adjust the number of marks at large for abundance estimates.

### 4.1.1 WCT Growth

Growth was similar in all blocks up to about age 6. Parameter estimates are summarized in Table 4.1, and varied among blocks in a way that indicated divergence at older ages where sample sizes were very small Figure 4.1.

**Table 4.1 Parameter estimates of von Bertalanffy growth models for the combined blocks in the lower mainstem, individual river blocks, and the different management regulation zones.**

| | Growth Parameters | | | |
|---|---|---|---|---|
| Section | $L_\infty$ | $K$ | $a_o$* | $CV$ |
| Lower Mainstem | 464 | 0.198 | -0.1 | 0.113 |
| Block A | 397 | 0.244 | -0.1 | 0.106 |
| Block B | 404 | 0.266 | -0.1 | 0.111 |
| Block C | 486 | 0.176 | -0.1 | 0.098 |
| Block D | 516 | 0.176 | -0.1 | 0.112 |
| Catch-and-Release | 446 | 0.200 | -0.1 | 0.104 |
| Catch-and-Keep | 473 | 0.199 | -0.1 | 0.113 |

* Indicates a fixed parameter for all sections.

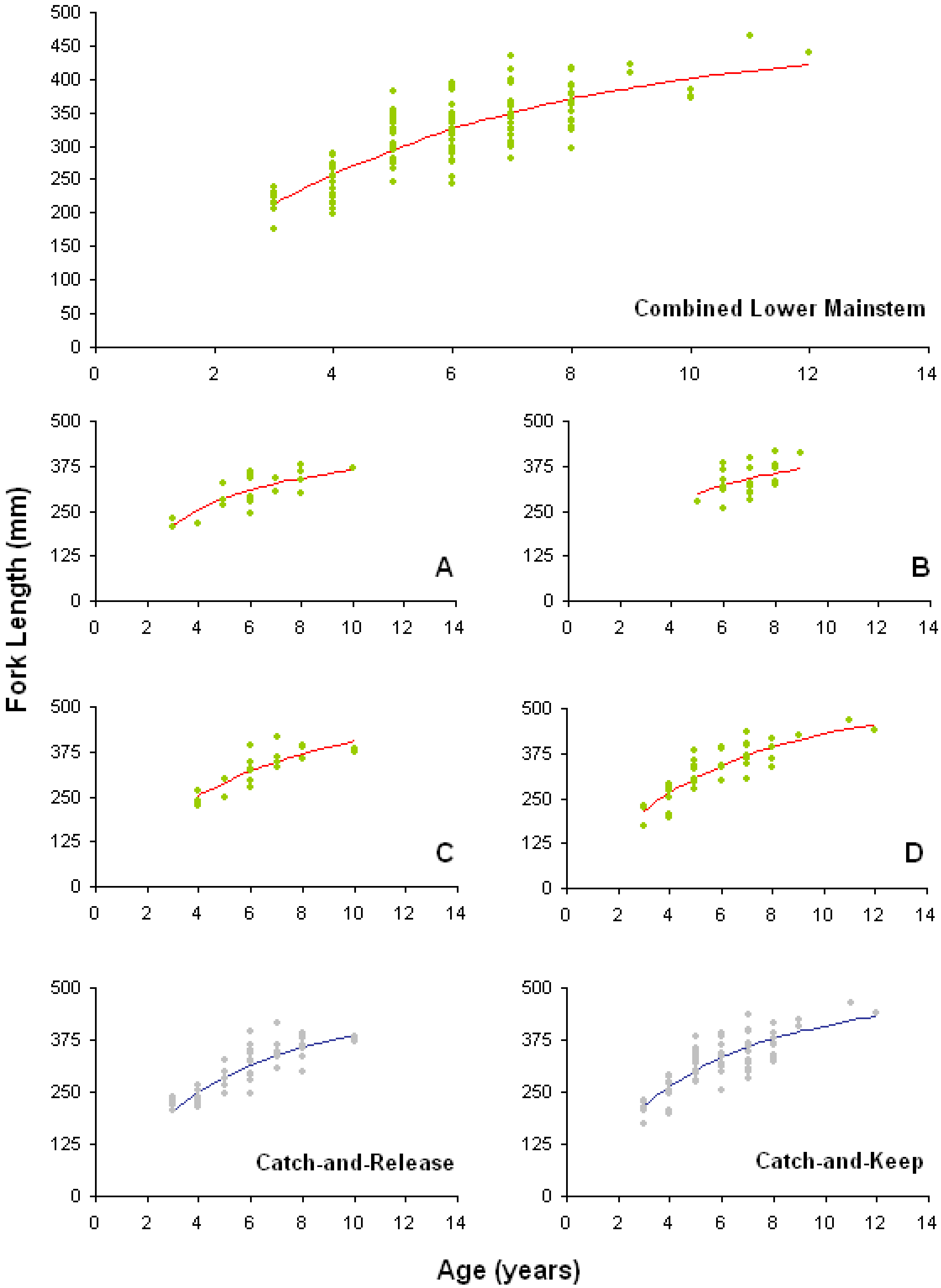

**Figure 4.1 von Bertalanffy growth models for the combined blocks of the lower mainstem, individual river blocks, and the two management regulation zones in 2007.**

### 4.1.2 WCT Mortality

Age at capture ranged from 3 to 12 (Figure 4.1). A system-wide catch curve for the 2007 tagged fish (all six blocks) indicated that Elk River WCT are maximally vulnerable to angling by age 6 (inset Figure 4.3; $R^2 = 0.91$). Although length was a poor indicator of age beyond age 3, ages could still be assigned probabilistically on the basis of the age-length key for the 2006 fish (Figure 4.2), from which I determined a mean age at length $\bar{a}_X$ to get age composition and estimate 2006 WCT total mortality *Z*. All the regression estimates of total mortality (*Z*) for both years, except Block E, are statistically significant ($\alpha = 0.05$) Table 4.2. Catch curves are displayed as the natural log of the catch (+1) for all age classes (Figures 4.3 -4). All age classes are plotted, but only fully vulnerable fish were included in the regression analysis.

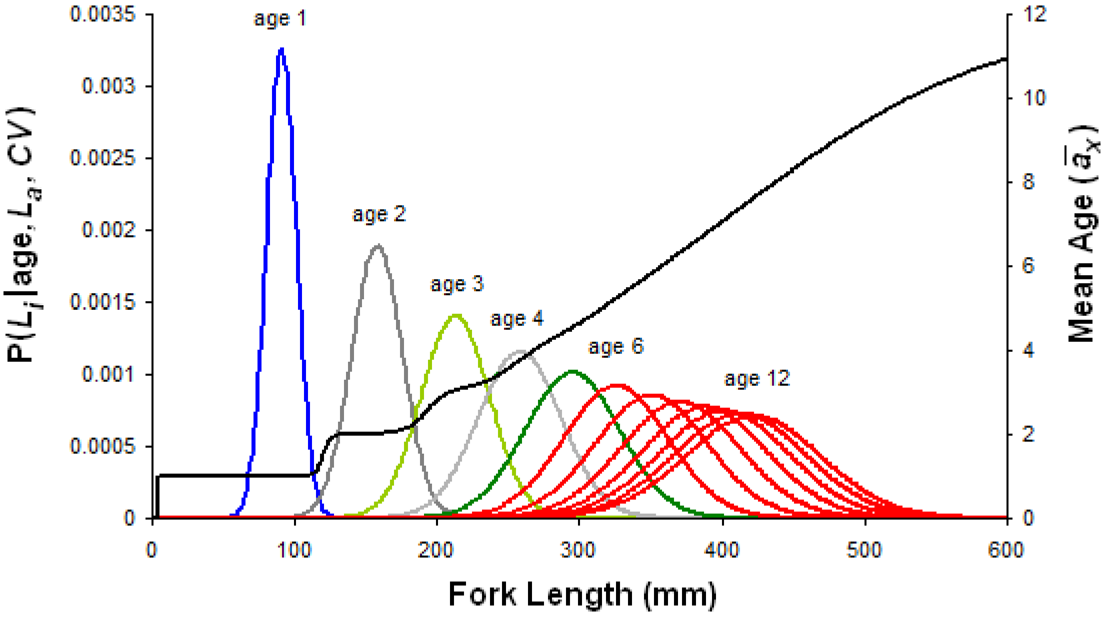

**Figure 4.2 Probability matrix for an age-length key of the combined blocks in the lower mainstem and the calculated mean age $\bar{a}_X$ for each length interval (black), given the estimated growth parameters from the 2007 catch. Ages 6 to 12 represent fully vulnerable age classes (red).**

**Table 4.2 Estimated total annual mortality rates *Z* from a linear regression analysis of the catch-at-age data for individual blocks, the lower mainstem, and the individual management regulation zones. All regressions are statistically significant ($\alpha=0.05$), except Block E.**

| | 2006 | | | 2007 | | | |
|---|---|---|---|---|---|---|---|
| River Section | $Z$ | df | p | $Z$ | df | p | $Z_{stable}$ |
| lower mainstem | 0.657 | 6 | 0.010 | 0.500 | 6 | 0.003 | 0.578 |
| Block A | 0.445 | 6 | 0.007 | 0.334 | 6 | 0.015 | 0.390 |
| Block B | 0.465 | 6 | 0.021 | 0.429 | 6 | 0.003 | 0.447 |
| Block C | 0.450 | 6 | 0.008 | 0.342 | 6 | 0.016 | 0.396 |
| Block D | 0.320 | 6 | 0.036 | 0.340 | 6 | 0.026 | 0.330 |
| catch-and-release | 0.626 | 6 | 0.001 | 0.455 | 6 | 0.24 | 0.540 |
| catch-and-keep | 0.563 | 6 | 0.010 | 0.553 | 6 | 0.002 | 0.558 |
| Block E | 0.185 | 6 | 0.214* | 0.235 | 6 | 0.084* | 0.210 |
| Block F | - | - | - | 0.359 | 6 | 0.008 | |

*Indicates a non-significant regression statistic.

### 4.1.3 WCT Abundance and Recruitment

The lower mainstem (Blocks A to D) WCT modal abundance estimate was 10,050 with a 95% credible interval of 6,850 – 19,050 fish in 2006. The 2007 modal abundance estimate was 16,200 fish with a 95% credible interval of 11,750 – 25,950 fish. Overall recruitment between years using stable (mean) abundance and mortality was 5,753 fish. The marginal probability distributions for the lower mainstem abundance estimates are shown in Figure 4.5. For the individual blocks and regulation zones, all results are summarized in Table 4.3. Abundances in blocks and zones are reported as density estimates with the associated 95% credible intervals along with the estimate of recruits per km. The probability distributions for all block and regulation zone density estimates follow in Figure 4.6.

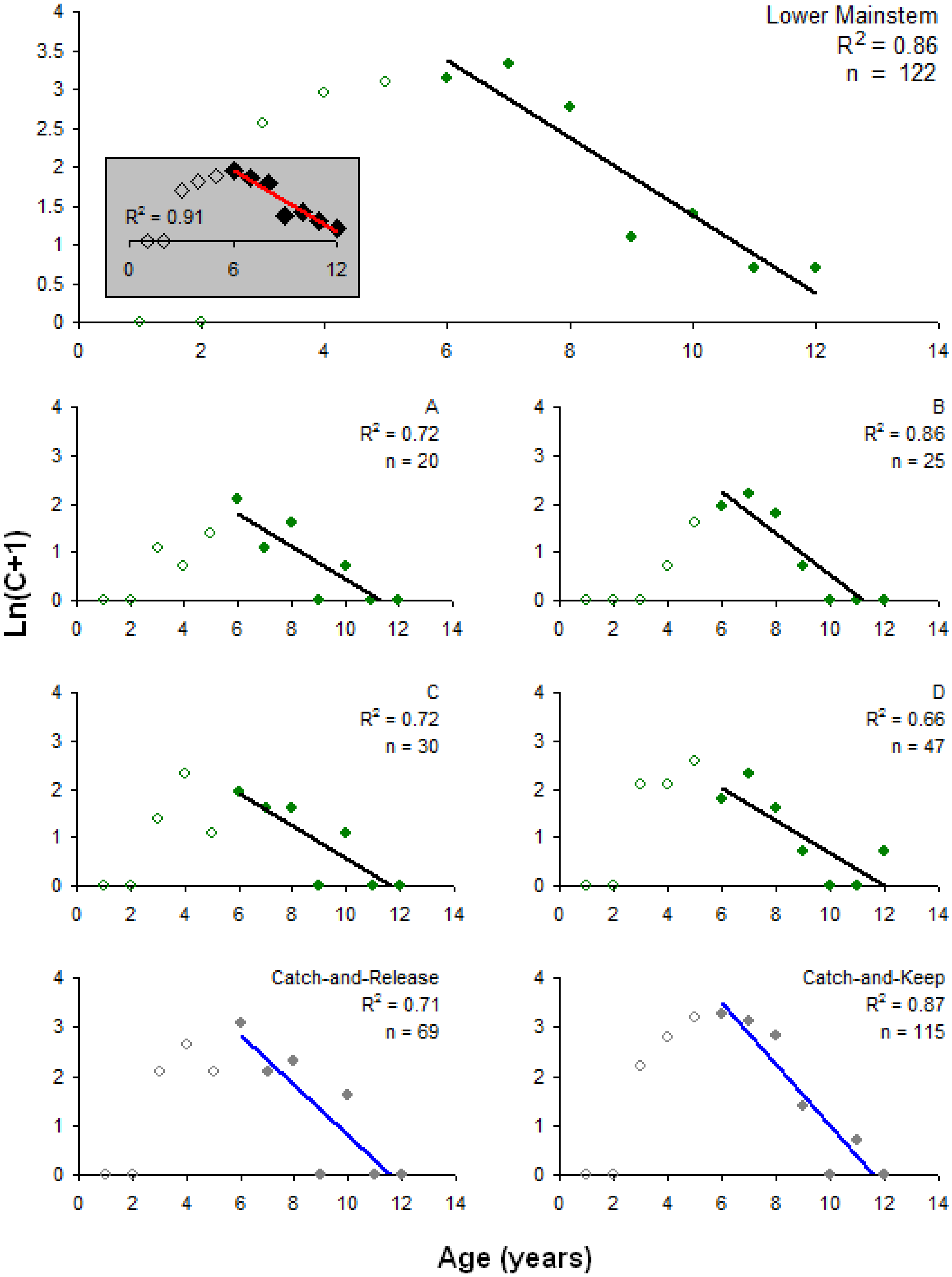

**Figure 4.3 Catch curve estimates of total mortality rate *Z* (regression slopes) from the 2007 catch-at-age data for fully vulnerable age classes (closed points) in the lower mainstem and individual river blocks (top three rows) as well as between the regulation management zones (bottom row) based on scale information throughout the entire system. Age 6 fish are considered fully vulnerable according to the system-wide catch curve for all 2007 tagged fish (top row, inset).**

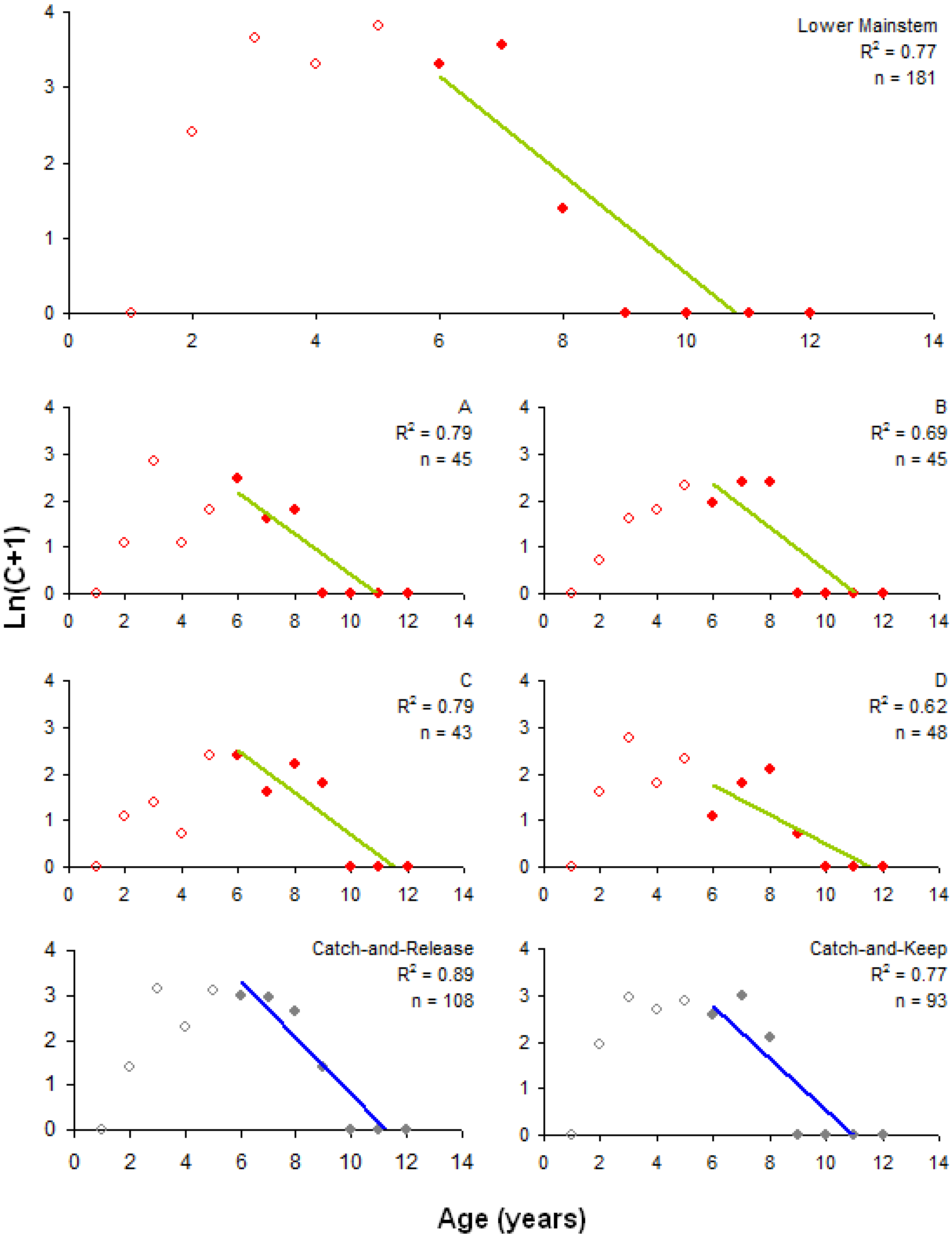

**Figure 4.4 Catch curves estimates of total mortality rate *Z* from the 2006 catch-at-age data for fully vulnerable age classes (closed points) in the lower mainstem and individual river blocks (top three rows), as well as between the regulation management zones (bottom row). Each catch curve is based on the composition data using a calculated mean age given length from the age-length key. Regression slopes are fitted to the group of ages 6 and older based on the known ages from 2007 scale information.**

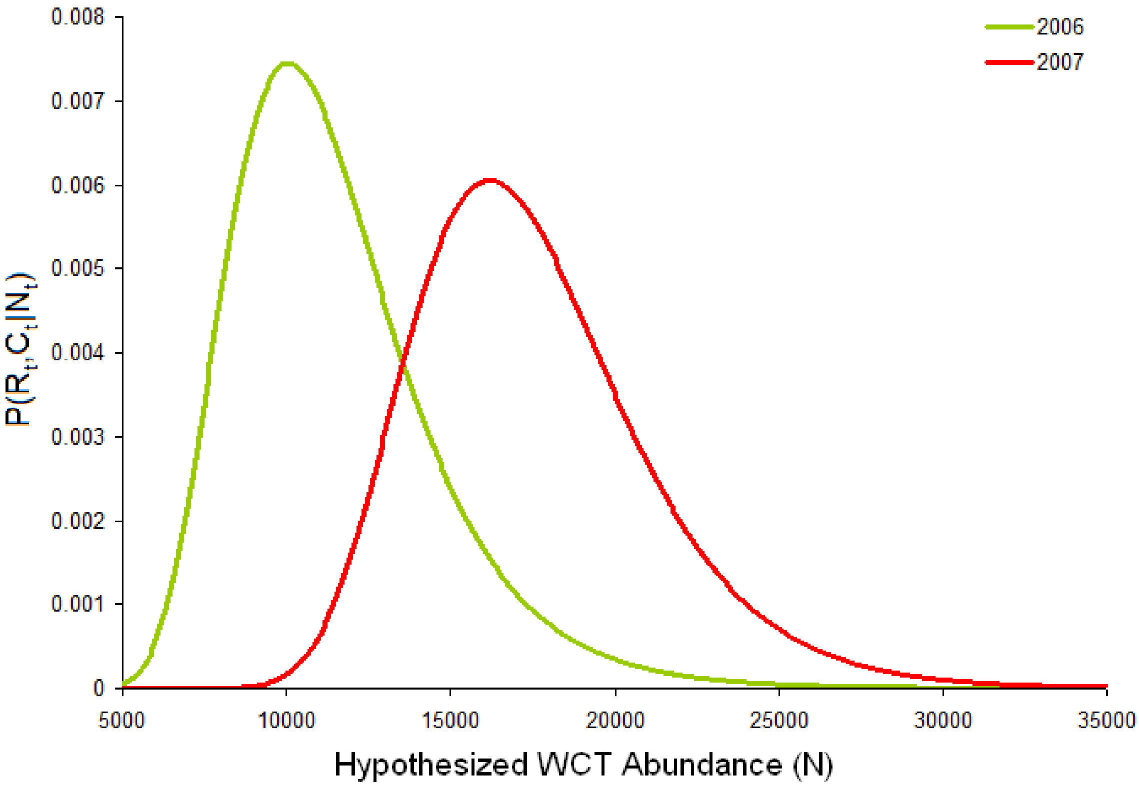

**Figure 4.5 Marginal probability distribution of WCT abundance (N) for the lower mainstem Elk River in 2006 (green) and 2007 (red).**

**Table 4.3 Maximum likelihood (modal) estimates of WCT abundance (N) and estimated density (WCT/km) with 95% credible intervals among the 4 river blocks in the lower mainstem between the individual management regulation zones. The observed snorkel counts (C) and percent counts in the abundance estimates (C/N) each year are included. Estimated recruits have also been displayed based on stable abundance and mortality estimates between years.**

| 2006 | N | C | C/N (%) | WCT/km | 95% CI | $N_{stable}$ |
|---|---|---|---|---|---|---|
| Block A | 5565 | 313 | 6 | 287 | 149 – 3017 | 6620 |
| Block B | 4025 | 233 | 6 | 250 | 131 – 3459 | 3705 |
| Block C | 795 | 185 | 23 | 61 | 36 – 189 | 1950 |
| Block D | 3985 | 470 | 12 | 211 | 121 – 962 | 4780 |
| Release Zones | 3595 | 498 | 14 | 111 | 69 – 286 | 5940 |
| Harvest Zones | 5745 | 703 | 12 | 164 | 103 – 402 | 6365 |
| **2007** | **N** | **C** | **C/N (%)** | **WCT/km** | **95% CI** | **Recruits/km** |
| Block A | 7675 | 680 | 9 | 396 | 211 - 2748 | 110 |
| Block B | 3385 | 518 | 15 | 210 | 123 – 773 | 83 |
| Block C | 3105 | 495 | 16 | 237 | 142 – 751 | 49 |
| Block D | 5575 | 867 | 16 | 296 | 188 – 715 | 71 |
| Release Zones | 8285 | 1175 | 14 | 255 | 161 – 432 | 76 |
| Harvest Zones | 6985 | 1385 | 20 | 200 | 136 - 380 | 78 |

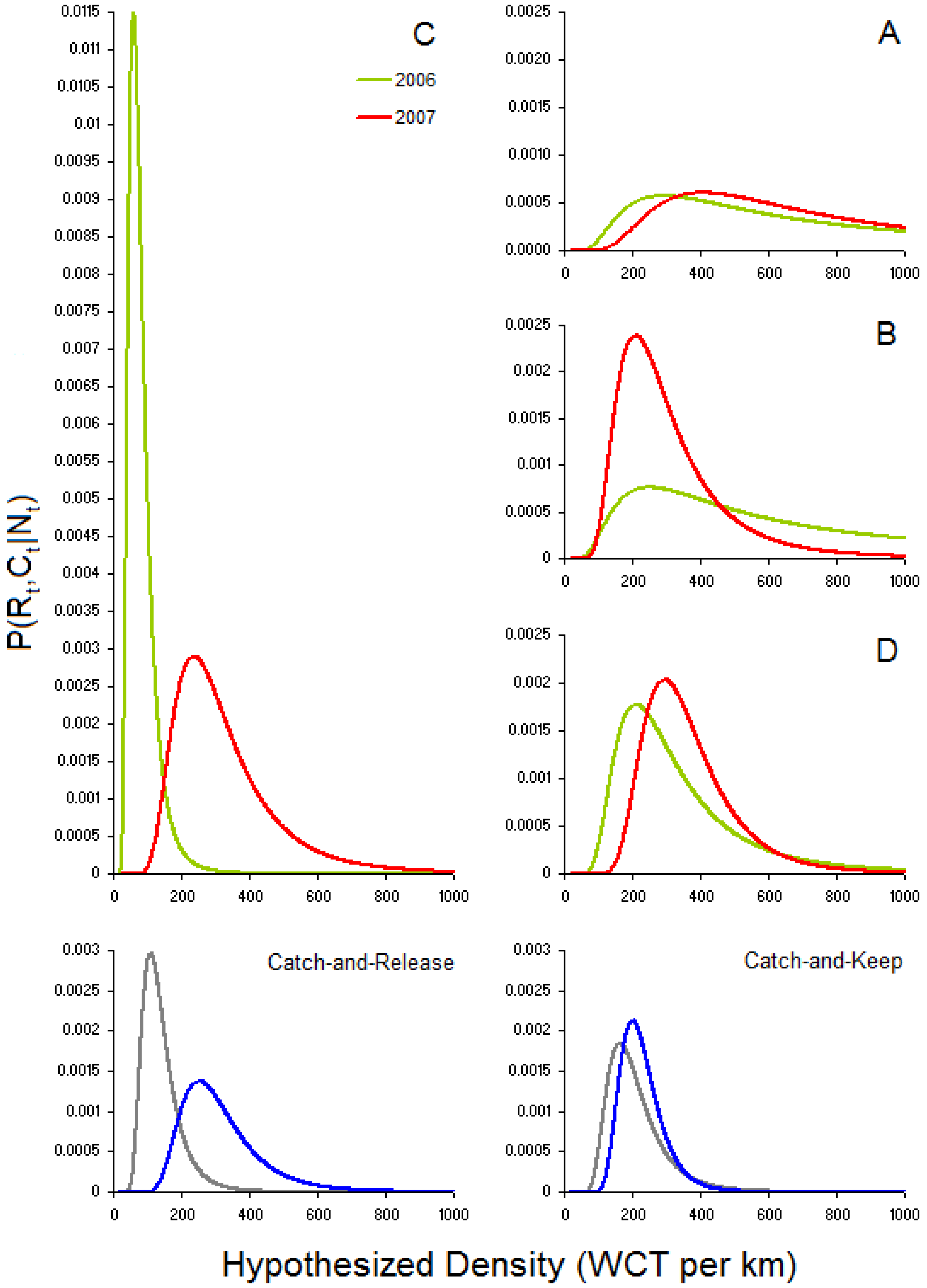

**Figure 4.6 Marginal probability distributions of WCT density across the four blocks in the lower mainstem (top three rows) and between regulation zones (bottom row) for both years.**

## 4.2 Tributary System

The next series of results assessed the tributary system as it successively divides up into the smaller streams that comprise the spawning areas for WCT, which I assumed to be important for recruitment in the mainstem. Blocks E and F are the respective mainstems of the Upper Elk and Michel drainages that comprise the first fractal division of tributaries. These streams meet at Sparwood (the north end of Block D). The second fractal divisions  extends further up from these two blocks and density estimates of juvenile WCT have been compared across the set of tributary streams (i.e. creeks).

### 4.2.1 First Fractal Division

The 2007 von Bertalanffy growth parameters, mortality, and abundance estimates are summarized in Table 4.4. Linear regression analyses of mortality for the 2007 catch-at-age data were statistically significant for Block F, but not Block E ($\alpha = 0.05$). Modal abundance estimates *N* have been reported in terms of fish density (WCT per km) with 95% credible intervals. Results for Blocks E and F are displayed in Figure 4.7.

**Table 4.4 2007 estimated WCT growth parameters, mortality, abundance, and density including 95% confidence intervals, for the upper river blocks in the first fractal division of the tributary system.**

| | Growth | | | | Mortalilty | | | Abundance | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Block | $L_\infty$ | $K$ | $a_o^a$ | $\sigma$ | $Z$ | df | p | $N$ | WCT/km | 95% CI | Recruits/km |
| E | 600 | 0.12 | -0.1 | 0.10 | 0.235 | 6 | 0.084 | 1085 | 58 | 36 – 150 | 12 |
| F | 417 | 0.29 | -0.1 | 0.11 | 0.359 | 6 | 0.008 | 2215 | 233 | 147 – 560 | 70 |

[a] Indicates a fixed parameter.

[b] The upper constraint for the parameter when minimizing the likelihood across all samples.

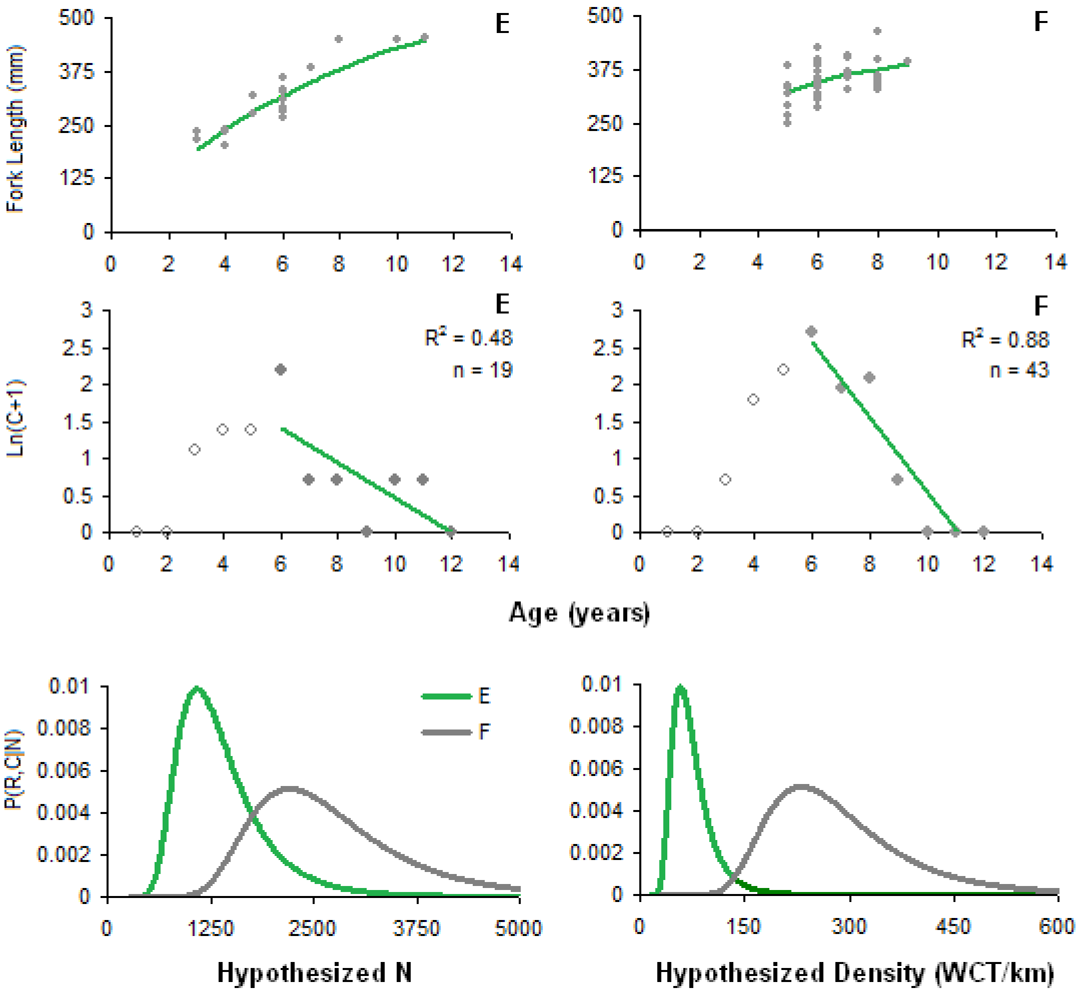

**Figure 4.7 Overall results for tagged WCT in the two blocks of the first fractal division of tributaries. The von Bertalanffy growth model (top row) and estimated annual mortality from catch-at-age data (middle row) are displayed for Blocks E (green) and F (grey) for 2007. Abundance and density estimates for the blocks are in the bottom row.**

### 4.2.2 Second Fractal Division

I utilized the capture probability information from multiple-pass sites in obtaining estimates of abundance for single pass sites. I plotted the parameter estimates for abundance *N* and capture probability *q* across all multiple-pass sites to look at the variation in q across sites (Figure 4.8). The global *q* was 0.370.

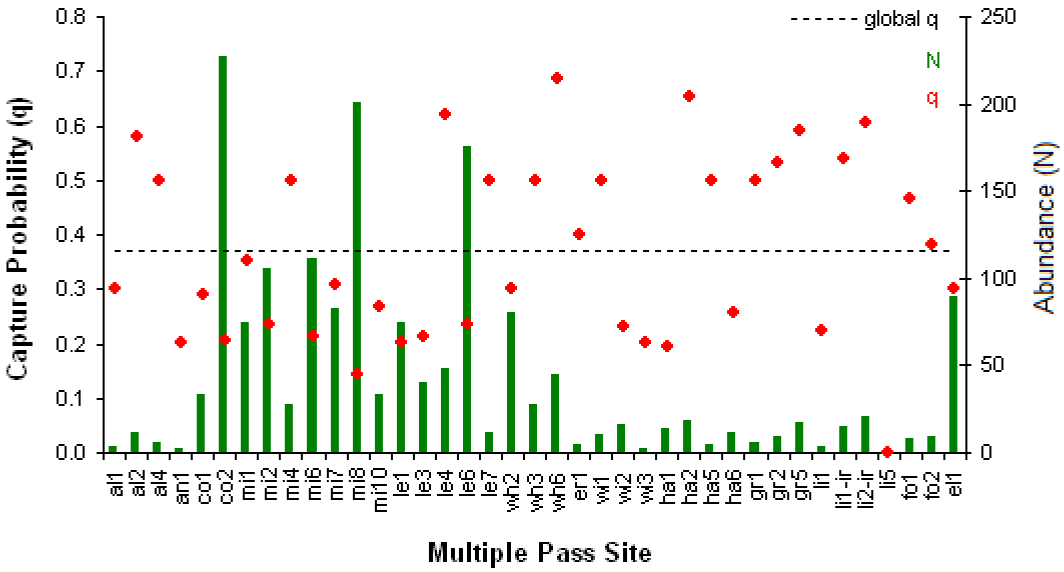

**Figure 4.8 Maximum likelihood estimates for capture probability *q* and abundance *N* of WCT in all multiple pass sites of the Elk River tributary system. A global *q* of 0.370 is also displayed as a horizontal dashed line.**

I used the likelihood profiles for individual multiple-pass sites and the extrapolated *N* using the global *q* in single pass sites to calculate an overall mean WCT density for each tributary (refer to Figure 4.9 as an example). The results for the minimum negative log likelihood estimates across all multiple pass sites in the second fractal division are displayed in Table 4.5 to include total estimated abundance *N* and WCT density with 95% confidence intervals. Cases where the likelihood profile failed to define an upper limit are noted (Table 4.5).

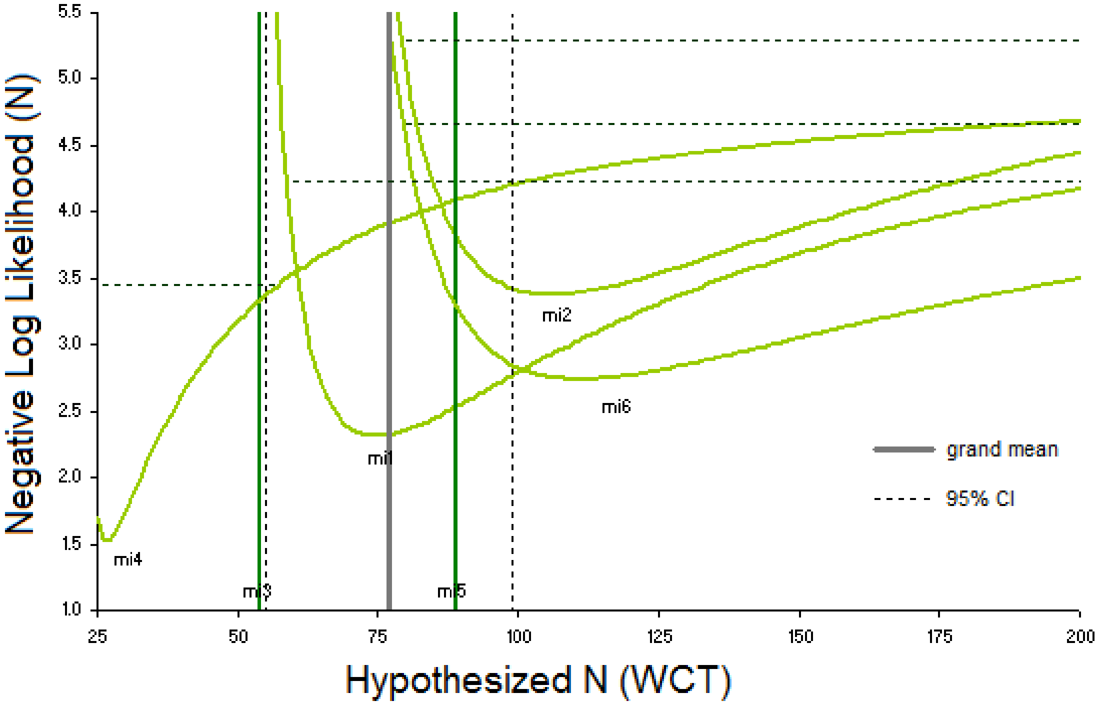

**Figure 4.9 Example of likelihood profiles for abundance (N) at multiple pass sites in Michel Creek 2nd fractal plane (light green). Dashed lines indicate the range of hypothesized values within the 95% confinence interval. Solid vertical lines indicate estimates of N for single-pass sites (mi3 and mi5; dark green) using a global *q* of 0.370. The pool of all estimates is represented by the grand mean and its 95% confidence interval (n=6; grey).**

To try and improve on these estimated abundances and densities, I applied the correction factor from the six sites where I simultaneously employed the mark-recapture method using sites where I trapped and marked at least ten fish. I used the difference between mark-recapture and depletion removal estimates to calculate a possibly less biased estimate of WCT density (Figure 4.10). Overall the mark-recapture estimates were 177% greater on average than the depletion estimates. The mean density estimates for the second fractal division of tributaries system were adjusted by this correction factor (Figure 4.11)

.

**Table 4.5 Abundance and density estimates of WCT (with 95% confidence intervals) in all multiple-pass sites within the second fractal division of tributaries.**

| Drainage | Tributary | Site | N | WCT/m$^2$ | 95% C.I. |
|---|---|---|---|---|---|
| Michel | Michel Creek | mi1 | 75 | 0.375 | 0.295 – 1.04 |
| | | mi2 | 106 | 0.530 | 0.395 – 1.781 |
| | | mi4 | 27 | 0.135 | 0.120 – 0.285 |
| | | mi6 | 111 | 0.555 | 0.394 – 3.288 |
| | Leach Creek | le1 | 75 | 0.376 | 0.210 – infinity* |
| | | le3 | 40 | 0.200 | 0.125 – infinity* |
| | | le4 | 48 | 0.240 | 0.230 – 0.290 |
| | | le6 | 176 | 0.881 | 0.686 – 1.753 |
| | Wheeler Creek | wh2 | 80 | 0.800 | 0.580 – 7.020 |
| | | wh3 | 27 | 0.270 | 0.240 – 0.570 |
| | | wh6 | 45 | 0.450 | 0.440 – 0.500 |
| | Erickson Creek | er1 | 5 | 0.025 | 0.020 – infinity* |
| | | er2 | 0 | 0.000 | - |
| | | er3 | 0 | 0.000 | - |
| | | er4 | 0 | 0.000 | - |
| | | er5 | 0 | 0.000 | - |
| Upper Elk | Wilson Creek | wi1 | 10 | 0.050 | 0.045 – infinity* |
| | | wi2 | 16 | 0.080 | 0.045 – infinity* |
| | | wi3 | 2 | 0.010 | 0.005 – infinity* |
| | Harmer Creek | ha1 | 14 | 0.070 | 0.030 – infinity* |
| | | ha2 | 18 | 0.181 | 0.170 – 0.220 |
| | | ha5 | 5 | 0.050 | 0.040 – 0.360 |
| | | ha6 | 12 | 0.120 | 0.110 – 0.140 |
| | Line Creek | li1 | 3 | 0.015 | 0.010 – infinity* |
| | | li1-ir | 15 | 0.013 | 0.013 – 0.058 |
| | | li2-ir | 21 | 0.022 | 0.022 – 0.031 |
| | | li5 | 0 | 0.000 | - |
| | Forsyth Creek | fo1 | 8 | 0.040 | 0.035 – 0.085 |
| | | fo2 | 9 | 0.045 | 0.040 – infinity* |
| | Upper Elk River | el1 | 89 | 0.445 | 0.365 – 0.829 |

*Indicates a failure to define the upper confidence limit.

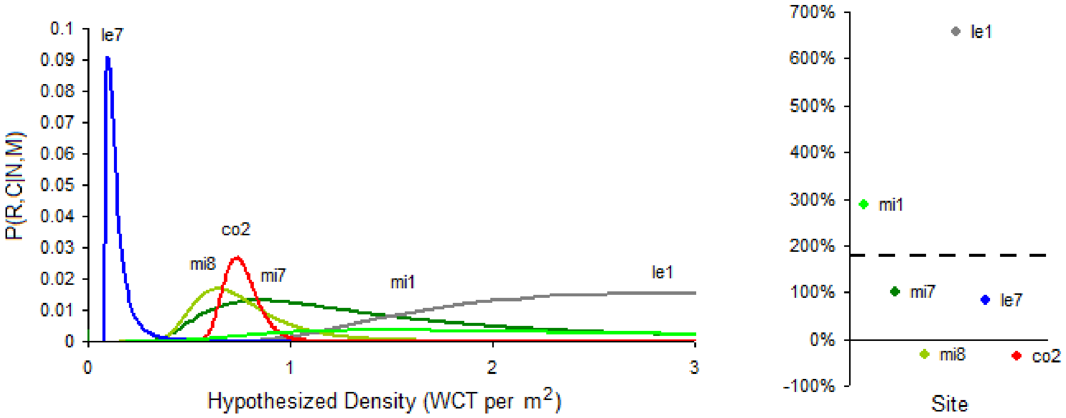

Figure 4.10 At left: probability distributions for WCT density for all sites where mark-recapture methodology was applied in conjunction to electrofishing. The figure only includes sites where at least 10 fish were trapped and marked. At right: the six sites showing the individual % differences and the mean difference (dashed line; 177%) between WCT mark-recapture and depletion removal density estimates.

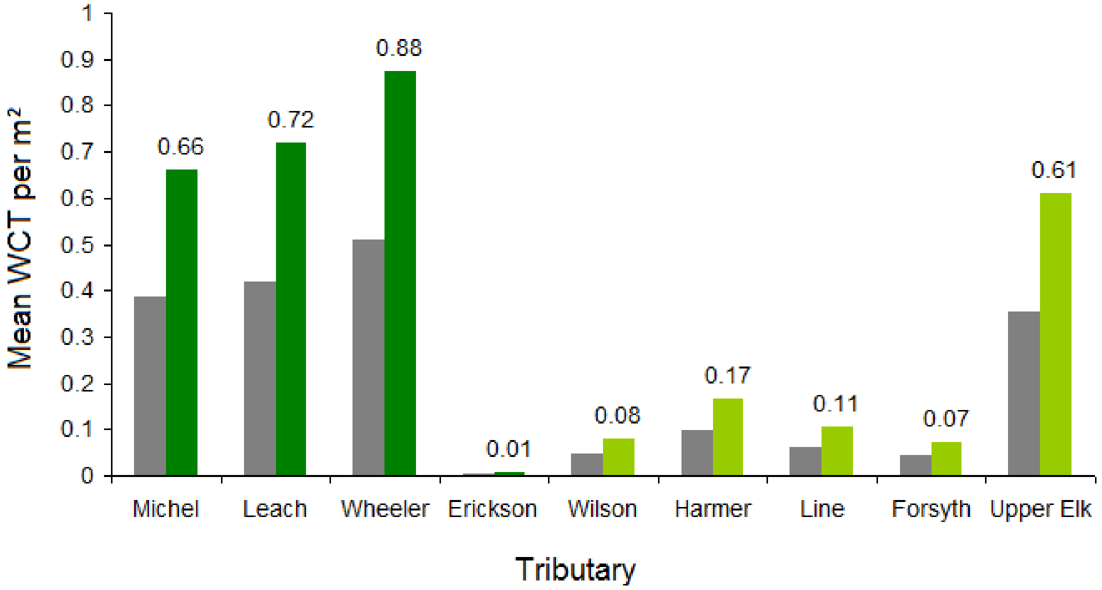

Figure 4.11 Mean WCT densities from the depletion estimates for all sites within individual tributaries (grey) and the final adjusted densities using the correction factor in both the Michel drainage basin (dark green) and the Upper Elk drainage basin (light green).

## 4.3 Movement

The use of numbered tags allowed me to better determine WCT movement over time. Recapture reports came from anglers for 21 WCT recaptured between 31 – 432 days following tagging. All fish stayed within the respective blocks and the results are presented in terms of the distribution of individual movement rates (Figure 4.12).

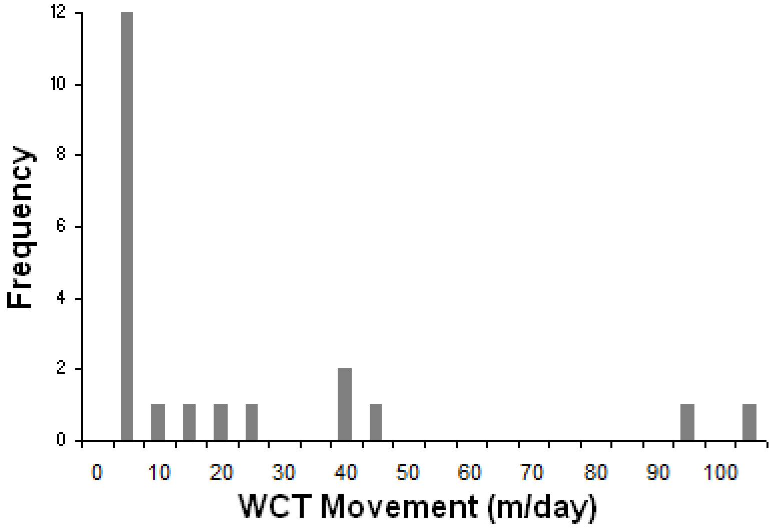

**Figure 4.12 Distribution of daily movement rates based on recapture information provided from voluntary reports of 21 fish recaptured at least 30 days after initially being tagged. The rate assumes a minimum distance of 50 m per unit time.**

## 4.4 Angling Effort

The regression analyses that examined boat and angler density *E* as a function of snorkel-counted fish densities *C* for WCT and BT are shown in Figure 4.13 for the lower mainstem. No regressions were statistically significant ($\alpha = 0.05$). In both years, boat density was positively correlated to WCT: $E_{2006} = 0.02C_{2006} – 0.14$; df=3, p=0.49 and $E_{2007} = 0.01C_{2007} – 0.06$; df=3, p=0.27. For BT, boat density was negatively correlated to observed fish densities in 2006 and showed no relationship in 2007: $E_{2006} = -0.24C_{2006} + 0.47$; df=3, p=0.64 and $E_{2007} = -0.00C_{2007} + 0.17$; df=3, p=0.98. For 2007, angler density was positively correlated to WCT: $E_{WCT} = 0.09C_{WCT} - 0.85$; df=3, p=0.22 and negatively correlated to BT $E_{BT} = -0.28C_{BT} + 3.3$; df=3, p=0.76. The examination of total WCT mortality $Z$ and fishing effort $E$ revealed no functional relationship: $Z = -0.00E + 0.43$; df=7, p=0.54 (Figure 4.14).

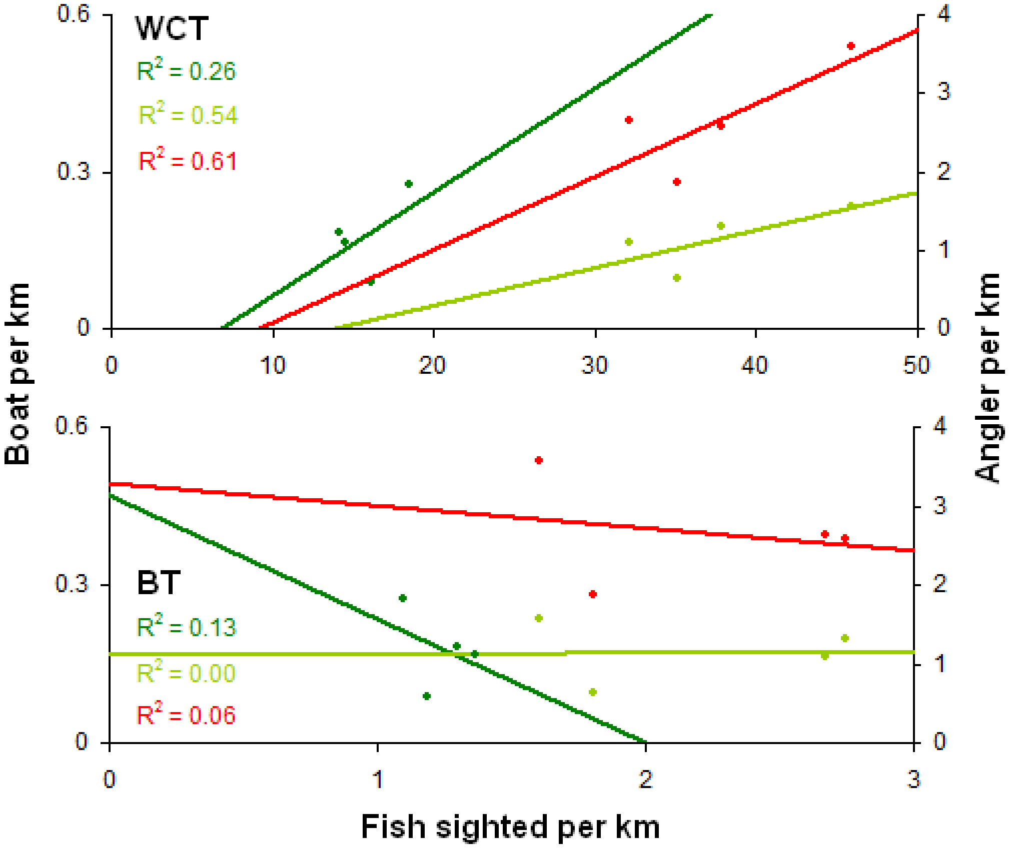

**Figure 4.13 Boat density as a function of fish density (in green) based on the shuttle data and angler density as a function of fish density based on my 2007 vehicle and trailer counts (in red) for a highly targeted species (WCT) and relatively untargeted species (BT) in the four lower mainstem river blocks. The 2006 observations are displayed in light green and the 2007 observations are displayed in dark green. None of the regressions are statistically significant (α=0.05, n=4).**

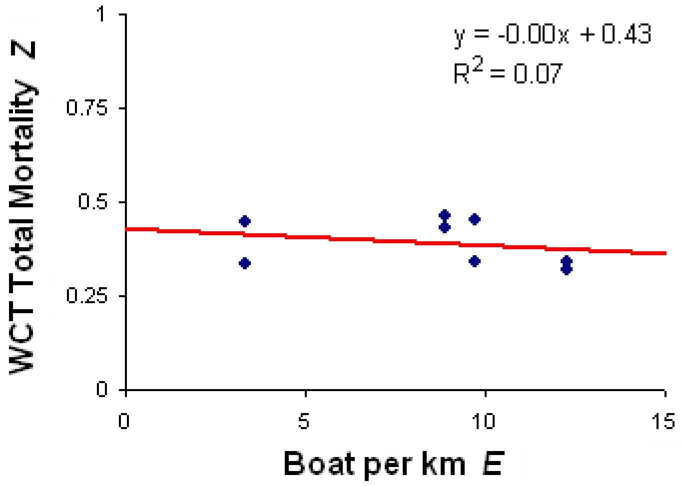

**Figure 4.14. Total WCT mortality *Z* vs. effort *E* across the four lower blocks for both years yielded no relationship (n=8).**

Catch-per-unit-effort across blocks did not reveal information to accurately estimate β. No regressions were statistically significant (α = 0.05) and the model fit was poor due inadequate contrast in N across blocks (Figure 4.15).

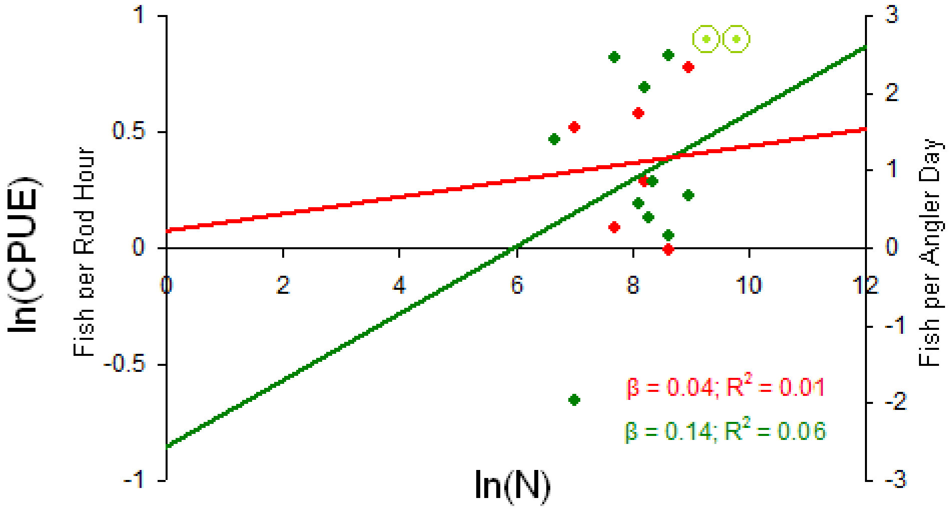

**Figure 4.15 Plot of the log-transformed CPUE in fish per rod hour from 2007 angler surveys (red; n=6) and the tagging program over both years (dark green; n=10) and WCT abundance estimates among blocks. Similarly, log-transformed CPUE expressed in fish per angler day from the angling guide reports of the Elk River (Tepper, personal communication) is plotted against the log of the respective 2006 and 2007 abundance estimates for the lower mainstem (encircled light green).**

## 4.5 Exotic Species

### 4.5.1 Rainbow Trout

For the two WCT sample sets, Leary *et al.* (2008) only detected RB alleles in the mainstem Elk River. All diagnostic loci for the sample set in the Michel drainage possessed WCT alleles only, indicating no evidence of hybridization. Allele frequencies were statistically homogenous ($X^2 = 9.003$, $p > 0.50$; Leary *et al.* 2008). The hybrid index developed from the Elk River sample indicated that all allospecific alleles were randomly distributed ($X^2 = 1.683$, $p > 0.10$; Leary *et al.* 2008) such that the sample came from a hybrid swarm (Figure 4.16). The Elk River WCT sample set possessed 0.008 RB alleles and 0.992 WCT alleles (Table 4.6).

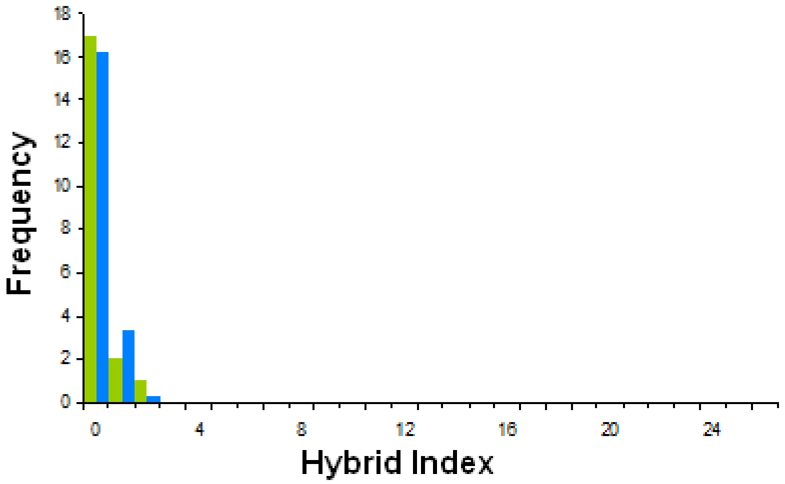

**Figure 4.16 The observed (light green) and expected (blue) random distribution of alleles in the hybrid index of 20 fins collected in the Elk River where RB alleles were detected.**

**Table 4.6 Allele frequencies at diagnostic loci for 20 fins from the mainstem Elk River and 25 voucher specimens from the Michel drainage. Bold values represent the presence of RB genotypes (from Leary *et al.* 2008).**

| | | Elk River (n=20) | | Michel (n=25) | |
|---|---|---|---|---|---|
| Locus | WCT Alleles | RB Alleles | Frequencies | RB Alleles | Frequencies |
| Occ34 | 225 | - | 1.000 | - | - |
| Occ35 | - | 200 | 0.025 | - | - |
| | 230 | - | 0.975 | - | - |
| Occ36 | - | 275 | 0.025 | - | - |
| | 324 | - | 0.025 | - | 0.140 |
| | 325 | - | 0.950 | - | 0.860 |
| Occ37 | 270 | - | 1.000 | - | - |
| Occ38 | 175 | - | 1.000 | - | - |
| Occ42 | 190 | - | 1.000 | - | - |
| Om55 | 220 | - | 0.700 | - | 0.700 |
| | 221 | - | 0.300 | - | 0.300 |
| Ssa408 | - | 178 | 0.025 | - | - |
| | 195 | - | 0.975 | - | - |
| Oki10 | 101 | - | - | - | 0.040 |
| | 105 | - | - | - | 0.400 |
| | 109 | - | - | - | 0.020 |
| | 117 | - | - | - | 0.160 |
| | 121 | - | - | - | 0.020 |
| | 125 | - | - | - | 0.080 |
| | 129 | - | - | - | 0.100 |
| | 133 | - | - | - | 0.120 |
| | 141 | - | - | - | 0.020 |
| | 145 | - | - | - | 0.040 |
| Omm1037-1 | 139 | - | 0.600 | - | 0.420 |
| | 151 | - | 0.400 | - | 0.560 |
| | 159 | - | - | - | 0.020 |
| Omm1037-2 | 104 | - | 1.000 | - | - |
| Omm1050 | 230 | - | 0.625 | - | 0.300 |
| | 234 | - | 0.325 | - | 0.640 |
| | 235 | - | - | - | 0.040 |
| | 236 | - | 0.025 | - | 0.020 |
| | - | 240 | 0.025 | - | - |
| Omy0004 | 77 | - | 1.000 | - | - |
| Omy1001 | 232 | - | 0.075 | - | 0.280 |
| | 236 | - | 0.375 | - | 0.180 |
| | 240 | - | 0.150 | - | 0.160 |
| | 244 | - | 0.025 | - | - |
| | 248 | - | - | - | 0.020 |
| | 256 | - | - | - | 0.020 |
| | 260 | - | - | - | 0.040 |
| | 264 | - | 0.125 | - | 0.120 |
| | 268 | - | 0.150 | - | 0.160 |
| | 272 | - | 0.075 | - | 0.020 |
| | 276 | - | 0.025 | - | - |
| Mean WCT | | | 0.992 | | 1.000 |
| Mean RB | | | 0.008 | | 0.000 |

### 4.5.2 Eastern Brook Trout

I used the information from the electrofishing surveys to determine the distribution of EB in the upper tributary system of the Elk drainage. The regression analysis of the relative proportion of EB and BT across all sites in the tributaries of the second and third fractal divisions as a function of stream temperature showed a significant positive correlation between $X_{EB}$ and stream temperature (df=9, p=0.007; Figure 4.17). Eastern brook trout density estimates derived from minimum log likelihood estimates in all sites in the second and third fractal division are shown along with the corresponding BT and WCT density estimates in Figure 4.18. The mean relative proportion of BT and EB for all sites within individual tributaries can be seen along with the respective stream temperature in Figure 4.19.

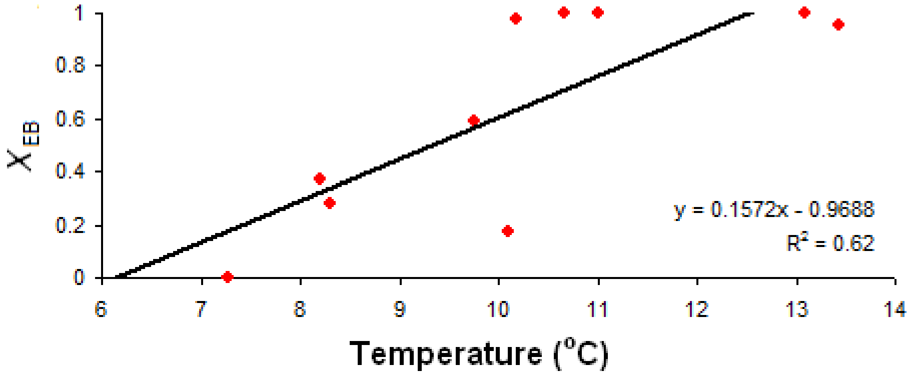

**Figure 4.17 The proportion of EB ($X_{EB}$) relative to BT for individual sites in the second and third fractal division of tributaries, as a function of stream temperature (°C).**

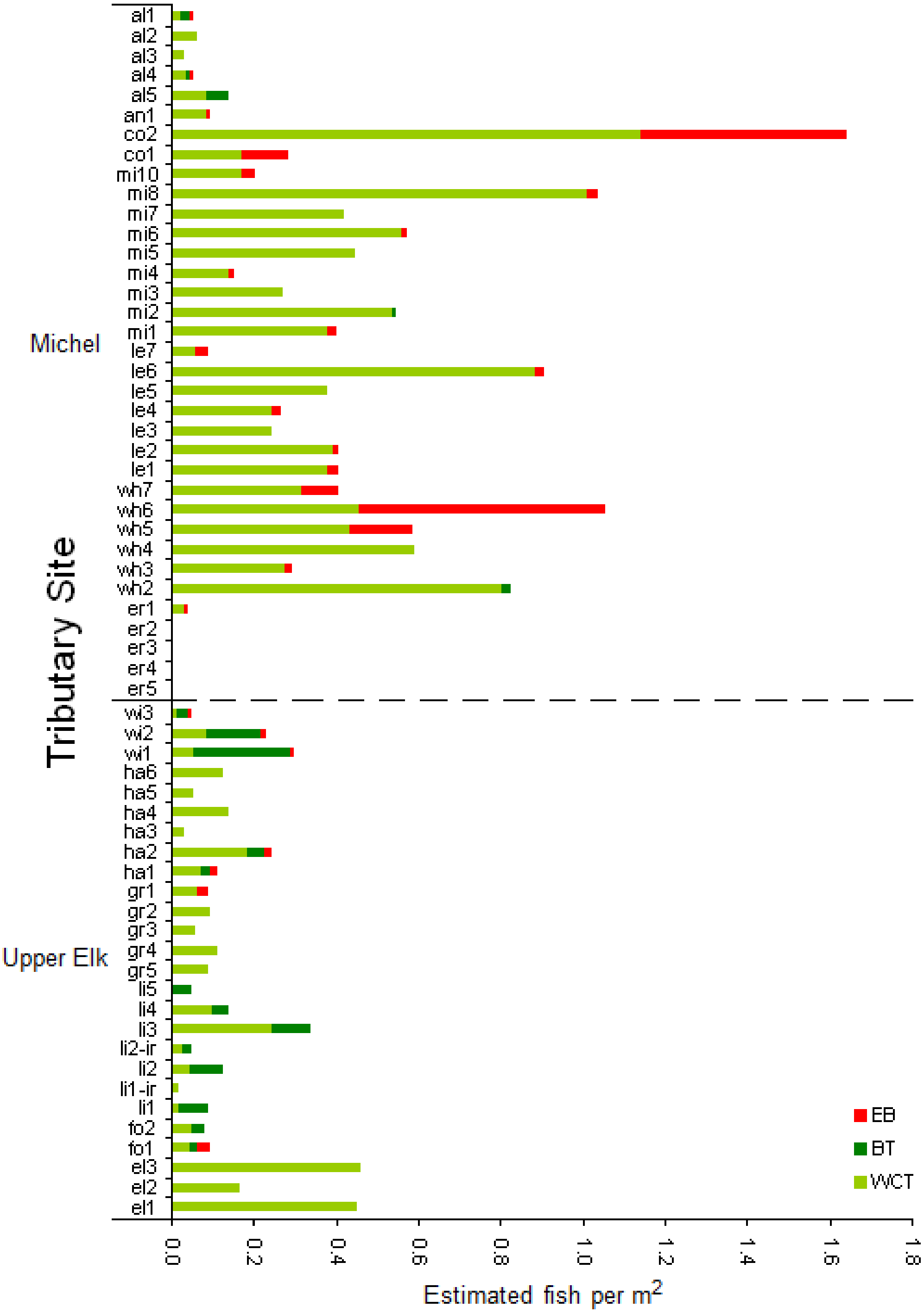

**Figure 4.18 Distribution of WCT and BT along with exotic EB across all 58 sites in the second and third fractal divisions of the Elk River's upper tributary system, which bifurcates into two main drainage basins: the Michel and the Upper Elk.**

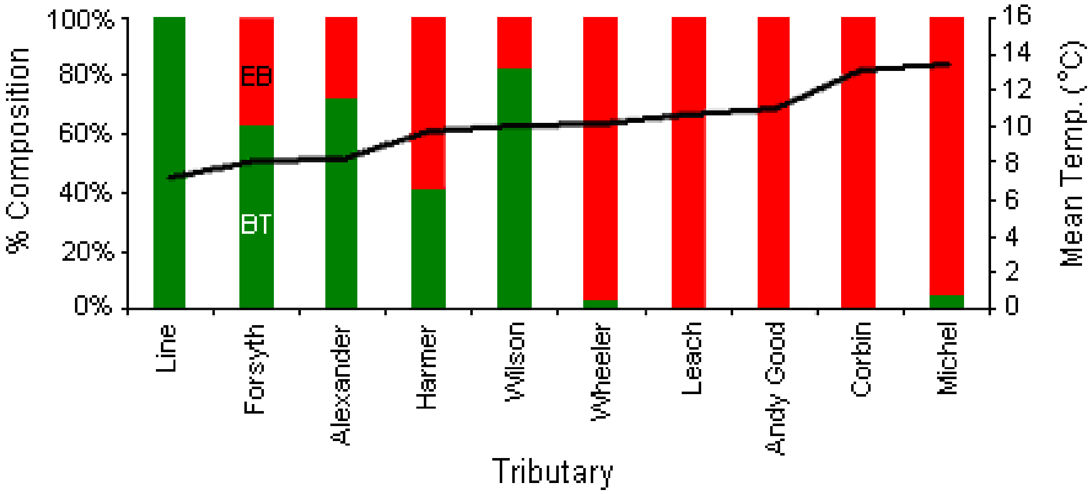

**Figure 4.19 Mean proportions of BT and EB across upper tributaries ranked in order of increasing stream temperature (°C).**

# 5 DISCUSSION

Ellison (1996) stated that the ecologist's role in management is to estimate the magnitude of response in populations, communities, and ecosystems to human-induced disturbances, develop experiments to examine any impacts, and design appropriate strategies in response to these impacts. This role can only be effective if decision-makers perceive it as legitimate and scientifically accurate. Holling (1978) noted that policy design requires better interaction between ecologists and decision makers. As many decision makers are not scientists, it is crucial for the ecologist to communicate his or her results in an intelligent and meaningful manner. In this final chapter, I have first interpreted the results and discussed the ecological implications given the uncertainty in the data. Next, I have given consideration to these implications in the context of fisheries science and current management practices. This has served as the core rationale in identifying a feasible and sustainable course for future management of the Elk River sport fishery. Finally, I have outlined the key directions for future research into Elk River westslope cutthroat trout and bull trout, which I believe should be part of an integrated, system-wide adaptive management strategy.

## 5.1 Ecological Implications

### 5.1.1 Lower Mainstem WCT

#### Growth

The growth parameters that I estimated were $L_\infty$ and $K$ ($a_o$ was fixed at -0.1 due to a lack of young fish in the sample). The results for the four blocks in the lower mainstem demonstrated a gradient in fish growth. Fish in the lower end of the mainstem grew slower, while fish in the upper end (Block D) grew the fastest. This is not surprising as the largest fish in the study were consistently caught in Block D, particularly in the upper half, and in Block E. Block D is a long stretch of river and is actually composed of two drift runs, with considerably more boat activity in the lower half. Mean fork length was reduced in the more heavily fished lower drift section of Block D, but it is not clear that growth is affected by the angling pressure. Block A had the least growth of all blocks and it received the least amount of effort (Figure 3.4).

Growth appeared to be more affected by fish density than by fishing effort, as Block A had the highest estimated density of fish of all the four blocks in both years, followed by B, then C in 2006, which indicated growth to be inversely related to density. In 2007, Block C had a slightly higher fish density than B, but both blocks were considerably lower than Block A (Table 4.3). Block D did not correspond with this trend, however, because it had high fish densities in both years and also displayed the fastest growth. Although a direct experimental manipulation of fish densities would be the ideal test for density-dependent growth, Block D WCT density and angling pressure could also be further examined between its two drift runs, which may help reveal which factor has a greater influence on WCT growth.

Without any length information for younger, invulnerable age classes, biases are likely to have existed in the growth curves. Taylor *et al.* (2005) have noted that fast-growing young fish and slow-growing old fish are selected for in instances when sampling gear is highly selective. The use of angling gear selects for fish greater than 150mm fork length (age 2+), and the smallest fish to be caught in this study was 162mm. Conversely, the largest fish was 465mm long, which is likely to be among the oldest fish in the system. In any case, selective capture of larger fish at young ages leads to an underestimation of $L_\infty$ and overestimates $K$ (Taylor *et al.* 2005). I was interested in comparisons across individual river blocks, so if there were biases in growth parameters, they likely exist in all blocks and should likewise affect them all such that the relative estimates of $L_\infty$ across blocks would still be evident.

### Mortality

Age-lengths keys based on the 2007 growth parameters were used to infer a mean age given length, determine the catch-at-age from the 2006 length data, and estimate 2006 total mortality; this assumes growth was constant between years. Therefore, the 2006 mortality estimates should be more cautiously interpreted. Scales gave me a reasonable indication of age, but it is important to consider the uncertainty in using scales to age fish compared to more reliable methods, such as otoliths. Fraley and Shepard (2005) revealed WCT to be 0.65 years older, on average, when aged using otoliths compared to scales. Discrepancies probably resulted from the failure of some fish to form a first-year scale annulus and an inability to discern between compressed and eroded annuli of the scale edge older fish. These discrepancies indicated that scale-age assignment was negatively biased and have been documented in previous studies assigning ages of cutthroat trout using scales (see Fraley *et al.* 1981;

Lentsch and Griffith 1987; Downs 1995). For the purposes of this research, I was again most interested in relative estimates between river sections, particularly in terms of the different fishing regulations. I also used the same standard method to age all fish, so there is no reason to assume that such negative bias would be more distinct in any of the individual blocks.

The 2007 mortality estimates $Z$ came directly from length and age observations, and the use of fisheries models for estimating growth and mortality has allowed the 2007 data to speak for themselves. Based on my analysis of a dynamic pool between ages 6 and 12, the WCT population in this system is among the oldest known cutthroat trout. Rieman and Apperson (1989) investigated 12 WCT populations in Idaho and Montana, only two of which had fish at age 7 or older. The upper South Fork of the Flathead River basin in Montana is comparable to the Elk River in that is has a genetically pure fluvial WCT population that exhibits a similar life history (Deleray *et al.* 1999). Fraley and Shepard (2005) followed this population for 12 years (1985-1996), tagging 513 fish with an age range of 2-9 years using scales, but a secondary examination of 20 otoliths revealed the largest fish, 432mm TL (total length), to be age 10. A 384mm fish tagged in 1988 was found to be at least age-11 based on its scale signature and subsequent recapture over a seven-year period (Fraley and Shepard 2005). The largest fish tagged by Fraley and Shepard (2005) was 452mm TL (total length), whereas I captured a fish as large as 465mm FL (~475-480 mm TL). Given the evidence, the Elk River WCT population does seem to be relatively long-lived and larger on average than other populations. At this stage, it is still unclear if the Elk River

WCT age and length data resulted from measurement biases, improved growth, or greater longevity; further examination of the age structure is required. Otolith examination would be a better method for reliably aging fish in future studies.

These data possessed some observation error in age and fork length measurements, but the models also had inherent biases and limitations. I designated a standard of age-6 for full vulnerability based on the system-wide catch curve in 2007 ($R^2$=0.91, n=201). Variable growth rates across blocks have influenced this designation such that blocks where growth rates are highest may have excluded fast-growing young fish from the catch curve analysis (e.g. age-5 WCT in Block D; Figure 4.3). The 2007 mortalities were also lower in individual blocks than in situations where I aggregated the catch for the lower mainstem or into regulation zones (Table 4.2). This could be partly due to size selective effects, but it seems to also result from small sample sizes. I had to add 1 to the ln($C_a$) for instances where there were no individuals in an age class, even though length and age were known with a reasonable degree of accuracy. Prince and Morris (2003) estimated Elk River WCT mortality post-mortem by ground-truthing individual radio tags (n=40), which may be a more accurate estimate given a small sample size.

The combined mortality from harvest, avian predation, and post-spawning deaths was previously estimated to be 21.1% for Elk River WCT (Prince and Morris 2003), which falls below the range of statistically significant *Z* values among river blocks in 2006 (32.0% - 46.5%) and 2007 (33.4% - 42.9%). This estimate came from a group of fish with unknown ages and thus was applied across all age classes. The catch curves analysis likewise assumed stable mortality and recruitment across ages, and although I had catch and age information from distinct river sections, the low sample sizes did make the results susceptible to effects from sampling error and apparent recruitment anomalies. Certain sampling biases can also affect mortality rates, such as in Block A in 2006. I drifted this block with a guide who spent a considerable amount of time at a shallow run with a large number of smaller fish of the same size (most likely age-3 siblings). He caught so many fish here that he actually recaptured a fish I had just tagged, at which point I suggested we move on. These fish show up in the 2006 catch curve and appear to be a recruitment anomaly, but they likely have resulted from this sampling bias (Figure 4.4). This cohort was excluded from the analysis because it was not considered fully vulnerable (i.e. age-3), but it demonstrates how difficulties can arise in discerning process and observation errors with small sample sizes.

In addressing mortality rates across blocks, it is appropriate to discuss the effects of the management regulations. I expected that mortality rates would be higher in catch-and-keep zones compared to catch-and-release zones, and this was the result for WCT in 2007. However, mortality rates were higher in catch-and-release zones in 2006. When I considered the average between years $Z_{\text{stable}}$, mortality rates are slightly higher in catch-and-keep zones (Table 4.2). As mentioned, the 2007 estimates come from more reliable age information, so there is more support for the 2007 results, although it remains difficult to confidently draw conclusions from these results about the efficacy of the regulations at reducing mortality. The predominance of catch-and-release fishing in all blocks has probably served the river well in keeping WCT mortality rates down, even in harvestable zones. It was not possible to discriminate fishing mortality from total mortality in the lower mainstem (Figure 4.14). The obvious direction for future management should be to better determine how catch-and-release fishing affects mortality, especially when fish are repeatedly captured.

### Abundance

The abundance model was fairly robust to variations in mortality, which influences the proportion of marked fish remaining at large during the snorkel surveys $M_t$. The principal source of variation in the modal abundance estimates came from uncertainty in capture probability, based on the observed $R_t$ and $C_t$. This was evident when comparing sums of individual blocks and management zones abundances with the entire lower mainstem $N$. In both years, the summed estimate across all blocks was considerably higher while the summed management zone estimate was slightly lower than the overall lower mainstem estimate which aggregated the data into a single likelihood (Table 4.3). These sums fell within the credible interval of the aggregated data for the lower mainstem population estimate and have further demonstrated uncertainty in the estimates.

The greatest uncertainty in abundance came from Block A (Figure 4.6), which also had the lowest capture probability, based on $R_t/(C_t - R_t)$ in both years. I expect this is due to three factors: 1) I observed too few tags (i.e. a low $R_t$), 2) I observed a low percentage of tagged fish relative to the total count (i.e. a high $C_t$), and 3) I have very limited information on how tag losses affected $R_t$, especially across individual blocks. When I snorkelled, I encountered a variety of habitats, and usually I saw tags in areas where fish aggregated (i.e. boulder gardens, log jams, slower moving and deeper pool areas). It seems that such aggregations had higher capture probability, as I was more likely to see a tag due to the large quantity of fish, but this could be misleading. There may also have been a lot more fish in these sections than I actually counted because the habitats were so complex relative to the simple channels that connected them. It is also possible that I had a greater propensity to spot the bright yellow tags in such aggregations than to accurately count the total number of fish visible, such that capture probabilities are biased upward and abundance is biased downward.

Most importantly, these factors are all compounded by effects from tag loss, which I treated as constant at 50% per year based on a sample of 8 fish in the entire system in 2007. Annual tag loss rates for anchor tags are highly variable, ranging from less than 5% for yellow perch *Perca flavescens* (Livings *et al.* 2007), 13% for northern pike *Esox lucius* (Gurtin *et al.* 1999), 51% for arctic grayling *Thymallus arcticus* (Buzby and Deegan 1999), and 58% for striped bass *Morone saxatilis* (Waldman *et al.* 1991). If tag loss rate has been underestimated, then there will be even fewer tags at large and capture probabilities will be lower, especially because I am counting these previously tagged fish as unmarked. Lower instances of tag resights will lead to higher abundance estimates;

particularly in 2007 because the first set of marked fish have been at large for an entire winter. The accuracy of any abundance estimate would likely improve if tag loss rates can be reduced or somehow better accounted for. The comparison of sums across block and management zone estimates with an overall estimate for the lower mainstem is a useful way of checking for accuracy of N in addition to 95% credible intervals. If everything adds up relatively the same, then there is more confidence in the estimates.

High values for $C_t$ resulted from my ability to see and count a large number of fish while snorkeling, but more time could have been allocated to tagging in order to mark a sufficient percentage of the population and reduce the uncertainty in the estimated abundances. Alternatively, I could have relied on catch data from volunteer anglers, assuming marked and unmarked fish are equally vulnerable to fishing gear. This proved to be too ambitious of a task as very few anglers accurately reported their complete catch. Still, I believe it is useful to have a fishery-dependent abundance estimate based on angler recaptures in comparison to snorkel counts, as it lends insight to one of the core assumptions of mark-recapture methodology: equal catchability of marked and unmarked fish.

A reduction in catch rates over the fishing season for Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* in a catch-and-release fishery has been reported despite an observation of repeated recapture of certain fish (Schill *et al.* 1986). Decreases in RB catch rates in several interior BC lakes have been partly attributed to learned hook-avoidance, but heterogeneity in intrinsic catchability (which included size-selective effects) was also an important factor (Askey *et al.* 2006). There has been support in Japanese studies on RB and white-spotted char *Salvelinus leucomaenis* in streams, where phenotypic variation in catchability overrides both learned hook-avoidance and size-selectivity effects such that caught and released fish are more likely to be recaptured (Yoneyama *et al.* 1996; Tsuboi and Morita 2004). Food resources in lotic systems such as the Elk River are less readily available than in lakes, and competition among individuals is likely to be more pronounced. Cutthroat trout are quite territorial and display dominance hierarchies (Sabo and Pauley 1997), which necessitates rapid responses to food availability. There is likely to be instances of learned hook avoidance over the summer, but strictly from my observations, it is plausible that intrinsic heterogeneity in catchability of Elk River WCT has allowed for some portion of fish to be pre-disposed to repeated capture. If such is the case, then it is reasonable to suspect that recapture information from angling data is also biased when tagged fish are drawn from a pool of the population that, on average, may have a greater propensity for capture.

As mentioned in Chapter 3, several fish were repeatedly recaptured in the same location over years (23.8% in the analysis of WCT movement). Three tagged fish were reported recaptured twice, one recaptured 3 times, and another (UBC-0045) was recaptured at least 4 times. Even though I did not conduct any analyses on mouth scarring, 49% of fish tagged in 2006 and 48% of fish tagged in 2007 had some degree of mouth scarring from previous capture (Figure 2.2). If the tagged fish are part of a more catchable pool, then they will also be preferentially sampled by anglers participating in a recapture survey. This inflates the expected recapture rates compared to a snorkel count and ultimately underestimates true abundance. When I snorkel, I am able to see considerably more fish than those in the “catchable” pool, especially because my observations include smaller, invulnerable fish. Therefore, by assuming equal “visibility” of all unmarked fish, it seemed appropriate to use a separate snorkel method for recapture in order to help to reduce such a bias, even though there is still likely to be a portion of fish that is both “uncatchable” and “invisible”, especially in the most complex habitats.

### Recruitment

The 2007 estimates consistently showed improvements in density and abundance in the four blocks between Sparwood and Elko. The observed densities during snorkel counts were also higher in 2007. As mentioned, this could be due to factors that influence capture probability, such as high tag loss over the first winter. It may have also resulted from an improvement in my ability to see fish, as it was reflected in a higher percentage of tags observed in 2007. I used the mark-recapture abundance and catch curve mortality estimates in a balance model to determine recruitment rates between tagging periods across blocks, between zones, and in the lower mainstem overall.

For the lower mainstem, the mean abundance and mortality indicated 5,753 new recruits in 2007, or 44% of the mean abundance estimate $N_{\text{stable}}$. Recruitment was reported per unit distance (fish/km) and was highest in Block A and lowest in Block C, both of which are catch-and-release zones, whereas Blocks B and D (catch-and-keep) had fairly similar recruitment rates (Table 4.3). Block C had low recruitment compared to all other blocks, despite showing the greatest increase in estimated WCT abundance and density between years. Recruitment was also higher in harvest zones. It reasonable to expect that harvest removal in these zones would exhibit some degree of recruitment compensation, but it is difficult to gain meaningful information on the Elk River WCT stock-recruitment relationship with only two years of data. Overall, the results indicated fairly strong recruitment, and I believe this information has an important role in ongoing management of these populations, whether active or passive, which must include not only the effects of the fishery on the adult stock, but also some means of annually monitoring recruitment. The method I have used for inferring recruitment in the lower mainstem has revealed a snapshot of the system state over a brief time period, which has been a useful means of getting some idea of the population dynamics of the fishery. Long-term monitoring of the dynamics should also consider how recruitment is influenced by ontogenetic shifts in distribution, which are likely affected by unrelated processes in other parts of the system.

### 5.1.2 WCT Distribution in Tributaries

The first fractal division of tributaries are the two upper blocks that flow from either tributary drainage and are considered relatively unfished compared to the lower mainstem (MOE 2003). The results for growth, mortality, and abundance again imply density dependent growth, as Block F had a much lower $L_\infty$ estimate compared to Block E, but had much higher abundance and density estimates (Table 4.4). The $L_\infty$ estimate in Block E was the highest in the whole study

(600mm FL), and was actually the upper constraint for the parameter when fitting the data across hypothesized values of $L_a$. Such a high value for $L_\infty$ is unrealistic and probably results from a combination of factors including a small sample of tagged fish with high variation in length and age, uncertainty in scale aging, and a lack of younger fish, but I do think it gives an accurate indication of the improved growth potential for adult WCT in Block E compared to Block F.

The density estimate for Block E was a bit surprising. As with the lower blocks, my 2007 estimate included tags from the previous winter, which tended to give higher abundance and density estimates in 2007. This implies that the WCT density in Block E may have been overestimated, yet this block still had considerably lower fish densities than Block F. When combined with the growth parameter estimates, the result has provided further evidence for density-dependent growth of Elk River westslope cutthroat trout.

The 2007 mortality rate was also higher in Block F, implying that even though these two blocks receive less drifting effort than the lower four, Block F is probably the more heavily fished of the two. The comparable (35.9%) estimate of mortality for Block F in 2007 indicated that Lower Michel Creek may receive as much angling activity from bank fishers as the lower four blocks, which are predominantly accessed by drift boats. Block F closely parallels the main highway through the Crowsnest Pass and is much more accessible than Block E to bank fishers. This block is also a catch-and-keep zone, whereas Block E is catch-and-release only, so these results further support a reduction in harvest mortality from catch-and-release management regulations. Recruitment was also estimated to be much higher in Block F, suggests that Michel drainage is more important to annual WCT recruitment than the upper Elk drainage. The juvenile WCT density estimates in the next fractal division of tributaries further supported this implication.

Prince and Morris (2003) found that a high percentage (75%) of adult WCT spawning occurred in side channels and gravel bars of the mainstem, but they also tracked fish that underwent spawning migrations into tributaries of the Upper Elk and Michel drainages. The majority of fish I observed in tributary surveys were juveniles (ages 0-2), but I also captured adults well after the spawning season. Stream-dwelling salmonids such as WCT tend to develop unique life history traits, especially when isolated by natural barriers like the waterfalls at Elko (Northcote and Hartman 1988). A percentage of the adult fish captured in the electrofishing program of this study were likely to be stream resident ecotypes that spend an entire lifespan in these tributaries. It is still unclear as to the degree to which juvenile fish migrate into the mainstem, whether these tributaries hold distinct population units, or both, but it is reasonable to assume that the Upper Elk River drainage consists of a meta-population dynamic that includes certain source and sink habitats (e.g. Block C and possibly Block E) in the mainstem as well as in tributaries. The spatial organization of mainstem adult spawning behaviour across all six block should be further examined. Based on the life history of the species, tributaries are probably important spawning destinations and a source for annual recruitment to the mainstem. The high percentage of WCT fry in sites of the Michel tributary system attests to this.

Wheeler, Leach, and Michel Creeks all had the highest densities of WCT (Figure 4.11), with fry being the most abundant age class. Densities were much lower in the tributaries around Block E in the Upper Elk drainage, but increased sharply in the sites near Elk Lakes Provincial Park. This suggests that WCT in the uppermost part of the Elk drainage are part of a distinct population unit and do not contribute greatly to recruitment of the lower mainstem fishery. This WCT population may be part of a smaller, restricted population that mainly resides in the Elk Lakes and surrounding stream system.

The relative difference in WCT density among tributaries was evident despite the use of a mark-recapture correction factor. Therefore the correction factor may not have been appropriate, especially given range of uncertainty in the abundance estimates for the six sites I used to estimate it (Figure 4.10). Also, because traps were size selective, fry could not be directly factored into the model and had to be accounted for with an assumption of equal capture probability when electrofishing. These results do support the notion that electrofishing methods underestimate abundance compared to mark-recapture methods (Rosenberger and Dunham 2005, Carrier *et al.* 2008 unpublished data). Relative abundance across sites is more important when monitoring an entire system and electrofishing methods alone were an economical means of covering such a large area. It may be beneficial to continue with the mark-recapture methods using traps that are less size selective, at least in the short term, so that a more precise correction factor can be developed. This factor can then be applied to a long-term electrofishing monitoring program using depletion removal methods.

Use of the likelihood developed by Schnute (1983) was limited in addressing parameter uncertainty. The model failed to provide confidence intervals if the data did not sufficiently conform to the expected depletion effect, given a binomial probability distribution of fish capture. Although Schnute (1983) developed versions of the model for equal and unequal catchability between passes, I use the equal catchability model. A second model added another catchability parameter for the first pass, which differed significantly from the remaining passes, which were constant. Schnute (1983) also mentioned a third model where catchability in the first pass differs from the remaining passes, which are not constant, but in turn differ from each other by a constant factor; however, he did not develop an estimation procedure for it. I used the first (and most parsimonious) model because I wanted to use a standardized modelling approach across all sites that would still allow me to make relative comparisons of WCT density among tributaries.

Although I did not directly address the potential effects of coal mining on WCT or BT recruitment in this thesis, I did sample in and around mined areas as part of the tributary investigation. The observations have allowed me to conclude that each mine has a unique set of conditions that have resulted in a wide array of WCT and BT abundances and age-structure. Corbin Creek is the first stream to enter Michel Creek below the drainage headwaters and flows directly out of a mine (EVCC's Coal Mountain Operations); however, it supported the highest densities in the entire tributary study. Despite these record high WCT densities, it had very little evidence of fry and age-1 fish and no BT. I did not consider the two sites in Corbin Creek when assessing WCT recruitment to the Elk River fishery, but the downstream sites (mi1-mi6) in the second fractal division also supported high WCT densities, with a high percentage of fry compared to older fish. Conversely, Erickson Creek flows out of EVCC's Elkview Operations and had the lowest WCT densities in the Michel tributary drainage. I found no fish at all in the four upper sites in 2006 (Table 4.5). Line Creek, which flows from EVCC's Line Creek Operations, also had low WCT densities, although it was one of the most important streams for BT recruitment.

The Upper Elk tributary drainage had low WCT densities compared to the upper reference sites draining out of Elk Lakes Provincial Park (el1, el2, and el3) located above all mine operations. The second set of reference sites at Forsyth Creek (fo1 and fo2) lay directly below Height of the Rockies Provincial Park and is also above the mines. It had the lowest mean WCT density in this tributary drainage (Figure 4.11). Therefore, no single factor could explain the results in terms of WCT densities in mine-affected streams.

Mining activities have increased the selenium load in Elk River streams to levels that may be toxic to aquatic life (MacDonald and Strosher 1998). Lemly (2004) identified that selenium mobilization in the waste generated from coal mining operations in British Columbia has the greatest potential to contaminate the province's stream fish. Lemly (1997) developed a deformity index with an established threshold to teratogenesis of 10 µgg$^{-1}$ dry weight in fish eggs, above which Se-induced deformities should increase rapidly. Deformities include spinal curvatures, missing or deformed fins, gills, opercula, and eyes, and abnormally shaped heads and mouths (Lemly 1993). Holm *et al.* (2005) noted that RB had significantly high instances of teratogenic deformities in a mine tributary in the Northeast Slopes region of Alberta. A toxicological study conducted by Kennedy *et al.* (2000) on Elk River WCT did not detect significant teratogenic deformities between fish reared from spawners in mined and unmined tributaries. In this study, I did not examine the Se levels in any of the voucher specimens, but I did observe what appeared to be instances of teratogenesis described by Lemly (1993) in WCT fry collected in a site below Coal Mountain Operations (Figure 5.1).

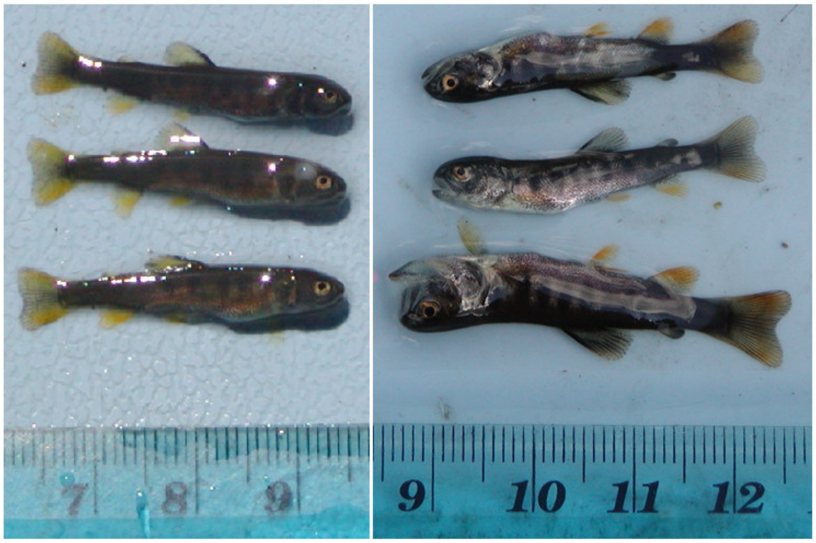

**Figure 5.1 WCT fry retained from electrofishing in site wh7 in upper Wheeler Creek and mi7 in upper Michel Creek, below the confluence of Corbin Creek draining out of EVCC's Coal Mountain Operations. All fry were killed by the electrofishing procedure.**

There is additional evidence that may implicate Se effects on Elk River WCT. Deformed opercula are commonly observed in adult WCT in the mainstem, which openly exposes one or sometimes both sets of gills. This may be a non-lethal result of mild Se-induced teratogenesis. Whether lethal or not, Se-induced teratogenesis does not appear to negatively affect WCT density, but selenium toxicology in Elk River WCT and BT should be further investigated as a source of mortality for developing fish.

My analysis of spatial distribution and recruitment of WCT in the Elk River considered the fractal network of drainage basin geomorphology (Horton 1945). The statistics of naturally branching patterns that comprise the stream ordering system suggest that such dendritic patterns result from a natural tendency for spread and dispersal with minimal effort (Pelletier and Turcotte 2000). It is expected that both spawning and recruiting fish would similarly follow a path of least resistance in moving to and from spawning destinations, as inferred by the resulting density estimates.

For active adaptive management, knowing the distribution and abundance of WCT and BT throughout the tributary system is an extremely powerful diagnostic tool that can allow for monitoring of a complex drainage system with relative simplicity. Quantitatively monitoring fish distribution within a network of streams can simultaneously reveal any localized effects in a virtual manner and not simply as a paired comparison. This would give a better indication of immediate, system-wide responses to adaptive experimentation and help to understand the effect of any locally applied management decision. For example, if a new resource development activity, such as BP Canada Energy's proposed coal-bed methane drilling program, resulted in an impact to the stream that severely diminished fish densities in Wheeler Creek, how would this affect the system state? On a larger scale, fish densities may be more likely to improve in the adjacent tributary nearby (i.e. Leach Creek) rather than in a tributary further away (Erickson Creek), and even less likely to elicit a response in another tributary drainage basin. Alternatively, one may instead expect fish densities to improve at a broader, system-wide scale in a creek with more comparable habitat (e.g. Grave Creek in the Upper Elk drainage), irrespective of its proximity to Wheeler Creek. Finally, if densities also simultaneously diminished in other streams where drilling did not take place, then it is reasonable to assume that it resulted from an unrelated environmental process, such as a climatic anomaly. Thus it seems that the key in this example is to determine how changes in fish density in one tributary influences the most probable fish density both in a) the existing tributary, b) in adjacent tributaries, and c) in the adjacent drainage basin, which can only be determined with an integrated monitoring regime across the entire system.

### 5.1.3 Exotic Species

#### Rainbow Trout

Rainbow trout have been cultured in BC for over a century (McPhail 2007) and have been introduced to lake and river systems of interior British Columbia resulting in WCT hybridization (Rubidge *et al.* 2001). In the Elk River system, RB introduction resulted from the provincial lake stocking program instituted by the

Ministry of Environment in the 1980s (Slaney *et al.* 1984; MOE 2008). Although these RB generally reside in lakes, they spawn in adjacent stream systems (McPhail 2007). Records indicate there are at least two known lakes where RB stocking occurs: Summit Lake, a headwater lake on the inter-provincial boundary in the Michel drainage; and Grave Lake, which flows into the Harmer-Grave Creek system in the Upper Elk drainage (MOE 2008). Hatchery-produced RB from the Premier Lake stock has been reported in Michel Creek in 1995 (MOE 2009). Recent changes in the stocking program ensure against further introgression, as all currently stocked RB are sterile triploids from the Kootenay Lake Gerrard broodstock (Ek, personal communication). The results from Leary *et al.* (2008) for this study have updated the existing information on the RB status in the Elk River.

The results indicated a mild degree of RB introgression (0.8% RB alleles) in the Elk River, and Michel Creek contains only pure WCT. This is exactly the opposite of what has been shown in previous reports. Rubidge *et al.* (2001) investigated RB introgression in WCT samples from the mainstem Elk River both above and below the dam and falls at Elko and did not find any evidence of RB alleles in the upper section (although they did find a single hybrid below the falls). Rubidge (2002) reported that tissue samples taken from the Elk River as part of the telemetry study by Prince and Morris (2003) were pure WCT (n = 20). Conversely, Rubidge and Taylor (2005) found that a sample of 30 fish taken from Michel Creek in 2000 showed a mean of 13.2% RB alleles. My results came from 25 voucher specimen samples, all of which were juvenile (ages 0 to 2). Parkinson (personal communication) mentioned that specimens collected in creeks may not be representative when such young fish are sampled as they may be siblings from a common brood, essentially leading to pseudoreplication. In the report, Leary *et al.* (2008) did not state their method for subsampling from the total of 50 voucher specimens that I prepared from the Michel drainage. Nonetheless, the results indicate that RB introgression levels have likely stabilized in the Michel Creek, probably due to the aforementioned change in stocking policy.

Leary *et al.* (2008) also showed that RB alleles in the Elk River came from a hybrid swarm based on a statistically homogenous distribution of alleles within the calculated hybrid index, given the observed 0.8% proportion of RB alleles (Figure 4.16). Based on the low percentage of RB alleles, these fish are post-$F_1$ hybrids and probably numerous generations past the initial hybridizing event. The strong fit between observed and expected distributions also indicates that these hybrids have not existed long enough in the system to have secondarily diverged due to genetic drift (Leary *et al.* 2008). My observation of a single adult RB while snorkelling the Elk River confirms their presence, but the fish I saw was huge (~500mm FL), so it was probably a recently stocked Gerrard triploid from a nearby lake. Gerrards are the world's largest RB and can grow to exceed 800mm in length (Andrusak and Parkinson 1984).

I also observed a juvenile (or possible stream resident adult) RB while electrofishing in Harmer Creek (166mm FL; ha4) in 2006 (Figure 5.2) and what appeared to be two young "cutbows" in upper Grave Creek (79 and 141mm FL;

gr5) in 2007. McPhail (2007) states that smaller fish (<100mm FL) of either species can be very difficult to discern, but I was able to identify all age classes except fry quite easily by the noted presence or absence of the cuts (red slashes) at the opercular base of the mandible. I am quite sure I identified juvenile RB and/or hybrids in these two creeks, which would indicate that there are still hybrids and possibly even non-hybridized fertile RB originating from nearby Grave Lake contributing to the observed hybrid swarm. The low percentage of RB alleles indicates that it has probably also stabilized. Grave Lake has very little stream discharge and much of the drainage from the lake is subsurface, which helps to isolate stocked fish populations in the lake.

**Figure 5.2 A rainbow trout retained while electrofishing in Harmer Creek near Grave Lake in 2006. The species was identified based on its pronounced unique iridescence (top left) and lack of characteristic cuts (reddish slashes) near the base of the operculum (right). The lower image shows the RB specimen beside a WCT.**

### Eastern Brook Trout

It is not known exactly how Eastern brook trout were introduced to the Elk River system. I was told by a lifelong local that they were put in the river to boost the sport fishery by the Fernie Rod and Gun Club well before his time. Although EB are seldom caught in the mainstem today, a few isolated populations do occupy several adjacent beaver ponds. This species has been recorded in several tributaries since as early as 1976 and is listed on the Fisheries Information Summary System (FISS) as both wild naturalized and hatchery production (although this second designation may be erroneous; MOE 2009). Results show that EB abundance is greatest in the Michel drainage, but has been found as far up the Elk Valley as Forsyth Creek (both in this study and according to FISS records; MOE 2009).

Eastern brook trout has been shown to outcompete WCT in reaches with higher amounts of pool habitats, fine sediments, LWD, and elevated temperatures (Shepard 2004). Based on the estimated densities, WCT displacement by EB has not been supported in this study, as EB has managed to successfully occupy several tributaries in the Michel drainage alongside WCT (Figure 5.3), especially Wheeler and Corbin Creeks. This does not appear to impinge on WCT recruitment, as the densities for WCT, including fry, were the highest in the Michel drainage in both years, whereas BT was virtually absent. This suggests that EB may have actually displaced BT in the Michel drainage. If this is the case, it is also be possible that an EB presence in the Michel drainage has actually improved WCT densities, perhaps by removing a predation effect from BT. A closer examination of Figure 4.18 shows that all tributaries where BT are found, including Alexander Creek (i.e. sites al1 to al5) in the Michel drainage, have relatively low WCT densities. However, in tributaries where EB are most abundant, WCT are also the most abundant, but BT are severely reduced to absent.

Bull trout recruitment appeared to be the most pronounced in Line and Wilson Creeks, although BT was also present in a number of sites in Forsyth and Harmer Creeks; all are tributaries of the Upper Elk drainage. There is additional evidence of BT displacement by EB from the regression analysis of stream temperature (Figure 4.17), which supports other studies (McMahon *et al.* 2007; Rodtka and Volpe 2007). The five main upper tributaries in the Michel drainage (Michel, Corbin, Andy Good, Leach, and Wheeler Creeks) all had elevated temperatures compared to the Upper Elk River tributaries, and I found only two BT over both years of sampling (none were found in 2007). However, Alexander Creek (also located in the Michel drainage basin) had low temperatures and was shown to contain BT at three of five sites in 2006 (Figure 4.19).

I found the largest EB in the upper site of Corbin Creek (co2), which drains out of EVCC's Coal Mountain Operations. Corbin Creek had high stream temperature and the length distribution for both EB and WCT compared to all other tributaries also indicated that these fish did not recruit here. There were no EB fry and very few WCT fry present in Corbin Creek, despite extremely high fish densities. Mine-affected streams are high in dissolved nitrogen, as the blasting of rock involves the use of N-based explosives. EVCC uses ammonium nitrate with fuel oil (ANFOL) as a blasting agent. Based on my water quality measurements, lotic conditions did not allow this eutrophic effect to deplete dissolved oxygen levels in any of the mine-affected tributaries. Consequently, streams draining out of open-pit mines can get enriched in nitrogen, which may act as a fertilizer to the benthos. This would boost productivity and enhance the food base such that adult fish may be drawn into the area from neighbouring tributaries.

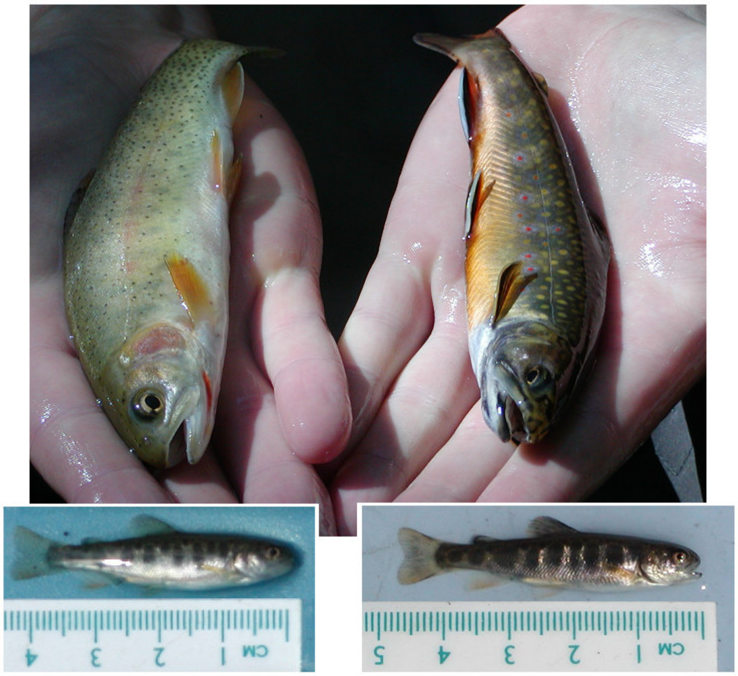

**Figure 5.3 Adult and fry WCT (left) and EB (right) found in sites in the Michel drainage.**

The FISS records indicate that EB have been found in many of Michel Creek's tributaries since 1976, but BT have not been detected in any of them (including Alexander Creek; MOE 2009). Therefore, it is not known if these tributaries would have historically contained much of a BT presence. Whether or not this is directly attributable to the elevated stream temperatures depends largely on the historical temperatures of these tributaries and if they have always been warm enough to exclude BT. If so, it means that EB currently occupy an unexploited niche. The data seem to indicate that upper Wheeler Creek serves an obvious recruitment area for EB, as I observed what appeared to be a resident source population of EB at one site in a slower moving reach (wh6) in 2006, with a relatively high density of EB fry. The uppermost sites in Wheeler Creek all showed a high percentage of EB (Figure 4.18). I did not find bull trout here in either year, but I did capture an age-1 BT at a site in lower Wheeler Creek (wh2) in 2006. There are no FISS records of historic fish distribution for Wheeler Creek (MOE 2009).

Probably the most interesting aspect of the current EB distribution in tributaries is that it likely results from heavy selection against larger fluvial ecotypes, which directly compete with adult native salmonids in the mainstem Elk River. A lone adult fluvial brook trout (~300mm FL) was observed in the mainstem during the snorkel survey in 2006. Consequently, this distribution may represent selection for smaller individuals that favour a stream-resident life history strategy and has worked to stabilize, and possibly restrict EB to the upper tributaries of the Michel drainage.

## 5.2 Fishery Management

Some grim instances of resource mismanagement have occurred in situations where there is no individual claim of ownership over the resource, resulting in unchecked market-driven entry into the game by external investors (Hardin 1968). In the Elk River, this has been exactly the case with the sport fishery in the 1980s.

Concerned local fishers alerted the Ministry of Environment about a stark decline in overall catch rates well before the surge in guided recreational fishing that currently dominates. Regulations have resulted from a series of investigations, starting with the creel study conducted by Martin (1984) assessing the relative impact of subsistence fishers, unguided recreational anglers, and guided angling activity. At that time, there was high harvest compared to catch-and-release, so a creel survey provided useful information on fish populations, such as age structure. Today, creel surveys offer very little information about the fish populations, but the Elk River continues to see renewed growth in fishing that is dominated by guide outfits and contributes greatly to the Elk Valley's summer tourist economy.

The continued growth of the Elk River sport fishery has resulted from a change in the values held by recreational fishers. Based on the WCT abundance estimates, it seems clear that the Elk River can only sustain such angling activity because of a preference for catch-and-release fishing. The Elk River may even serve as a useful model for larger fisheries. Current regulations generate a great deal of revenue from recreational anglers, but I believe this revenue could be more effectively re-invested into the fishery such that it addresses important questions about the population dynamics of the actual sportfish as well as angling quality and effort responses to management. I also believe the guide community should be more accountable to its resource. I have proposed a more comprehensive management strategy that is both economically feasible and better integrates the user base with the fishery.

### 5.2.1 Effort Dynamics

The regression analyses that modeled effort as a function of fish density were not statistically significant, but they did suggest that drift anglers respond well to variations in abundance of WCT. This is not surprising as WCT is the targeted species for the vast majority of anglers, who are capable of learning about its distribution when deciding where to fish. The lack of significance is not a surprise as these data come from individual blocks (n=4) and there is a lot of variation within blocks. Fish tend to aggregate in more complex habitats, but such variation may not be as important to the overall numerical response per block because the river blocks correspond well to access points for putting in and taking out boats. Drift anglers cover entire blocks at a time so they are more likely to use the information from the total catch per trip rather than variability in catch rates within each trip when deciding which section to drift.

Catch rates were not very sensitive to changes in total or block-wise abundance, but anglers did appear to disperse among the blocks according to visually-determined WCT densities. Low fish densities would deter anglers from fishing certain sections, and the analysis for WCT suggested there to be an observed lower limit to fish density, about 10 – 15 WCT/km for both years, below which no angling effort would be expected (Figure 4.13). At higher WCT densities, it is likely that other factors would affect the distribution of drift boat anglers, such as proximity to town and expenses like fuel and shuttle service needs, etc. Interference competition could also be an important factor influencing angler distribution that can lead to a breakdown in the relationship between CPUE and abundance (Gillis *et al.* 1993; Gillis and Peterman 1998).

Though I could not demonstrate hyperstability in CPUE with these data, a hyperstable relationship between CPUE and abundance could result from an ideal free distribution of anglers, who spatially distribute themselves such that profitability is equalized across all sections (Hilborn and Kennedy 1992). At least some proportion of anglers likely choose to forgo river blocks with known higher fish densities due to overcrowding and instead move into less popular blocks with lower densities. These anglers would likely search more effectively and could even have higher catch rates in sections of relatively low abundance. Conversely, interference competition among drift boats in blocks of higher abundance would also reduce CPUE as all the “sweet spots” where fish aggregate become occupied and temporarily exclude neighbouring boats, which continue to drift and search. I definitely observed this type of competition among drift boats while tagging and especially while snorkelling. I would snorkel through sections occupied by drift boats and visually see the aggregations of fish. Anglers would sometimes get annoyed by my presence and even shout threats at me. Behavioural vulnerability exchange effects may prolong the reduction in catch rates in these more heavily fished spots as the captured and released fish become temporarily invulnerable (Cox and Walters 2002).

Walters and Martell (2004) have identified a two-stage search process that can lead to hyperstability and seems to best describe the drift boat effort dynamics on the Elk River. This process divides total fishing into search time and handling time and conforms to Holling's (1959) disc equation, which has been used to model predator feeding rates. The former is the time spent drifting between the "sweet spots" and the latter is the time spent systematically fishing them (Walters and Martell 2004). It would be useful to investigate how well angler behaviour on the Elk River follows such a search process. More detailed CPUE monitoring across the lower mainstem and over the course of a summer could partition the number of hours spent drifting and the number of fish landed while anchored.

### 5.2.2 Guiding

The guide community should be enforced to comply with its requirement to accurately report total catch each trip. Snorkel surveys can potentially provide sufficiently high resight rates to calculate reasonable abundance estimates, but Walters and Martell (2004) warn against estimating total abundance using mark-recapture data from small tagging studies unless a large percentage of the total population is examined for tags. If guides were offered an incentive to assist in tagging and to examine and record the tagged proportion of fish, then annual abundance estimates of the vulnerable stock could be obtained without the need for secondary snorkel counts. A much higher percentage of the population could also be tagged, thereby increasing the precision of either estimate.

The guides have an interest in protecting this fishery and they have been rather vociferous about certain aspects that potentially threaten their rights to the resource. In particular, I observed several discussions within the guiding community about illegal guiding activity and I think that this sort of protectionism, in conjunction with the presence of conservation officers, already serves the river well enough in terms of ensuring user compliance. I did not address the issue of illegal guiding activity for this research, but I fail to see why the guide community has demonstrated such reluctance to participate in the mark-recapture research. I was dismayed by the lack of participation by most of the guides and several of the guide outfits, although there was noted participation by a few long-time local guide outfits, guides, and avid anglers from the Elk Valley.

I wanted to use the guides' catch and tag recapture data to model the population and see how it compared with my snorkel estimates, but I did not get enough information to derive an estimate. As previously mentioned, angling will selectively take larger fish and it is expected that a population estimate based on this method would underestimate true abundance because only the "catchable" population is included. Snorkel counts may be more reliable, but they were very time consuming and I had to derive the population estimate each year from a single snorkel event (n=1). There are so many guides on the river that each guide's individual tag report in conjunction with total catch would allow for a much more precise fishery-dependant abundance estimate. The guides know the river well enough that if they helped tag fish annually in the pre-season and subsequently recorded each time and place they caught a fish with a numbered tag, the data would be invaluable in understanding WCT movement and improving on the precision of the estimates.

Many guides fail to see the value of reporting catch and effort data, and most fail to understand the value of tag information in determining total abundance, but they might be more cooperative if their participation was somehow factored into the annual angler day allotment process on the Elk River. A rather simple way to make guides more accountable to the fishery would be to offer them an incentive:

1) Those guides that assist to tag fish and report catch and recapture information will be ranked in accountability in terms of angler days received on the Elk River. Tagging assistance could be provided in the weeks before the main fishing season (mid-June) when the guides are already actively fishing the different river blocks to learn where the fish are.
2) Those guides that are low on accountability (i.e. either didn't help tag or don't accurately report catch and tag recaptures) will be given less priority for the allotment of angler days on the Elk River.

Regulations to restrict harvest and dissuade non-resident overcrowding have been in place since the East Kootenay Angling Management Plan was drafted in 2005. Still, a large percentage of angling activity (>95% of guided anglers in 2006 and 2007; Figure 1.2) comes from non-residents who must pay a $20 daily user fee for access to one of the most heavily fished rivers in the province. They also must purchase a special classified waters angling license in addition to the standard non-resident angling license. Appropriately, there is enough revenue generated annually by the fishery to monitor and better understand Elk River sportfish population dynamics through an adaptive management program.

### 5.3 Elk River Adaptive Management

The final component of this chapter is an explicit recommendation for improving adaptive management of the Elk River system. My results have depicted the current system state with some degree of uncertainty. It is obvious that enough interest exists across multiple industries to annually contribute and actively engage in the process of adaptive experimentation and policy development. There is already an excellent experimental management program for the system in terms of contrasting spatial policy treatments (the catch-and-release/catch-and-keep zones and disturbed/undisturbed tributary systems). What is really lacking at this point is (1) a sound monitoring program for measuring treatment responses more precisely, especially catch-and-release mortality rates, and (2) a collaborative process between government and user groups to jointly examine the monitoring results, model effects of other policy alternatives, and modify the experimental policy treatment plan over time in response to results of the collaborative analysis (Walters, personal communication).

A number of industry players could annually contribute to an improved adaptive management strategy on the Elk River. Funding contributions could go towards continual graduate-level aquatic ecological research.  The recreational fishery generates enough revenue from angling licenses and user fees, but other industries could also be included. The existing mine operations owned by Elk Valley Coal Corporation have each affected tributaries in different ways. This initial investigation has brought forth a number of new questions that can be further addressed. BP Canada Energy intends to undertake a large-scale drilling program in the Michel drainage and aquatic monitoring is chief among the ecological concerns held by the local communities. Tembec Industries actively logs a large amount of private and public land in the Upper Elk drainage and its

Sustainable Forest Action Plan expressly states a willingness to partake in adaptive management (Tembec 2005).

My investigation is the first to quantify some important parameters affecting the population dynamics of Elk River WCTand is an appropriate baseline for continual monitoring and experimentation with the fishery. Walters and Holling (1990) stated that a balance of learning and risk does not always favour the management of unique and independent systems that have been experimentally perturbed. However, in instances where a collection of similar units exist and can be independently managed, this conclusion changes drastically to become more a question of how large an experiment to conduct (Walters and Holling 1990). Zonation of the Elk River mainstem into individual management units with a layout of tributaries into individual subdividing stream units within a fractal drainage network provide an ideal spatial structure for adaptively managing Elk River sportfish. I have outlined what I consider to be important research questions that could be pursued in the adaptive management strategy for WCT and BT.

### 5.3.1 Westslope Cutthroat Trout

The Elk River supports record high fishing activity mainly targeted at WCT and this benefits the summer tourist economy. This is not overly surprising given the predominance of catch-and-release activity on a population that apparently has some of the largest and oldest fish of the subspecies. However, it seems unwise to allow continual growth in the fishery without adequate management of stock. If growth in the fishery is allowed to occur, then it should be based on the results from continual direct monitoring of the population. Uncertainty in WCT abundance estimates resulted from limited information on age and growth as well as indeterminable effects from fishing mortality, tag loss, and capture probability of tagged fish. Age could be determined more precisely (e.g. from otoliths). There are also better ways to determine growth, either from recapture data that includes actual length changes in individual fish (Fabens 1965), or by back-calculating growth rates from scale or otolith annuli (Ricker 1971), both of which can be directly compared with effort to help clarify if WCT growth is density-dependent. Angling guide participation in an annual tagging and recapture program is a key means to improving this understanding.

A critical research question that needs to be addressed as soon as possible in the adaptive management program is the spatial organization of recruitment sources for the mainstem river sections that are treated differently (Walters, personal communication). Do the recruits to each section represent a mixture of juveniles from many or all tributary recruiting areas, or does each section represent a nearly closed population of fish that spawn in particular tributary areas and have recruits just from those areas? Prince and Morris (2003) showed that WCT underwent spawning migration into tributaries in the upper system, but they also found that fish tagged in the lowest blocks spawned in smaller tributaries within individual blocks, such as Hartley Creek draining into Block C and Lizard Creek draining into Block B. Such ecological linkage among experimental areas has major implications for interpretation of differences in recruitment among treatment areas and for appropriately determining the scale of future treatment areas (Walters 1986).

Gerking (1959) first proposed that stream salmonids commonly display restricted movement, to which a number of studies have lent support. In the Elk River, I also noticed high site-fidelity for WCT and the evidence suggested that about half of the tagged fish didn't move at all, even over a time frame that exceeded two years. Presumably, these fish would have to move at some point, either into overwintering habitat or to spawning locations, but I also noticed that many areas where the fish were tagged and later recaptured might also serve as suitable overwintering habitat. I started to wonder whether or not these fish were actually undergoing spawning migrations at all, especially if they are repeatedly captured over the course of the summer.

Based on the analysis of total mortality as a function of boat density (Figure 4.14), it was not possible to directly discern an effect from fishing mortality. Repeated capture has also been demonstrated in the Elk River from recapture reports and mouth damage observed on about half of the fish caught. It seems from these results that repeatedly caught fish also tend to be less mobile. If a fish is caught numerous times over a summer, I expect it to expend a great deal of energy resisting capture every time it is hooked. Cox and Walters (2002) also proposed that caught and released fish will alternate between vulnerable and invulnerable states. This may reduce foraging efforts and ultimately cause reduced growth rates. Adult WCT likely require a minimum amount of resources to sustain energy reserves over the winter and successfully migrate and spawn each spring. If these energy requirements are not met due to sustained recapture, then it is reasonable to expect that these fish may actually forgo spawning. This presents a more subtle and indirect impact to the fishery that is worth investigating.

As a next step, it would be valuable to monitor a group of radio-tagged fish over a longer time period. This includes both repeatedly captured and relatively uncatchable individuals (captured by some alternative method other than angling), to better determine post-hooking mortality and see whether spawning is impeded by repeated capture.

### 5.3.2 Bull Trout

Bull trout is not as economically important to the Elk River fishery and little is known about the status of the population or whether the current population has successfully recovered from an earlier collapse. It was difficult to study due to low catchability, so limited information was available from the snorkel observations. My decision to snorkel earlier in the summer did not seem to improve on the observed BT densities, which were much lower than WCT in both years (less than 10% of the total count in all sections). The low BT densities may help to explain why Elk River WCT length and age are so much greater than reports from other systems, which may be partly due to reduced BT predation. Because Elk River BT is not targeted by anglers, it seems that the current fishery-related impacts are minimal. The fish are easy to spot while snorkelling and an annual snorkel count is an adequate means of monitoring the adult stock in the lower mainstem in conjunction with WCT. If threats to BT conservation exist in the Elk River, they would likely come from unrelated factors in the tributary system, which are worth investigating.

I observed low BT densities in the tributaries compared to WCT. Moreover, BT was altogether absent from most of the tributaries in the Michel drainage. Evidence here suggests that BT recruitment may be impeded by the presence of exotic EB in warmer streams of the Michel drainage and previous results have demonstrated that brook trout has a negative effect on bull trout that is exacerbated at higher water temperatures (McMahon et al. 2007). Alternatively, it is also possible that BT does not naturally occupy this drainage and EB is using an unexploited niche, which does not seem to impede WCT recruitment. In the Upper Elk drainage, an observed presence of EB warrants continual monitoring of both BT and EB recruitment, especially if stream temperatures continue to increase due to warming trends (Rieman *et al.* 2007). In the colder streams of the Upper Elk drainage, BT densities were the highest in Line and Wilson Creeks, indicating that these tributaries are important to recruitment. Additional tributaries should be examined to better determine important BT recruitment areas and the common factors that best describe these habitats. It would even be useful to track a number of individual adult BT in the mainstem using radio tags to find out where they are spawning.

I did not directly examine the mining effects WCT or BT, but I observed deformed WCT fry in mine-affected streams. This did not appear to negatively affect WCT densities. This investigation indicates that BT densities are low overall, except in two tributaries, one of which is mine-affected (Line Creek), suggesting that mines have no effect on BT density. A toxicological assessment has been done for Elk River WCT (Kennedy *et al.* 2000), but BT have not been investigated. I did not observe instances of teratogenesis in BT fry while sampling, but it is worthwhile to compare the selenium levels in BT in the upper tributaries and examine the potential for teratogenic mortality on developing fish.

Hybridization between BT and EB has never been examined in this river system, but it is known that hybrids exist elsewhere (Leary *et al.* 1983) and have markedly reduced fertility (Kanda *et al.* 2002). Therefore, if hybridization is present, it will threaten bull trout conservation in the Elk River. The isolated nature of Elk River BT makes it even more vulnerable to the detrimental effects of introgression with EB (Lesica and Allendorf 1995), so it should be a priority in future management to first determine whether or not hybrids exist in the system.

### 5.4 Conclusions

Westslope cutthroat trout has recovered from an earlier collapse, largely spurred by a shift in conservation ethics by anglers, who now prefer to catch-and-release. The Elk River may even support some of the largest and oldest known WCT. Recreational fly-fishing is an economic enterprise that has led to a surge in development of a guiding industry that appears relatively ambivalent, perhaps even apathetic about the long-term state of the resource. Sustainable fishery policy development requires more active participation by entrepreneurs in order to best manage the WCT stock.

The BT stock has stabilized with observations suggesting that abundances are low overall. The fishery does not appear to impact BT, as most effort is directed toward WCT, but the situation in tributaries needs to be addressed. Adaptive management should seek to better understand the factors that have the greatest influence on BT recruitment: identify the critical spawning habitats in tributaries and elucidate any interactions with mobilized selenium and exotic EB.

Economic development of any natural resource may aspire to achieve a sustainable outcome, but its application must be directed toward local ecosystems. Sustainability is generally defined to meet current levels of human need without compromising the needs of future generations. Recognition of the more subtle levels of human need, such as the role of ecosystem services, is at the forefront of an ever-evolving definition. This thesis is a starting point for stakeholders in the Elk River system to jointly engage in an adaptive management program. In order to be effective, managers must experiment with the options, objectively define the uncertainty of each choice, and weigh the costs and benefits of each outcome. A sustainable level of management can be achieved if human needs are properly defined and a universally acceptable benchmark has been established. Adaptive management is both an ideal means by which to arrive at this benchmark and to move beyond it as the very notion of sustainable development evolves in the face of changing human values.

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# APPENDICES

## Appendix A

### Tagging Data Sheet

Date: Block:
Start time: Finish: Assistance:

| Tag | Species | GPS | Fork (cm) | Weight (kg) | Circum. (cm) | Gear | Scar | Angler | Time |
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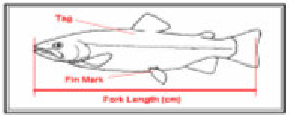
## Summer 2007 Angle-Capture Data Sheet - Anglers please report these data to WWW.ELKRIVERFISHTRACKER.COM

Name:

**Data Marking Key:**

| | |
|---|---|
| *Species* | |
| Bull Trout | 1 |
| Cutthroat | 2 |
| | |
| *Secondary Mark* | |
| Unmarked fin | U |
| Left pelvic fin mark | L |
| Right pelvic fin mark | R |
| Both pelvic fins marked | B |
| | |
| *Habitat Block* | |
| Elko dam to Morrissey bridge | A |
| Morrissey bridge to North Fernie bridge | B |
| North Fernie bridge to Hosmer bridge | C |
| Hosmer bridge to Sparwood bridge | D |
| Sparwood bridge to Line Creek bridge | E |
| Michel Creek bridge to Sparwood | F |
| | |
| *Accessibility* | |
| Accessible | Y |
| Inaccessible | N |
| | |
| *Gear* | |
| Dry fly | a |
| Nymph | b |
| Streamer | c |
| Spoon | d |
| Spinner | e |
| | |
| *Mouth Scar* | |
| Healthy (unscarred) | 0 |
| Single lacerated lip | 1 |
| Both lips lacerated | 2 |
| Single lip detached or missing | 3 |
| Both lips detached or missing | 4 |
| Severe (jaw dislocation or separation) | 5 |



| Date | Species | Tag # | Fin | Block | Location | Length (cm) | Access | Gear | Scar | Time | Effort (mins) |
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# Important Points for Recapture Participants:

- Please decide if you are going to record your catch before you go out (i.e. don't decide to fill out the sheet just because you caught a tagged fish). If you only record your catch because you caught a tagged fish, you will introduce a bias to the analysis.

- When you go out and fish, remember that ALL the fish you catch need to be recorded on the data sheet, NOT just the marked fish. Only include fish that have been successfully landed. It is important that all participants be honest about the data, which will remain confidential.

- Please record the number on the anchor tag for all tagged fish that you capture (e.g. UBC 0001).

- If the fish does not have an anchor tag, please be sure to examine the left pelvic fin to see if it has been clipped. Run your fingers along the belly and you will feel the scar. If so, the scar will indicate that the fish was tagged, but the tag has been lost. In this way, I will be able to calculate a tag loss rate, which is important for the snorkel count in September.

- Record your best estimate of the fork length for each fish. Because you will still have to do this for tagged fish, your estimate will be compared with the known fork lengths for the tagged fish. In this way, I will be able to calculate your measurement error and use it to get a more precise length for all the untagged fish you catch.

- I am interested in knowing the catchability for different sections of the river based on accessibility to walk-and-wade anglers. Highly accessible areas are those that can be walked to in 15 minutes or less from the nearest access point (such as a roadside turnout on Hwy. 3). To determine catchability, I will need to know both the catch (i.e. the total amount of fish caught) and the effort (i.e. the total time spent angling) in each section.

- The map I will provide includes both the initial points of capture, expressed in GPS waypoints, and the other important landmarks on the river (e.g. Hwy. 3 tunnel), which you can use to determine a more precise location of capture for each fish. Please give the best estimate of your location relative to these waypoints or to the landmarks.

- When you have completed the data sheet, contact me at the following email: chad.wilkinson@gmail.com, or phone me at (604)605-0785. You can also mail the data sheet to me at the following address:

UBC Fisheries Centre
315.3 Aquatic Ecosystems Research Laboratory
2202 Main Mall
Vancouver, BC
V6T 1Z4

## Angler Survey Form - Please answer to the best of your knowledge

TODAY Date: Time:

Approximately how long (in hours) have you been fishing today? ________________ List the nearest block ________ and waypoint ________

| Have you remained in the same area? (If not, please list all blocks and waypoints) | Duration (hours) |
|---|---|
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| How many fish have you caught and released and/or harvested at this/these location(s)? | Species/Fork Length? | Gear Used? |
|---|---|---|
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SUMMER 2006 and 2007

| Which other days have you fished the Elk River in the past two summers? | Where? (list each block/waypoint) | Catch per block: |
|---|---|---|
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Status (Resident/non-resident/alien): ________________________________ Region of origin ________________________________

| Have you caught any tagged fish? (Please list all known tag numbers) | Where? (list block/waypoint) | When (date/approx. time)? |
|---|---|---|
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What type of rod do you normally use? ________________________ Gear (circle appropriately): dry fly/nymph/streamer/spinner/spoon

**Thank you for your participation! Your personal information below is optional.**

Name: Phone/Email:

# 2007 Electro-Fishing Data Sheet

| | |
|---|---|
| Date: | Trib.: |
| Site: | |
| GPS: | |

| | |
|---|---|
| **Bull trout** | **1** |
| **Cutthroat trout** | **2** |
| **Brook trout** | **3** |
| **Whitefish** | **4** |

**Water Quality Information**

| Time | Con. | Temp. | DO2 | pH | Turb. |
|---|---|---|---|---|---|
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| First Pass | | | Second Pass | | | Third Pass | | | Fourth Pass | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sp. | FL (mm) | Mark | Sp. | FL (mm) | Mark | Sp. | FL (mm) | Mark | Sp. | FL (mm) | Mark |
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| Marked Fish | |
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**Other Notes:**

## Tributary Habitat Data Sheet

Tributary:

| | Site 1 | Site 1 | Site 3 | Site 4 | Site 5 |
|---|---|---|---|---|---|
| **Channel and Flow** | Date: | Date: | Date: | Date: | Date: |
| Pattern | | | | | |
| Confinement | | | | | |
| Process | | | | | |
| Flow Condition | | | | | |
| Gradient (%) | | | | | |
| Stage | | | | | |
| Flood Signs Height (m) | | | | | |
| Channel Width (m) | | | | | |
| Wetted Width (m) | | | | | |
| Max Riffle Depth (m) | | | | | |
| Max Pool Depth (m) | | | | | |
| Pool/Riffle/Run (%) | | | | | |
| Mean Velocity (m/s) | | | | | |
| Discharge (m^3/s) | | | | | |

**Streambank Characteristics:**

| | | | | | |
|---|---|---|---|---|---|
| Height (m) | | | | | |
| Form | | | | | |
| Bars (%) | | | | | |
| Process | | | | | |
| Texture | | | | | |
| Cover (%) | | | | | |

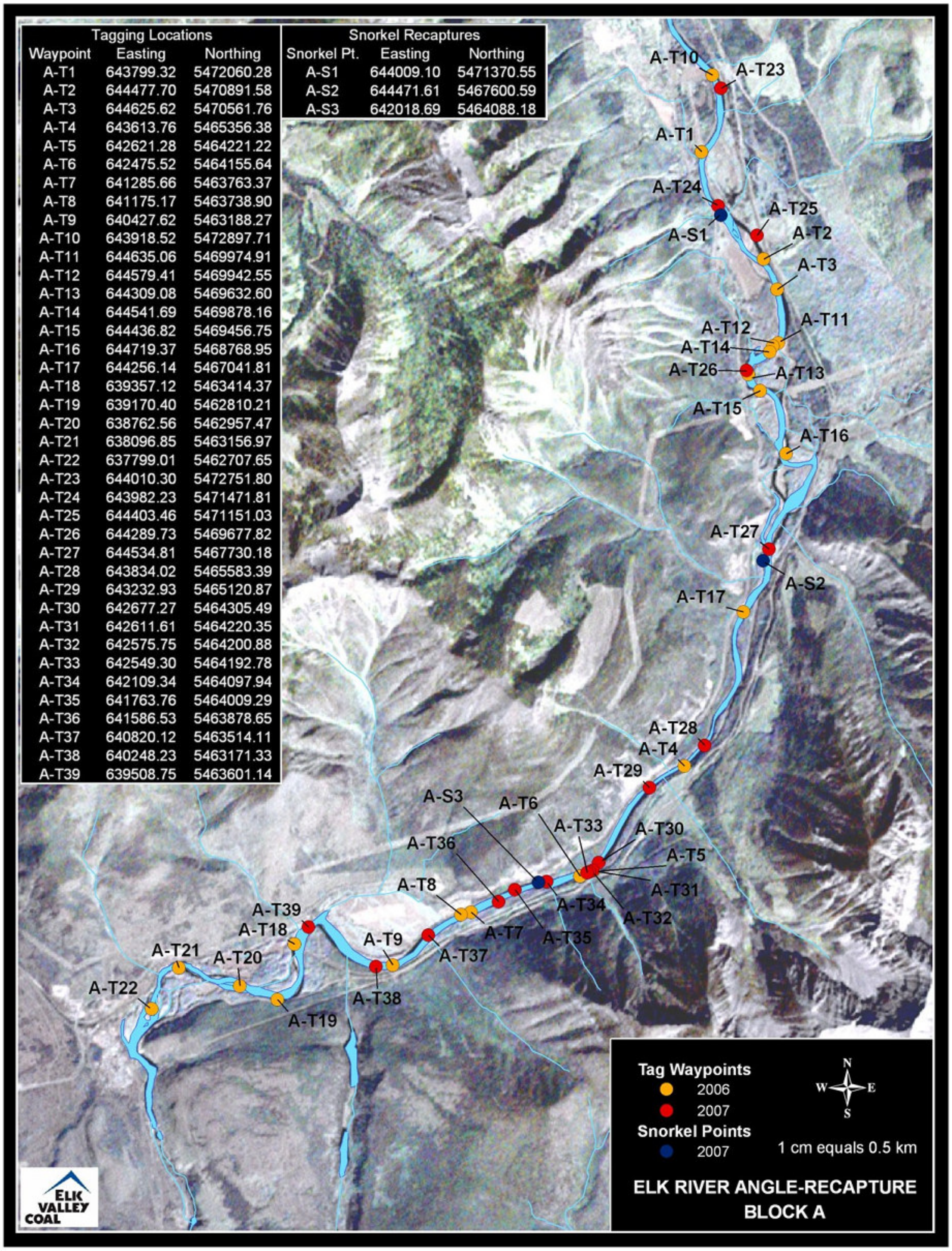
**Streambed Characteristics:**

| | | | | | |
|---|---|---|---|---|---|
| Sand, silt, clay (<2mm) | | | | | |
| F. gravel (2 -16 mm) | | | | | |
| C. gravel (16- 64 mm) | | | | | |
| F. cobble (64 - 128 mm) | | | | | |
| C. cobble (128 -256 mm) | | | | | |
| Boulder (> 256 mm) | | | | | |
| Bedrock | | | | | |
| Compaction | | | | | |
| Algal cover (%) | | | | | |

**Cover Characteristics:**

| | | | | | |
|---|---|---|---|---|---|
| Composition (%) | | | | | |
| Pool depth | | | | | |
| LWD | | | | | |
| Boulder | | | | | |
| Instream vegetation | | | | | |
| Overhanging vegetation | | | | | |
| Cutbanks | | | | | |
| Turbulence | | | | | |
| Crown Closure | | | | | |
| Total (%) | | | | | |

# Appendix B



Tagging Locations

| Waypoint | Easting | Northing |
|---|---|---|
| A-T1 | 643799.32 | 5472060.28 |
| A-T2 | 644477.70 | 5470891.58 |
| A-T3 | 644625.62 | 5470561.76 |
| A-T4 | 643613.76 | 5465356.38 |
| A-T5 | 642621.28 | 5464221.22 |
| A-T6 | 642475.52 | 5464155.64 |
| A-T7 | 641285.66 | 5463763.37 |
| A-T8 | 641175.17 | 5463738.90 |
| A-T9 | 640427.62 | 5463188.27 |
| A-T10 | 643918.52 | 5472897.71 |
| A-T11 | 644635.06 | 5469974.91 |
| A-T12 | 644579.41 | 5469942.55 |
| A-T13 | 644309.08 | 5469632.60 |
| A-T14 | 644541.69 | 5469878.16 |
| A-T15 | 644436.82 | 5469456.75 |
| A-T16 | 644719.37 | 5468768.95 |
| A-T17 | 644256.14 | 5467041.81 |
| A-T18 | 639357.12 | 5463414.37 |
| A-T19 | 639170.40 | 5462810.21 |
| A-T20 | 638762.56 | 5462957.47 |
| A-T21 | 638096.85 | 5463156.97 |
| A-T22 | 637799.01 | 5462707.65 |
| A-T23 | 644010.30 | 5472751.80 |
| A-T24 | 643982.23 | 5471471.81 |
| A-T25 | 644403.46 | 5471151.03 |
| A-T26 | 644289.73 | 5469677.82 |
| A-T27 | 644534.81 | 5467730.18 |
| A-T28 | 643834.02 | 5465583.39 |
| A-T29 | 643232.93 | 5465120.87 |
| A-T30 | 642677.27 | 5464305.49 |
| A-T31 | 642611.61 | 5464220.35 |
| A-T32 | 642575.75 | 5464200.88 |
| A-T33 | 642549.30 | 5464192.78 |
| A-T34 | 642109.34 | 5464097.94 |
| A-T35 | 641763.76 | 5464009.29 |
| A-T36 | 641586.53 | 5463878.65 |
| A-T37 | 640820.12 | 5463514.11 |
| A-T38 | 640248.23 | 5463171.33 |
| A-T39 | 639508.75 | 5463601.14 |

Snorkel Recaptures

| Snorkel Pt. | Easting | Northing |
|---|---|---|
| A-S1 | 644009.10 | 5471370.55 |
| A-S2 | 644471.61 | 5467600.59 |
| A-S3 | 642018.69 | 5464088.18 |

Tag Waypoints

● 2006

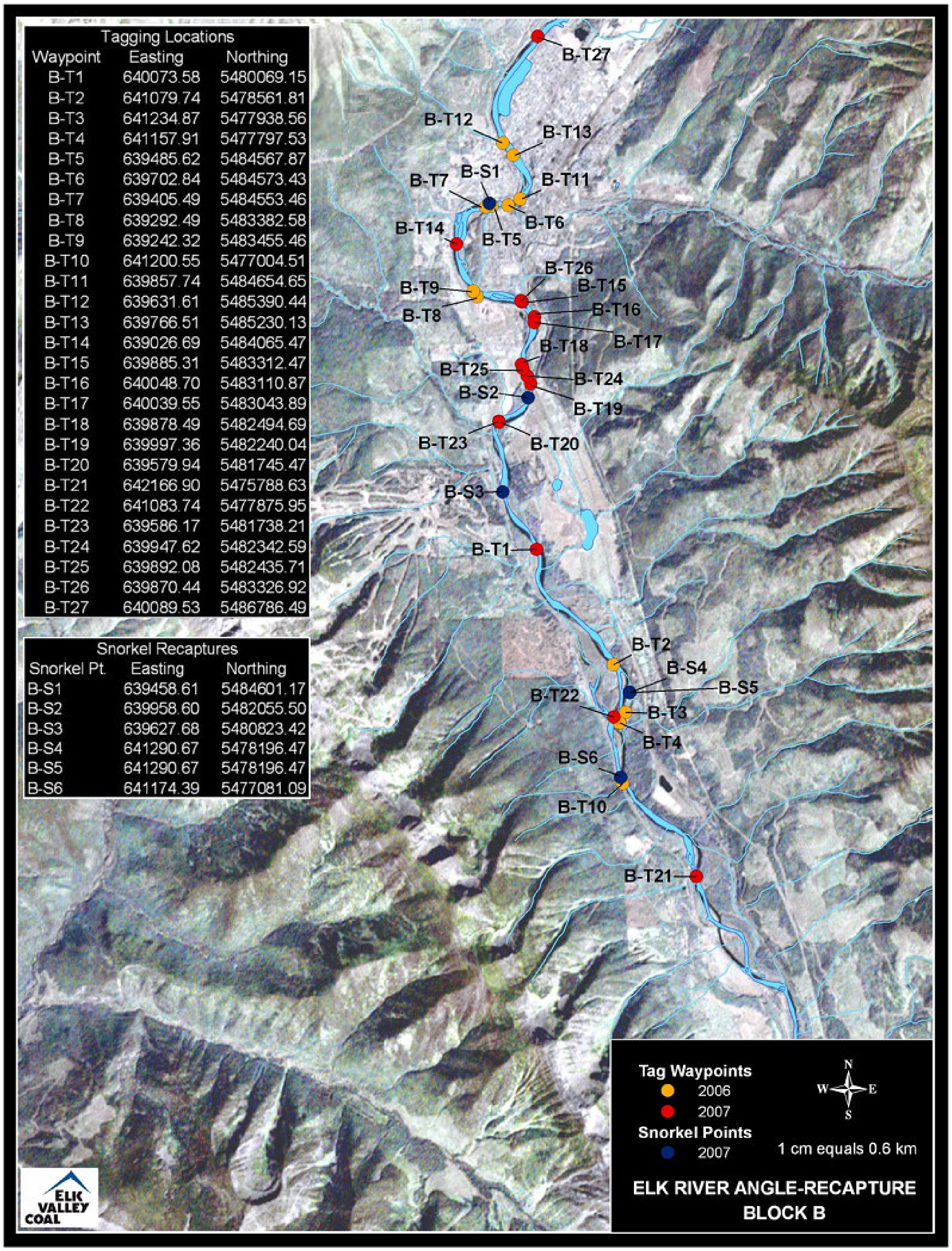
● 2007

Snorkel Points

● 2007

1 cm equals 0.5 km

ELK RIVER ANGLE-RECAPTURE BLOCK A



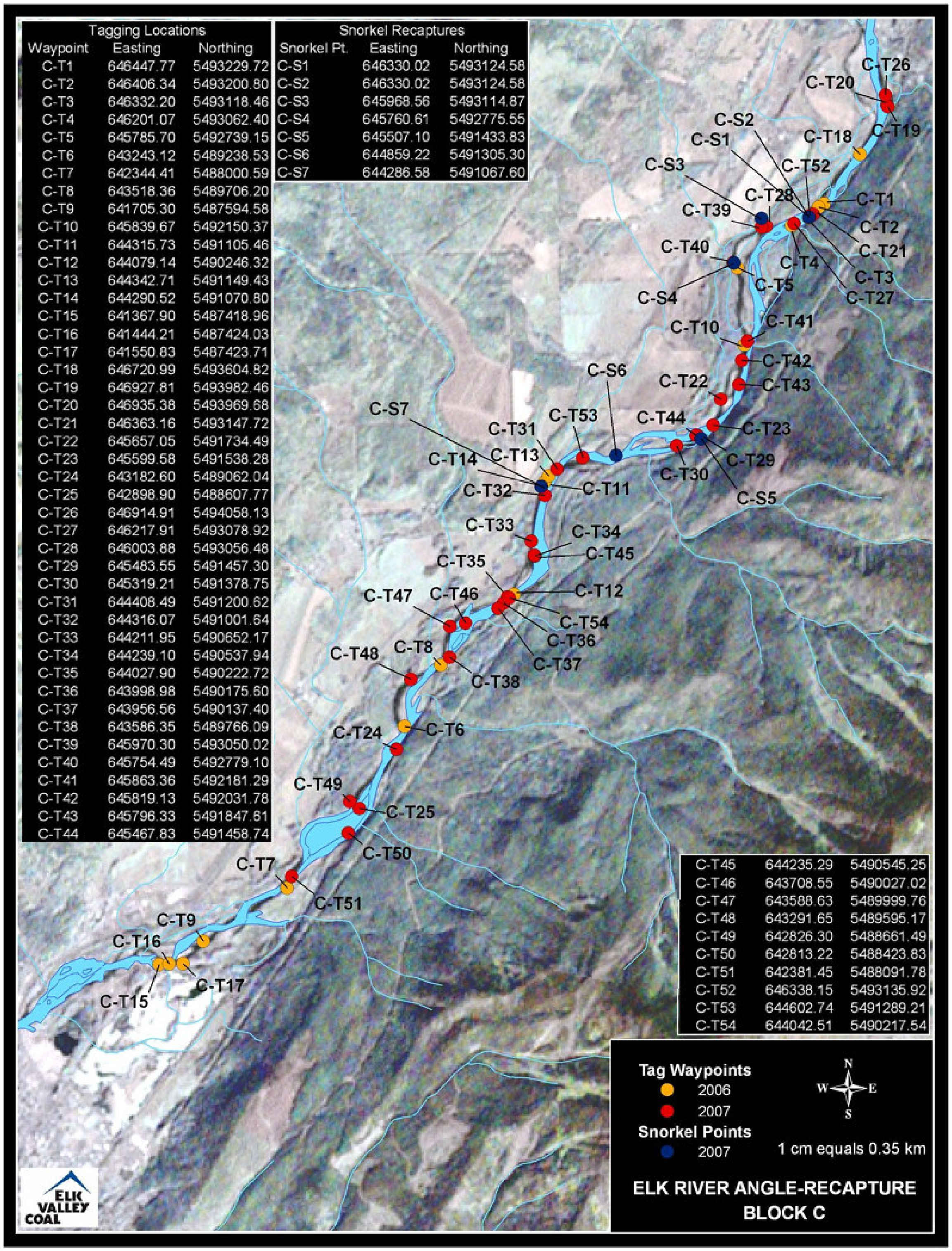
ELK RIVER ANGLE-RECAPTURE
BLOCK B

Tagging Locations

| Waypoint | Easting | Northing |
|---|---|---|
| B-T1 | 640073.58 | 5480069.15 |
| B-T2 | 641079.74 | 5478561.81 |
| B-T3 | 641234.87 | 5477938.56 |
| B-T4 | 641157.91 | 5477797.53 |
| B-T5 | 639485.62 | 5484567.87 |
| B-T6 | 639702.84 | 5484573.43 |
| B-T7 | 639405.49 | 5484553.46 |
| B-T8 | 639292.49 | 5483382.58 |
| B-T9 | 639242.32 | 5483455.46 |
| B-T10 | 641200.55 | 5477004.51 |
| B-T11 | 639857.74 | 5484654.65 |
| B-T12 | 639631.61 | 5485390.44 |
| B-T13 | 639766.51 | 5485230.13 |
| B-T14 | 639026.69 | 5484065.47 |
| B-T15 | 639885.31 | 5483312.47 |
| B-T16 | 640048.70 | 5483110.87 |
| B-T17 | 640039.55 | 5483043.89 |
| B-T18 | 639878.49 | 5482494.69 |
| B-T19 | 639997.36 | 5482240.04 |
| B-T20 | 639579.94 | 5481745.47 |
| B-T21 | 642166.90 | 5475788.63 |
| B-T22 | 641083.74 | 5477875.95 |
| B-T23 | 639586.17 | 5481738.21 |
| B-T24 | 639947.62 | 5482342.59 |
| B-T25 | 639892.08 | 5482435.71 |
| B-T26 | 639870.44 | 5483326.92 |
| B-T27 | 640089.53 | 5486786.49 |

Snorkel Recaptures

| Snorkel Pt. | Easting | Northing |
|---|---|---|
| B-S1 | 639458.61 | 5484601.17 |
| B-S2 | 639958.60 | 5482055.50 |
| B-S3 | 639627.68 | 5480823.42 |
| B-S4 | 641290.67 | 5478196.47 |
| B-S5 | 641290.67 | 5478196.47 |
| B-S6 | 641174.39 | 5477081.09 |

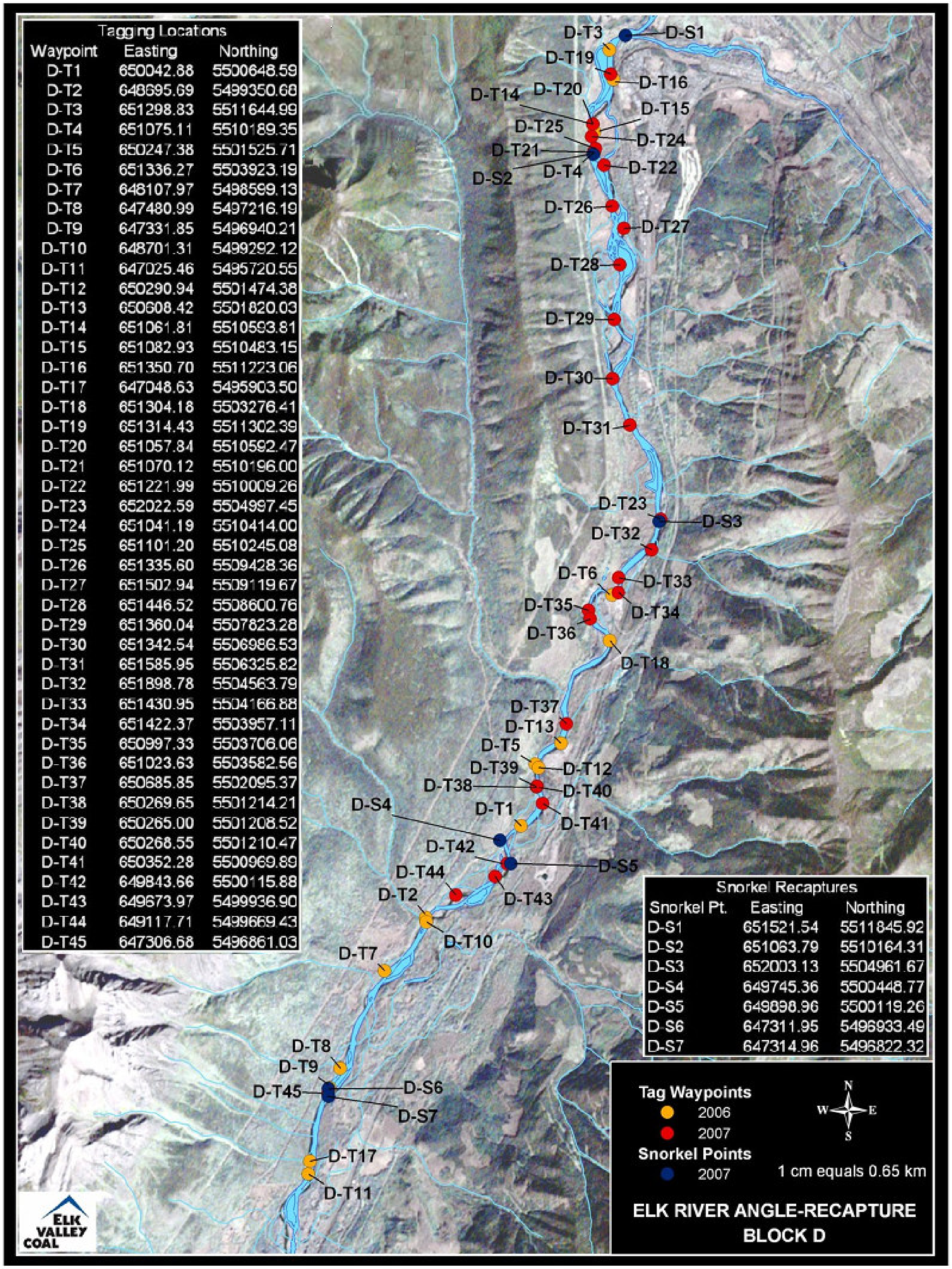


Tagging Locations

| Waypoint | Easting | Northing |
|---|---|---|
| C-T1 | 646447.77 | 5493229.72 |
| C-T2 | 646406.34 | 5493200.80 |
| C-T3 | 646332.20 | 5493118.46 |
| C-T4 | 646201.07 | 5493062.40 |
| C-T5 | 645785.70 | 5492739.15 |
| C-T6 | 643243.12 | 5489238.53 |
| C-T7 | 642344.41 | 5488000.59 |
| C-T8 | 643518.36 | 5489706.20 |
| C-T9 | 641705.30 | 5487594.58 |
| C-T10 | 645839.67 | 5492150.37 |
| C-T11 | 644315.73 | 5491105.46 |
| C-T12 | 644079.14 | 5490246.32 |
| C-T13 | 644342.71 | 5491149.43 |
| C-T14 | 644290.52 | 5491070.80 |
| C-T15 | 641367.90 | 5487418.96 |
| C-T16 | 641444.21 | 5487424.03 |
| C-T17 | 641550.83 | 5487423.71 |
| C-T18 | 646720.99 | 5493604.82 |
| C-T19 | 646927.81 | 5493982.46 |
| C-T20 | 646935.38 | 5493969.68 |
| C-T21 | 646363.16 | 5493147.72 |
| C-T22 | 645657.05 | 5491734.49 |
| C-T23 | 645599.58 | 5491538.28 |
| C-T24 | 643182.60 | 5489062.04 |
| C-T25 | 642898.90 | 5488607.77 |
| C-T26 | 646914.91 | 5494058.13 |
| C-T27 | 646217.91 | 5493078.92 |
| C-T28 | 646003.88 | 5493056.48 |
| C-T29 | 645483.55 | 5491457.30 |
| C-T30 | 645319.21 | 5491378.75 |
| C-T31 | 644408.49 | 5491200.62 |
| C-T32 | 644316.07 | 5491001.64 |
| C-T33 | 644211.95 | 5490652.17 |
| C-T34 | 644239.10 | 5490537.94 |
| C-T35 | 644027.90 | 5490222.72 |
| C-T36 | 643998.98 | 5490175.60 |
| C-T37 | 643956.56 | 5490137.40 |
| C-T38 | 643586.35 | 5489766.09 |
| C-T39 | 645970.30 | 5493050.02 |
| C-T40 | 645754.49 | 5492779.10 |
| C-T41 | 645863.36 | 5492181.29 |
| C-T42 | 645819.13 | 5492031.78 |
| C-T43 | 645796.33 | 5491847.61 |
| C-T44 | 645467.83 | 5491458.74 |
| C-T45 | 644235.29 | 5490545.25 |
| C-T46 | 643708.55 | 5490027.02 |
| C-T47 | 643588.63 | 5489999.76 |
| C-T48 | 643291.65 | 5489595.17 |
| C-T49 | 642826.30 | 5488661.49 |
| C-T50 | 642813.22 | 5488423.83 |
| C-T51 | 642381.45 | 5488091.78 |
| C-T52 | 646338.15 | 5493135.92 |
| C-T53 | 644602.74 | 5491289.21 |
| C-T54 | 644042.51 | 5490217.54 |

Snorkel Recaptures

| Snorkel Pt. | Easting | Northing |
|---|---|---|
| C-S1 | 646330.02 | 5493124.58 |
| C-S2 | 646330.02 | 5493124.58 |
| C-S3 | 645968.56 | 5493114.87 |
| C-S4 | 645760.61 | 5492775.55 |
| C-S5 | 645507.10 | 5491433.83 |
| C-S6 | 644859.22 | 5491305.30 |
| C-S7 | 644286.58 | 5491067.60 |



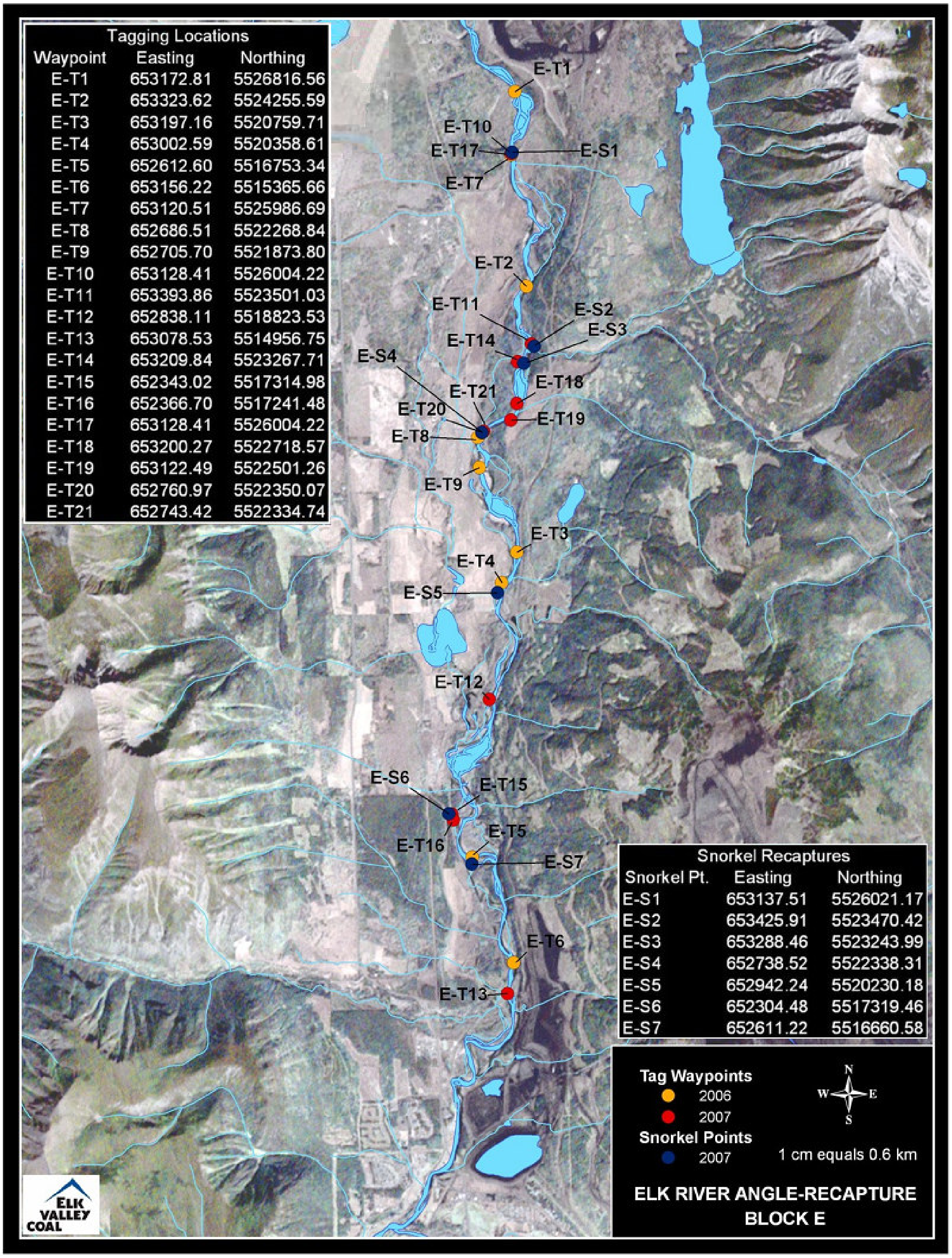
ELK RIVER ANGLE-RECAPTURE
BLOCK D

Tagging Locations

| Waypoint | Easting | Northing |
|---|---|---|
| D-T1 | 650042.88 | 5500648.59 |
| D-T2 | 648695.69 | 5499350.68 |
| D-T3 | 651298.83 | 5511644.99 |
| D-T4 | 651075.11 | 5510189.35 |
| D-T5 | 650247.38 | 5501525.71 |
| D-T6 | 651336.27 | 5503923.19 |
| D-T7 | 648107.97 | 5498599.13 |
| D-T8 | 647480.99 | 5497216.19 |
| D-T9 | 647331.85 | 5496940.21 |
| D-T10 | 648701.31 | 5499292.12 |
| D-T11 | 647025.46 | 5495720.55 |
| D-T12 | 650290.94 | 5501474.38 |
| D-T13 | 650608.42 | 5501820.03 |
| D-T14 | 651061.81 | 5510593.81 |
| D-T15 | 651082.93 | 5510483.15 |
| D-T16 | 651350.70 | 5511223.06 |
| D-T17 | 647048.63 | 5495903.50 |
| D-T18 | 651304.18 | 5503276.41 |
| D-T19 | 651314.43 | 5511302.39 |
| D-T20 | 651057.84 | 5510592.47 |
| D-T21 | 651070.12 | 5510196.00 |
| D-T22 | 651221.99 | 5510009.26 |
| D-T23 | 652022.59 | 5504997.45 |
| D-T24 | 651041.19 | 5510414.00 |
| D-T25 | 651101.20 | 5510245.08 |
| D-T26 | 651335.60 | 5509428.36 |
| D-T27 | 651502.94 | 5509119.67 |
| D-T28 | 651446.52 | 5508600.76 |
| D-T29 | 651360.04 | 5507823.28 |
| D-T30 | 651342.54 | 5506986.53 |
| D-T31 | 651585.95 | 5506325.82 |
| D-T32 | 651898.78 | 5504563.79 |
| D-T33 | 651430.95 | 5504166.88 |
| D-T34 | 651422.37 | 5503957.11 |
| D-T35 | 650997.33 | 5503706.06 |
| D-T36 | 651023.63 | 5503582.56 |
| D-T37 | 650685.85 | 5502095.37 |
| D-T38 | 650269.65 | 5501214.21 |
| D-T39 | 650265.00 | 5501208.52 |
| D-T40 | 650268.55 | 5501210.47 |
| D-T41 | 650352.28 | 5500969.89 |
| D-T42 | 649843.66 | 5500115.88 |
| D-T43 | 649673.97 | 5499936.90 |
| D-T44 | 649117.71 | 5499669.43 |
| D-T45 | 647306.68 | 5496861.03 |

Snorkel Recaptures

| Snorkel Pt. | Easting | Northing |
|---|---|---|
| D-S1 | 651521.54 | 5511845.92 |
| D-S2 | 651063.79 | 5510164.31 |
| D-S3 | 652003.13 | 5504961.67 |
| D-S4 | 649745.36 | 5500448.77 |
| D-S5 | 649898.96 | 5500119.26 |
| D-S6 | 647311.95 | 5496933.49 |
| D-S7 | 647314.96 | 5496822.32 |



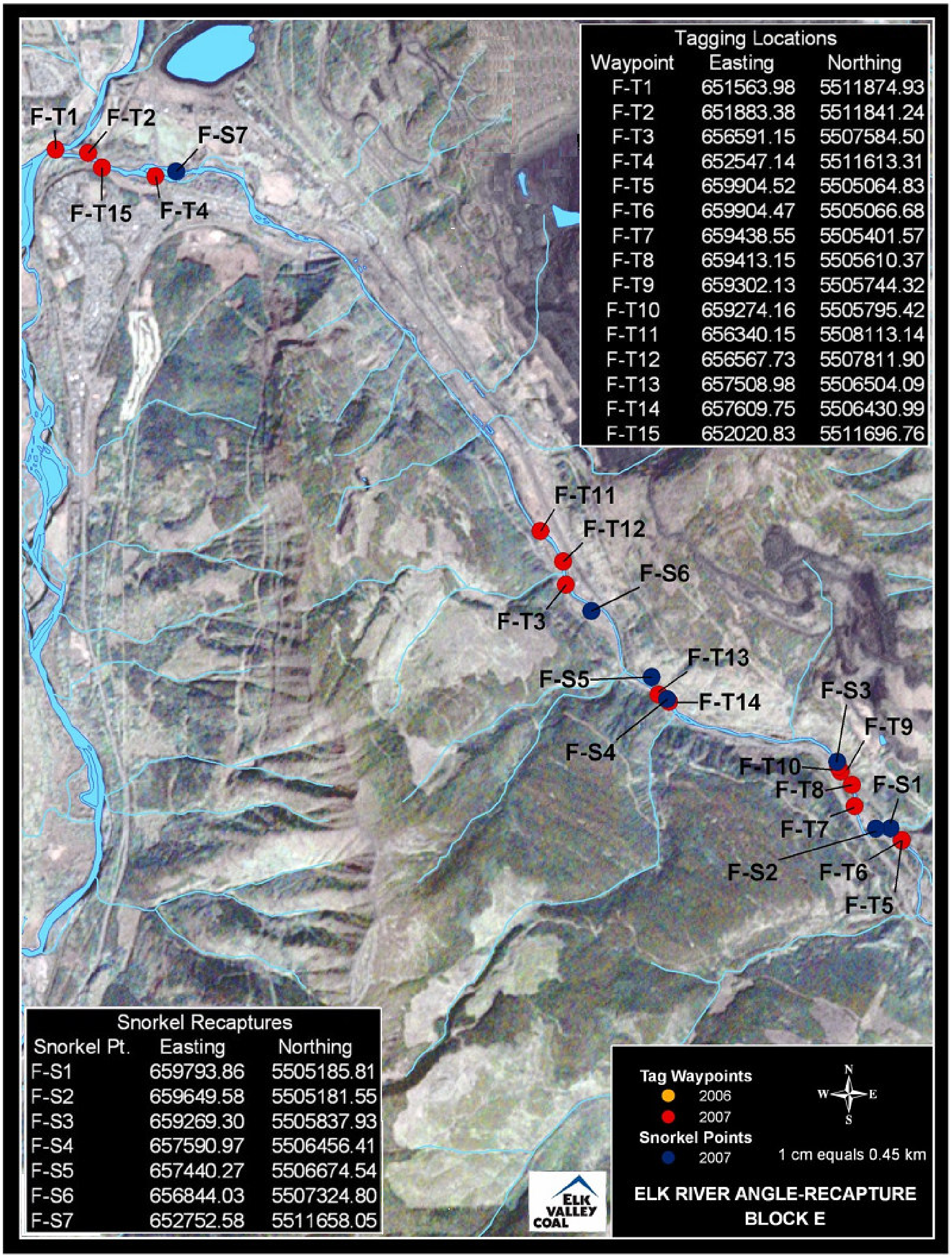
ELK RIVER ANGLE-RECAPTURE
BLOCK E

Tagging Locations

| Waypoint | Easting | Northing |
|---|---|---|
| E-T1 | 653172.81 | 5526816.56 |
| E-T2 | 653323.62 | 5524255.59 |
| E-T3 | 653197.16 | 5520759.71 |
| E-T4 | 653002.59 | 5520358.61 |
| E-T5 | 652612.60 | 5516753.34 |
| E-T6 | 653156.22 | 5515365.66 |
| E-T7 | 653120.51 | 5525986.69 |
| E-T8 | 652686.51 | 5522268.84 |
| E-T9 | 652705.70 | 5521873.80 |
| E-T10 | 653128.41 | 5526004.22 |
| E-T11 | 653393.86 | 5523501.03 |
| E-T12 | 652838.11 | 5518823.53 |
| E-T13 | 653078.53 | 5514956.75 |
| E-T14 | 653209.84 | 5523267.71 |
| E-T15 | 652343.02 | 5517314.98 |
| E-T16 | 652366.70 | 5517241.48 |
| E-T17 | 653128.41 | 5526004.22 |
| E-T18 | 653200.27 | 5522718.57 |
| E-T19 | 653122.49 | 5522501.26 |
| E-T20 | 652760.97 | 5522350.07 |
| E-T21 | 652743.42 | 5522334.74 |

Snorkel Recaptures

| Snorkel Pt. | Easting | Northing |
|---|---|---|
| E-S1 | 653137.51 | 5526021.17 |
| E-S2 | 653425.91 | 5523470.42 |
| E-S3 | 653288.46 | 5523243.99 |
| E-S4 | 652738.52 | 5522338.31 |
| E-S5 | 652942.24 | 5520230.18 |
| E-S6 | 652304.48 | 5517319.46 |
| E-S7 | 652611.22 | 5516660.58 |



ELK RIVER ANGLE-RECAPTURE
BLOCK E

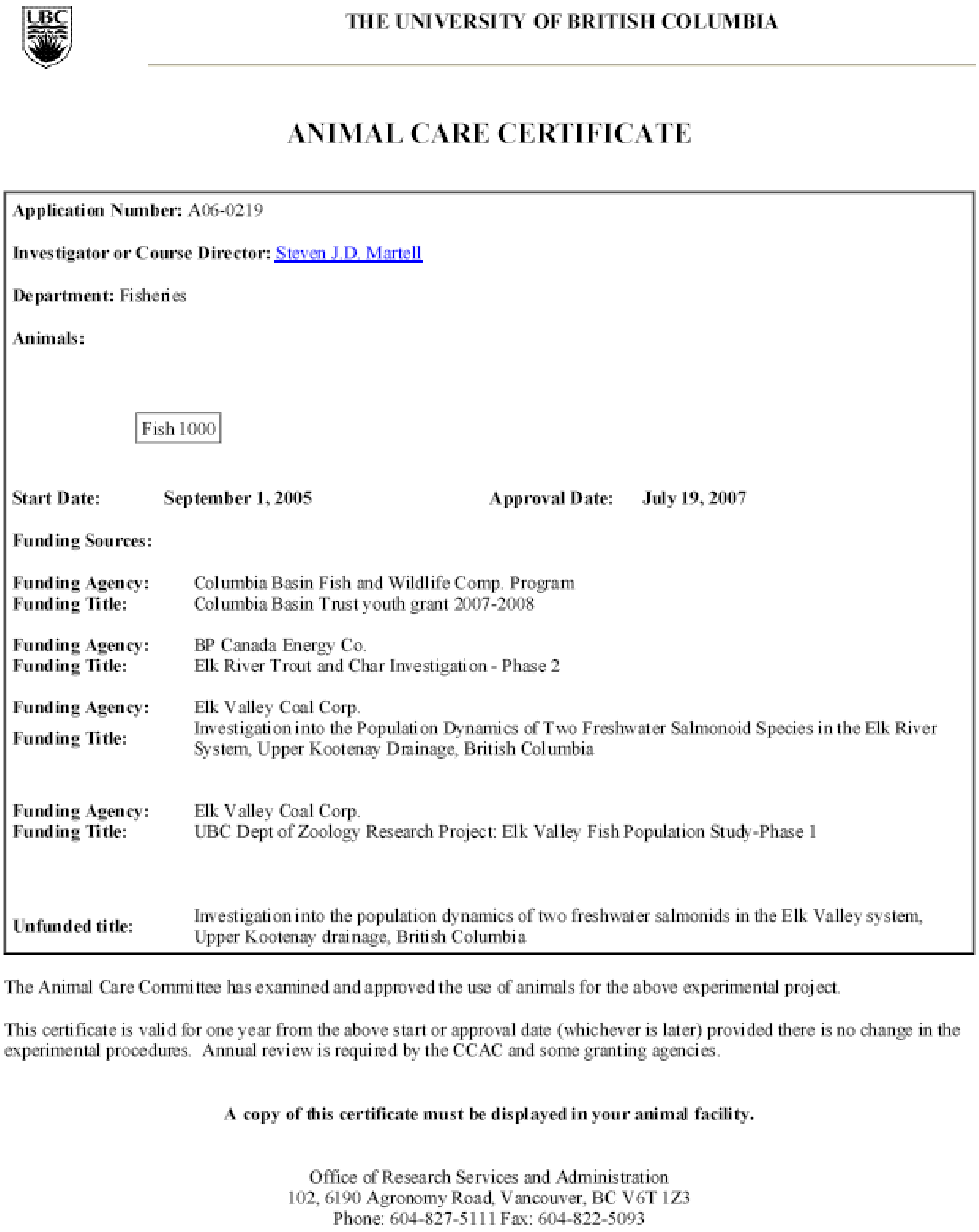
Tagging Locations

| Waypoint | Easting | Northing |
|---|---|---|
| F-T1 | 651563.98 | 5511874.93 |
| F-T2 | 651883.38 | 5511841.24 |
| F-T3 | 656591.15 | 5507584.50 |
| F-T4 | 652547.14 | 5511613.31 |
| F-T5 | 659904.52 | 5505064.83 |
| F-T6 | 659904.47 | 5505066.68 |
| F-T7 | 659438.55 | 5505401.57 |
| F-T8 | 659413.15 | 5505610.37 |
| F-T9 | 659302.13 | 5505744.32 |
| F-T10 | 659274.16 | 5505795.42 |
| F-T11 | 656340.15 | 5508113.14 |
| F-T12 | 656567.73 | 5507811.90 |
| F-T13 | 657508.98 | 5506504.09 |
| F-T14 | 657609.75 | 5506430.99 |
| F-T15 | 652020.83 | 5511696.76 |

Snorkel Recaptures

| Snorkel Pt. | Easting | Northing |
|---|---|---|
| F-S1 | 659793.86 | 5505185.81 |
| F-S2 | 659649.58 | 5505181.55 |
| F-S3 | 659269.30 | 5505837.93 |
| F-S4 | 657590.97 | 5506456.41 |
| F-S5 | 657440.27 | 5506674.54 |
| F-S6 | 656844.03 | 5507324.80 |
| F-S7 | 652752.58 | 5511658.05 |

# Appendix C



THE UNIVERSITY OF BRITISH COLUMBIA

## ANIMAL CARE CERTIFICATE

**Application Number:** A06-0219

**Investigator or Course Director:** Steven J.D. Martell

**Department:** Fisheries

**Animals:**

Fish 1000

**Start Date:** September 1, 2005 **Approval Date:** July 19, 2007

**Funding Sources:**

**Funding Agency:** Columbia Basin Fish and Wildlife Comp. Program
**Funding Title:** Columbia Basin Trust youth grant 2007-2008

**Funding Agency:** BP Canada Energy Co.
**Funding Title:** Elk River Trout and Char Investigation - Phase 2

**Funding Agency:** Elk Valley Coal Corp.
**Funding Title:** Investigation into the Population Dynamics of Two Freshwater Salmonoid Species in the Elk River System, Upper Kootenay Drainage, British Columbia

**Funding Agency:** Elk Valley Coal Corp.
**Funding Title:** UBC Dept of Zoology Research Project: Elk Valley Fish Population Study-Phase 1

**Unfunded title:** Investigation into the population dynamics of two freshwater salmonids in the Elk Valley system, Upper Kootenay drainage, British Columbia

The Animal Care Committee has examined and approved the use of animals for the above experimental project.

This certificate is valid for one year from the above start or approval date (whichever is later) provided there is no change in the experimental procedures. Annual review is required by the CCAC and some granting agencies.

**A copy of this certificate must be displayed in your animal facility.**

Office of Research Services and Administration
102, 6190 Agronomy Road, Vancouver, BC V6T 1Z3
Phone: 604-827-5111 Fax: 604-822-5093

***A06-0219*** **Elk River trout and char investigation (Version 2.0)**

**Principal Investigator: Steven J.D. Martell**

**1. Study Team** [View Form]

*1.1. Please select the Principal Investigator (PI) for the study. Once you hit Select, you can enter the PI's name, or enter the first few letters of his or her name and hit Go. You can sort the returned list alphabetically by First name, Last name, or Organization by clicking the appropriate heading.*

| Last Name | First Name | Rank | |
|---|---|---|---|
| Martell | Steven J.D. | UBC/College for Interdisciplinary Studies/Fisheries | Assistant Professor |

*1.2. Provide the name of ONE primary contact person in addition to the PI who will receive ALL correspondence regarding this application. This primary contact will have online access to read, amend, and track the application.*

| Last Name | First Name | Rank |
|---|---|---|
| Walters | Carl J. | Professor |

*1.3 Co-Investigators: List all Co-Investigators of the study. These members WILL have online access to read, amend and track the application.*

*1.4. Study Team Members - Online Access List all study team members who WILL HAVE online access to read, amend and track the application.*

| Last Name | First Name | Employer | Rank | Online Training | Practical Training |
|---|---|---|---|---|---|
| Wilkinson | Chadwick E | Zoology | Graduate Student | | |
| Walters | Carl J. | Fisheries | Professor | | |
| Martell | Steven J.D. | Fisheries | Assistant Professor | 1937 | |

*1.5. Study Team Members - No Online Access List all associates who WILL NOT HAVE online access to the application. To delete a study team member from the list below, select the box next to his or her name and hit Delete.*

| Last Name | First Name | Employer | Rank/Job Title | Contact Number | Completed Animal Care Training? | Certificate Number |
|---|---|---|---|---|---|---|
| Cloutier | Louis | Elk River Guiding Co. | Volunteer angling guide | (250) 423-7239 | no | |
| Mason | Bret | Elk River Guiding Co. | Volunteer angling guide | (250) 423-7239 | no | |
| Clarke | Beckie | Elk River Guiding Co. | Volunteer angling guide | (250) 423-7239 | no | |
| Cooper | Ned | Elk River Guiding Co. | Volunteer angling guide | (250) 423-7239 | no | |
| Lafortune | Chris | UBC | Electro-fishing field assistant | (250) 423-7117 | no | |
| Williams | Craig | UBC | Tagging field assistant | (250) 278-2363 | no | |
| Jakubec | Don | Tembec Industries Ltd. | Fernie Rod and Gun Club - volunteer angler | (250) 423-4583 | no | |