Peace Project Water Use Plan

Fish Index

Implementation Year 4

Reference: GMSMON #2

Peace River Fish Index Project – 2011 Studies

Study Period: August 24, 2011– September 24, 2011

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PEACE RIVER FISH INDEX PROJECT
- 2011 STUDIES -

Prepared for

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EXECUTIVE SUMMARY

In 2001, BC Hydro initiated the Large River Fish Community Indexing Program to help define the effects of dam and reservoir operations on fish populations in flow regulated watersheds and to ensure operations are both environmentally and economically sustainable. The program has occurred annually from 2001 to the present. During that period the goal of the program was to establish cost-effective monitoring protocols to provide reliable indices of fish population characteristics. In 2008, the Large River Fish Community Indexing Program for the Peace River, subsequently referred to as the Peace River Fish Index Project, was implemented under the Peace Water Use Plan (WUP). The WUP includes management plans to enhance fish habitat and fish productivity in the Peace River system. As such the goal of the Fish Index Project has shifted from evaluating monitoring protocols to monitoring target fish populations to assist in the evaluation of the effectiveness of Peace River management plans and associated physical works projects implemented under the WUP.

The 2011 Peace River Fish Index Project study area encompassed a 92 km portion of the Peace River from just downstream of the Peace Canyon Dam to downstream of the Moberly River confluence. Repeated sampling (six sessions) in three sections (1, 3, and 5) occurred from 24 August to 24 September, 2011 using a boat electrofisher in nearshore habitats.

Field sampling conditions (i.e., discharge, water clarity, and water temperature) were generally similar to conditions during previous studies. While water clarity and water temperature were within the range recorded since 2001, discharge was higher than recorded during previous studies.

General fish community characteristics in 2011 were similar to results of previous investigations. Thirteen large-fish species were recorded and Mountain Whitefish was numerically dominant. The other two target species, Arctic Grayling and Bull Trout, were not abundant.

<u>Arctic Grayling</u>

In total, 175 Arctic Grayling were sampled for biological characteristics. Similar to results of previous studies, Age 0 fish were not encountered. Fish from Sections 1, 3 and 5 exhibited similar biological characteristics. Samples were dominated by Age 1 and Age 2 fish. There were no measurable differences between the sections in terms of length-at-age, body condition-at-age, growth, and apparent annual mortality. There continues to be annual shifts in length and age distributions of the Arctic Grayling sample populations, which are related to strong age classes in a particular year.

Arctic Grayling catch rates were low in 2011. Arctic Grayling were scarce in Section 1 and fish abundance was similar among Sections 3 and 5. Arctic Grayling catch rates in Sections 3 and 5 increased from 2010 suggesting a reversal of the continued decline since 2007. The biological data did not show any large shift in population structure or health that could explain reversal abundance. As such, the change may reflect natural variation in Arctic Grayling abundance and recruitment from Peace River tributaries. Age 1 Arctic Grayling were recorded in all three sections. The contribution of Age 1 Arctic Grayling has been zero in Section 1 until 2011. In Sections 3 and 5, Age 1 Arctic Grayling were recorded during all sample years, but recruitment has varied annually.

Bull Trout

In total, 227 Bull Trout were sampled for biological characteristics. Length and age distributions of Bull Trout were similar among sections. Fish from Age 2 to 6 dominated and Bull Trout older than Age 7 (adults) were not well represented. Bull Trout population health, in terms of growth and body condition, are similar among sections. Fish grow very quickly and exhibit good body condition. Age and length distributions of the combined sample (Sections 1, 3, and 5) remained stable across years. Age 1 fish were largely absent. During all sample years, age distributions were dominated by subadults. The paucity of adult fish was likely caused by use of tributaries for spawning and as such, the results do not reflect the actual age structure of the Peace River Bull Trout population.

Bull Trout catch rates were low and there were no strong section differences. There has been no large change in Bull Trout catch rates for the duration of the index project. Age 3 Bull Trout were recruited in each section during all years of the study, but the recruitment index has remained at approximately or below 1.0 fish/km.

Mountain Whitefish

In total, 10,673 Mountain Whitefish were available for analyses and the 2011 results were consistent with previous studies. There were spatial differences in the biological characteristics of Mountain Whitefish. Fish in Section 1 exhibited truncated age and length distributions while fish in Sections 3 and 5 exhibited multi-modal length distributions that represented a wider range of ages. There were spatial differences in Mountain Whitefish growth and body condition. In Section 1 younger age classes tended to have higher mean lengths and older age classes had lower mean lengths compared to fish in Sections 3 and 5. The annual mortality of Mountain Whitefish also differed between sections.

There continues to be small annual differences in Mountain Whitefish age and length distributions based on strengths of younger age classes; however, the spatial differences remain consistent among years. In terms of population health, some parameters (i.e., growth curves, anabolic constants, and body condition-at-age) indicated no strong temporal change in population health. However, Mountain Whitefish body condition in 2011 was below the long term mean for most ages in all three sections.

Mountain Whitefish continue to be abundant in 2011 and catch rates in each section were the highest on record. Catch rates of Mountain Whitefish within each section varied annually. In Section 1, the downward trend that commenced in 2004 ended in 2007, after which catch rates varied only slightly before the large increase in 2011. Section 3 and Section 5 Mountain Whitefish exhibited cyclic abundance with highs recorded in 2005 and 2008 and 2011. Annual recruitment of Age 1 Mountain Whitefish differed between sections. During most years recruitment indices were much lower in Section 1 compared to Sections 3 and 5. In 2011, there was a substantial decline in Mountain Whitefish recruitment in all three sections. The data suggests a cyclic pattern of recruitment based on a three year period.

<u>Population Estimates</u>

Overall, the program was highly successful (in terms of the number of marks applied and recaptured) for Mountain Whitefish, but less so for Arctic Grayling and Bull Trout. The population estimate of Arctic Grayling in Section 5 was 66 (CV = 23.1%) fish. Because of sparse recoveries in Section 3, the posterior distribution is highly skewed and mean estimate is unreliable. There is a 0.95 probability that the population size is at least 91 Arctic Grayling in Section 3.

The Bull Trout, population estimate was 331 (CV = 29.1%) in Section 3. Because of sparse recoveries, the posterior distribution is highly skewed and mean estimate is unreliable. There is a 0.95 probability that the population size was at least 117 and 175 Bull Trout in Sections 1 and 5, respectively.

Bayes sequential model population estimates for Mountain Whitefish were 26,671 (CV = 6.1%) fish in Section 1, 18,710 (CV = 4.5%) fish in Section 3, and 15,542 (CV = 6.4%) fish in Section 5. The population estimates for Mountain Whitefish in 2011 were second only to 2010 estimates and were approximately double the historical record of estimates deemed to be valid. The year-to-year increase in population size is too large to be due to recruitment into the sampled population. We believe that low water caused the fish to move into the study area before the start of sampling from unsampled areas. In other words, a different population was sampled in 2011. We believe that similar dynamics occurred in 2004 and 2010.

Catchability

The estimated catchability coefficients were consistent for all sections within 2011. However, the coefficients were inconsistent across years and sections where the population estimates were deemed to be reliable or represent the same population. In 2011, the catch rate increased with population size suggesting stable catchability. Examination of years having low catchability coefficients suggests a correlation with sample periods subjected to minimum flows, but the relationship was not consistent across all sections.

Recommendations

The initial goal of the program was to establish fish monitoring protocols that can be used reliably to provide an index of target fish populations. The findings of the 2011 Peace River Fish Index Project indicated that the monitoring protocols are suitable to meet this goal, particularly for Mountain Whitefish.

Based on the findings of the 2011 Peace River Fish Index Project we recommend the following:

1. Repeat the standard program to extend the time series data. Sample Sections 1, 3, and 5 to extend sampling history. The continuous record of consistent and rigorous sampling is a valuable baseline for the target populations. Adding years to the data set will increase its value.
2. Maintain the current study design and sampling protocols.
3. Address the issue of under estimation of Mountain Whitefish age derived from scales by development of a "correction factor" using incremental growth data for known aged marked fish that are recaptured. This approach allows use of historical index data, but may require an additional 2 to 3 years of growth data before it can be implemented.

The ultimate purpose of the Fish Index Project is to assist in the evaluation of the effectiveness of Peace River management plans, designed to improve fish habitat and productivity, by monitoring target fish populations. The following are recommendations to adjust the current Fish Index Project in order to assist in the evaluation of the effectiveness of Peace River Side Channel Plan.

1. Continue the standard program in Sections 1, 3, and 5 and maintain the current study design and sampling protocols. The adult cohort of Peace River fish populations, which is targeted by the Fish Index Project, is sufficiently mobile to allow monitoring of side channel restoration effects without requiring spatial adjustment to the current sections.
2. Large-fish species expected to respond to side channel restoration (i.e., for spawning or rearing) should be added to the list of existing target species. Standard sampling protocols should be applied to those species (i.e., measurement of biological characteristics and fish numbers).

ACKNOWLEDGEMENTS

Mainstream Aquatics Ltd. would like to thank persons from BC Hydro; specifically Brent Mossop for initiating the study, Kim Hawkins for administering the project, as well as Michael McArthur for participating in the field program. The interest of these individuals is appreciated.

Bill Gazey of W.J. Gazey Research was responsible for the population estimate and age structured mark-recapture model components of the study and co-authored the report.

Persons associated with Mainstream Aquatics Ltd. who participated in the study were as follows:

Rick Pattenden	Senior Biologist and Coauthor
Chantal Pattenden	Senior Technician
David Winarski	Technician
Jason Leathem	Technician
Todd Sherstone	Technician
Jamie Smithson	Technician
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1.0 INTRODUCTION

1.1 BACKGROUND

In 2001, BC Hydro initiated the Large River Fish Community Indexing Program to help define the effects of dam and reservoir operations on fish populations in flow regulated watersheds and to ensure operations are both environmentally and economically sustainable. The program occurred annually from 2001 to 2007. During that period the goal of the program was to establish cost-effective monitoring protocols to provide reliable indices of fish population characteristics.

In 2008, the Large River Fish Community Indexing Program for the Peace River, subsequently referred to as the Peace River Fish Index Project, was integrated into the Peace Water Use Plan (WUP). The WUP Committee expressed concern about the status of fish habitat and fish productivity in the Peace River system. To address this concern, management plans are being implemented that include the Peace River (PCR) Side Channel Plan, the PCR Ramping Plan, and the PCR Flood Pulse Plan. Further information on the WUP and the management plans is available at the BC Hydro website http://www.bchydro.com/planning_regulatory/water_use_planning/northern_interior.html#Peace_River The results of the Fish Index Project will assist in the evaluation of the effectiveness of Peace River management plans, designed to improve fish habitat and productivity, by monitoring target fish populations.

Mainstream Aquatics Ltd. (Mainstream) and its study team completed the Peace River fish index projects from 2001 to 2010. Mainstream was contracted by B.C. Hydro to complete the 2011 program. Similar to previous investigations the study team consisted of two primary members. Mainstream Aquatics Ltd. was the overall managing consultant and was responsible for the field program, the biological characteristics component, and relative abundance component of the study. W.J. Gazey Research was responsible for the population estimate component and related topics.

1.2 OBJECTIVES

The 2011 program objectives were as follows:

1. To extend time series data on the abundance, distribution, and biological characteristics of nearshore target fish populations in the Peace River in standard sections and control sections using a standardized boat electrofishing sampling program.
2. To build upon previous investigations to further refine the sampling strategy, sampling methodology and analytical procedures required to establish a long term monitoring program for fish populations in the Peace River.

3. To update the existing electronic storage and retrieval system for fish population and habitat monitoring data for the Peace River.
4. To identify gaps in data and our understanding of fish populations, procedures for sampling them, and to provide recommendations for future monitoring and fisheries investigations.
5. Present the information in a technical report.

It should be noted that sampling of Control Sections was not undertaken in 2011. Reasons for this omission are identified in Section 2.1.1.1.

An additional component of the 2011 program was implemented based on findings presented in the 2009 study titled “Growth analysis for the integration of age composition and incremental length data” (Gazey 2011: a companion report under the indexing project) and the results of the 2010 index project (Mainstream and Gazey 2011). The results of both studies indicated that Mountain Whitefish growth estimates derived from scales was not consistent with growth estimates derived from length-at-recapture of marked fish. Errors associated with age data derived from scales (the standard approach used by the index project), would hinder development of an age structured mark-recapture (ASMR) model for Peace River target fish populations.

To address this issue a stand-alone investigation was completed to develop a methodology to estimate the age of fish from length-at-age and mark-recapture data. The results of that study are presented in Gazey (2012).

1.3 TARGET SPECIES

As with previous studies, three target species were investigated in 2011:

- Mountain Whitefish (*Prosopium williamsoni*)
- Arctic Grayling (*Thymallus arcticus*)
- Bull Trout (*Salvelinus confluentus*)

1.4 STUDY AREA

The study area was similar to previous programs (Figure 1.1). The study area included a 90 km portion of the Peace River from just downstream of the PCN Dam (Km 145) to downstream of the Moberly River confluence (Km 53). Sampling occurred in three previously sampled standard sections: Section 1, Section 3, and Section 5 (Table 1.1; Appendix A).

Table 1.1 Standard sections of the 2011 Peace River Fish Index Project.

Area	Section	Location[a]	Section Length (km)	Sampled Length (m)[b]	Percent of Section Sampled[c]
Hudson's Hope	1	Km 137.0 to 145.2	8.2	11,772	52.9
Downstream of Halfway River	3	Km 89.8 to 99.2	9.4	18,789	63.2
Downstream of Moberly River	5	Km 53.4 to 64.8	11.4	14,183	51.8

[a] Based on distance upstream from the British Columbia/Alberta boundary (Km 0).
[b] Length of nearshore habitat sampled in each section.
[c] Percent of total nearshore habitat sampled in each section.

1.5 SAMPLE PERIOD

Sampling occurred during a 32 day window between 24 August and 24 September 2011.

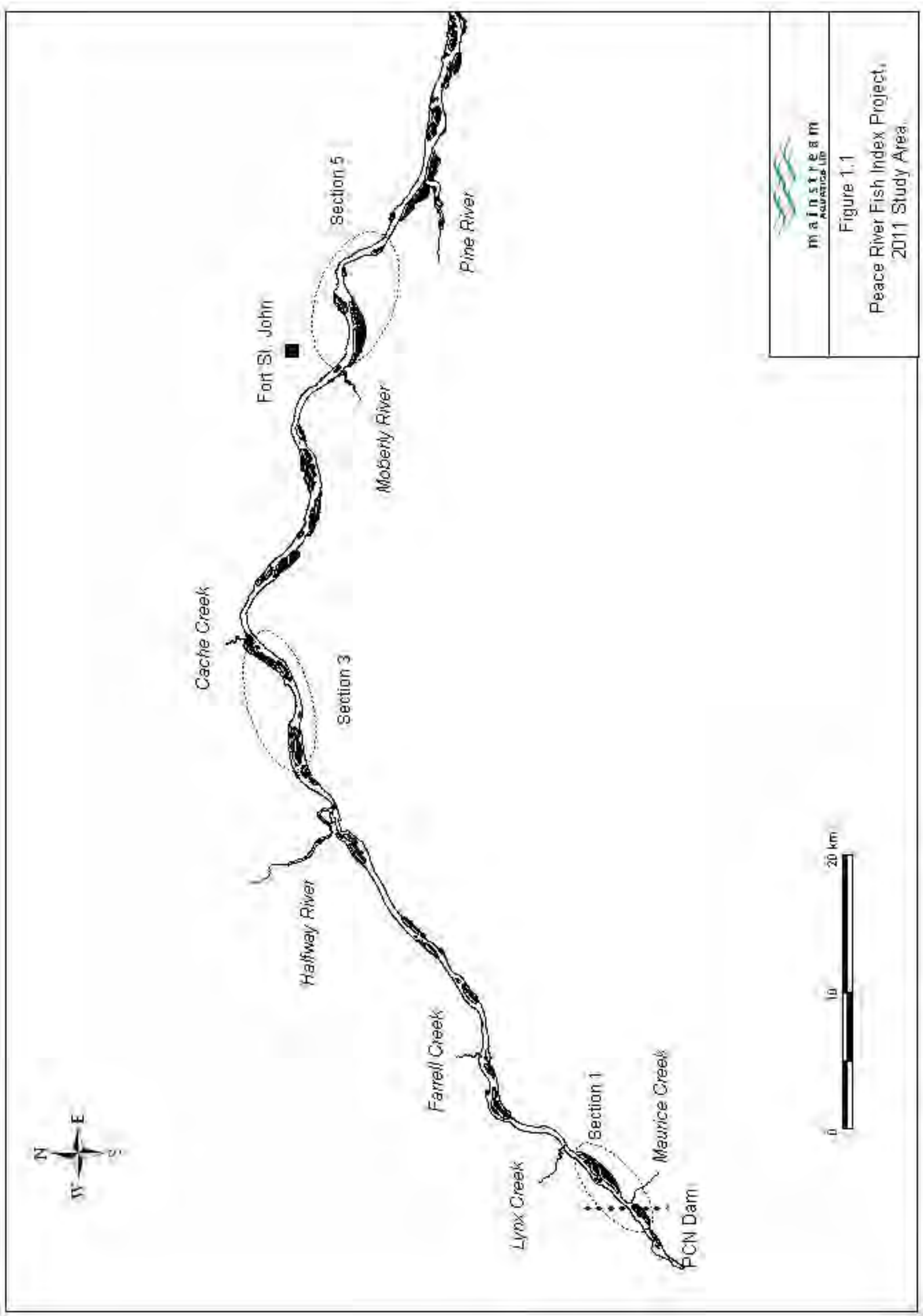

Figure 1.1
Peace River Fish Index Project, 2011 Study Area.

2.0 METHODS

2.1 FIELD PROGRAM

2.1.1 Approach

The field program collected data to quantify fish numbers (relative abundance and population estimates) and biological characteristics of target fish populations in the Peace River. A fundamental requirement of the field program was to generate reliable population estimates for each of the target fish species. The field program was designed to address this requirement.

2.1.1.1 Alterations to Standard Approach

Upon initiation of the 2011 field program very large numbers of Mountain Whitefish were encountered in Section 1 and Section 3 (approximately 200% higher than previously encountered). Existing sampling protocols were not able to cope with the large number of fish. Specifically, fish collections could not be completed within the required period of time and the available number of PIT tags was insufficient to mark all collected fish.

The study team discussed options to address the situation. Based on these discussions, and discussions with BC Hydro representatives (Kim Hawkins, WLR Program Administrator), adjustments were made to the sampling program as follows:

1. The number of sampled sites was reduced by from 15 to 14 in each of Section 1 and Section 3.
2. The maximum number of Mountain Whitefish marked with PIT tags was limited to 50 fish at each site per session in each of Section 1 and Section 3.
3. When the number of fish captured during a sample event in a site exceeded the capacity of the live-well (i.e., approximately 100 fish) sampling was terminated. When time permitted (i.e., sufficient daylight hours) the remainder of the site was sampled.
4. Aging structures were not collected from previously PIT-tagged Mountain Whitefish when the number of fish to be processed during a single sample event exceeded 50 fish.
5. Sample effort assigned to control sites was re-assigned to the standard sites.
6. Nontarget fish species were not captured or enumerated during recapture Sessions 5 and 6.
7. Standard sampling protocols were maintained in Section 5.

The adjustments were made in order to allow completion of the field program while maintaining the integrity of the project. The adjustments did not compromise achievement of most study objectives (Section 1.1). The one exception was that control sections were not sampled in 2011. This omission will will interrupt the continuity of the time series data for the control sections.

2.1.1.2 Standard Sampling

Sites

As for previous fish index studies, sites selected in 2002 based on habitat characteristics, accessibility, and presence of target fish species were sampled in 2011. The nearshore areas (i.e., river margins, generally 0.5 – 2.0 m depth) of fourteen discrete sites were sampled in each of standard Sections 1 and 3 using a boat electrofisher; fifteen discrete sites were sampled in Section 5 (Table 2.1; Appendix Table A2). Standard sites ranged in length from 445 m to 1840 m.

Table 2.1 Number and length of sites sampled in standard sections, 2011 Peace River Fish Index Project.

Section	Number of Sites	Length (m)[a]		
		Average	Minimum	Maximum
1	14[b]	841	445	1092
3	14[c]	1326	855	1840
5	15	946	502	1171

[a] Does not include instances of reduced length of some sites during specific sample sessions (See Section 2.1.1.2).
[b] Includes 7 SFC sites and 7 SFN sites; see Table 2.2 for definitions.
[c] Includes 8 SFC sites and 6 SFN sites; see Table 2.2 for definitions.

Each standard site represented one of two distinct habitat categories (Table 2.2): nearshore habitat with physical cover (SFC) or nearshore habitat without physical cover (SFN). These habitat categories were selected for sampling during initial studies because they represented the two dominant habitat categories in the study area and could be effectively sampled using boat electrofisher (P&E and Gazey 2003). The SFC and SFN habitat categories were defined based on three physical characteristics: bank slope/depth, water velocity, and the presence of physical instream cover. The number and type of sites in standard sections were distributed as follows:

Section 1 - 7 SFC sites and 7 SFN sites
Section 3 - 8 SFC sites and 6 SFN sites
Section 5 - 8 SFC sites and 7 SFN sites

Table 2.2 Site habitat categories and characteristics, 2011 Peace River Fish Index Project.

Habitat Category	Bank Habitat[a]	Instream Habitat	Water Velocity[b]	Bank Configuration[b]	Physical Cover	Dominant Substrate
SFN	A3	Run	Moderate to High	Gradual Slope/ Shallow Water	Absent	Rock
SFC	A1/A2	Run	Moderate to High	Gradual Slope/ Shallow Water	Present	Rock

[a] Habitat types defined in RL&L (2001).
[b] Based on subjective measure by experienced habitat biologist.

Effort

All activities occurred during daylight hours to ensure crew safety and to maximize the number of sites sampled and the number of fish processed. All sites in each section were sampled six times. The first four sessions were used to collect biological data from all fish species encountered and to mark and recapture target fish species. Sessions 5 and 6 focused on obtaining recapture data for the three target species, therefore, Mountain Whitefish were not marked or processed for biological data to maximize time spent sampling. In general, two days were required to sample each section during each of the first four sessions. During the last two sessions, each section was sampled completely in one day. In general there was a four-day rest period between sample events during Sessions 1 to 4 and a two-day rest period between Sessions 5 and 6. The distribution of sampling effort is summarized in Table 2.3. Unless otherwise indicated, 'effort' refers to time spent electrofishing throughout the report.

Table 2.3 Distribution of sampling effort (hours of electrofishing) in standard sections, 2011 Peace River Fish Index Project.

Section	Session and Effort (h)						Total
	1	2	3	4	5	6	
1	1.5	1.5	1.6	1.6	1.6	1.6	9.4
3	2.1	2.3	2.6	2.4	2.6	2.6	14.6
5	1.7	1.8	1.9	1.8	1.9	1.9	11.1
Total	5.3	5.6	6.1	5.8	6.1	6.1	35.1

Excessive numbers of fish prevented sampling of the entire length of some sites (Table 2.4). Reduced sampling occurred three times in Section 1, seven times in Section 3, and once in Section 5. The percent reduction in sampled length ranged from 3% to 35%. The occurrence of reduced sampling effort events represented 4% of the total sampling program (11 of 258 sample events).

Table 2.4 Summary of sample events when entire site length was not sampled, 2011 Peace River Fish Index Project.

Section	Site	Date	Total Length (m)	Length Not Sampled (m)	Percent Not Sampled
1	0101	26-Aug-11	614	100	16
	0109	27-Aug-11	958	200	21
	0116	03-Sep-11	955	30	3
3	0305	10-Sep-11	1486	215	15
	0305	16-Sep-11	1486	300	20
	0308	25-Aug-11	1486	525	35
	0310	17-Sep-11	1208	100	8
	0315	25-Aug-11	1674	400	24
	0315	05-Sep-11	1674	298	18
	0315	11-Sep-11	1674	215	13
5	0504	08-Sep-11	582	80	14

2.1.2 Fish Capture Methods

A boat electrofisher was used to capture fish in nearshore habitats along the channel margin. Larger-sized fish were targeted (> 150 mm fork length) in water depths ranging from 0.5 to 2.0 m. Sampling was restricted to areas ≤ 2.0 m deep because boat electrofishing effectiveness on the Peace River is severely reduced beyond this depth.

A 5 m boat electrofisher propelled by a 175 Hp sport-jet inboard motor was used to sample fish. The craft was equipped with a fixed-boom anode system and Smith-Root Type VIA electrofisher system. Electrofisher settings were generally maintained at an amperage output of 3.0 to 4.5 A, pulsed DC current, and a frequency of 60 Hz. These settings were sufficient to immobilize all three target species and minimize injury rates of susceptible species such as Mountain Whitefish. The electrofisher settings were similar to those employed during previous studies.

The sampling procedure involved drifting downstream at motor idle along the channel margin, while outputting a continuous current of electricity. In general, boat position was maintained at a water depth of 1.25 m to 1.50 m by monitoring the depth with a sounder. The only instance when this sampling protocol changed occurred when backwater areas greater than two boat lengths were encountered. In these situations, the boat was turned into the backwater at its downstream end and the channel margin in the backwater area was sampled in an upstream direction.

Two netters positioned on a platform at the bow of the boat captured immobilized fish while the boat operator maintained the position of the craft along the channel margin. To provide a representative sample of the fish community netters were instructed not to bias their catch towards a particular species or fish size. Netters were equipped with nets having a diameter of 45 cm, a depth of 40 cm, and a mesh size of 5 cm. To facilitate capture of smaller fish, the bottom surface (40 cm^2) of each net had a mesh size of 1.5 cm. This mesh size allowed capture of fish to a minimum size of approximately 150 mm.

Netters were instructed to retrieve a random sample of immobilized fish of any species and size (> 150 mm) that were accessible from their netting position on the platform. To minimize the potential for electrofisher induced injury, no more than one fish was netted at a time and immobilized fish were removed from the water as quickly as possible and immediately placed into an onboard holding livewell.

The only exception to the above sampling protocol occurred when a rare species or life stage was encountered. In this situation, the boat was turned towards the fish and netters made every effort to capture the individual. This protocol was used to increase the probability that a rare species or life stage encountered in the field is recorded in the catch data. This protocol may cause an over estimate of the catch of a rare species or life stage, but the bias is constant because this sampling protocol is used consistently.

Upon completion of an electrofishing section, captured fish were enumerated, processed, and released. To avoid recapture of previously collected fish, processed fish were released near the middle of the sample site.

2.1.3 Observed Fish

A standardized approach to enumerate observed fish was used during the standard sampling program. Each netter was instructed to count un-netted fish ≥ 250 mm total length that were present in a defined observation zone at the bow of the boat electrofisher. Observations were restricted to four species: Arctic Grayling, Bull Trout, Mountain Whitefish, and rainbow trout. At the end of a sample site, each netter recorded the number of observed fish on a data record sheet. To minimize observer bias, netters were not coached and they were instructed not to compare results.

2.1.4 Processing Fish

All captured fish were held in a 230 L holding tank equipped with a water circulating system, which provided a water exchange rate of 19 L/min. During Sessions 1 through 4, data recorded for each fish included species, fork length (to the nearest 1 mm), weight (to the nearest 2 g), and presence of a tag, tag scar, or fin clip. An appropriate nonlethal ageing structure (Mackay *et al.* 1990) was collected from all unmarked individuals of the three target species. The first two rays of the right pectoral fin were collected from Bull Trout, while several scales situated immediately below the back third of the dorsal fin and above the lateral line were collected from Arctic Grayling and Mountain Whitefish. Sagittal otoliths were collected opportunistically from Mountain Whitefish that succumbed during sampling. Ageing structures were placed in labeled envelopes and air-dried before storage. All field data were entered electronically using a TDS Ranger handheld computer into a Microsoft® Excel spreadsheet.

As part of the population estimate component of the study in the standard sections, individuals of target fish species ≥ 250 mm fork length in good condition were marked using Passive Integrated Transponder tags, or "PIT tags". Tags were of the ISO type (134.2 kHz), which have a 15 digit numeric code. Tags, tag applicators, and tag readers were supplied by AVID Canada. After tag insertion, a Power Tracker VIII tag reader was used to record the numeric code. PIT tags used in 2005 were of the FECAVA type (125 kHz), which have a 10 digit alpha-numeric code. The Power Tracker VIII could read both PIT tag types. Prior to 2005, fish were marked with a uniquely numbered T-bar Floy tag (FD-94).

This fish processing procedure was modified during recapture Sessions 5 and 6 to shorten processing time. All captured fish were examined for the presence of a tag. For all marked Mountain Whitefish, tag numbers were recorded and fish were measured for fork length prior to release. Mountain Whitefish without tags were assigned a length category, enumerated, and released. Length categories were ≥ 250 mm fork length (taggable) and < 250 mm fork length (not taggable). All Arctic Grayling and Bull Trout were processed, tagged, and released.

2.1.5 Measured Parameters

In addition to fish capture and biological characteristics, other parameters measured during the standard program included the following:

- Date and time
- Effort (seconds/meters)
- Sample method settings
- Surface water conductivity (microsiemens) was measured using Hanna HI98311 EC/TDS meter (± 2% full scale).
- Surface water temperature was measured using Hanna HI98311 EC/TDS meter (± 0.1^{o}C)
- Water clarity (cm); using a secchi plate mounted on a pole (plate was 2.5 cm wide x 21 cm long partitioned into three equal sections of black, white, and black)
- Relative observer skill (high [1]; moderate [2]; low [3]; nil [4]).

The information was either processed and analyzed, or stored for future reference (Appendix B).

2.2 OFFICE PROGRAM

2.2.1 Age Data

Ages were obtained from all Arctic Grayling and Bull Trout collected during the program (unmarked and previously marked fish captured for the first time in 2011). For previously marked Bull Trout the absence of an ageing structure (pectoral fin ray) required use of age data obtained during previous studies.

The large number of Mountain Whitefish scales required use of a random subsample of ageing structures. A random number generator was used to select ageing structures from approximately 8% of nonfloy-tagged Mountain Whitefish captured for the first time in 2011 (previously PIT-tagged and unmarked fish) in each section using the random number generator function in SPSS© software. Floy-tagged fish were not included due to strong, negative tag effects on growth (Mainstream and Gazey 2007). PIT-tagged fish were included due to the high percentage of marked fish present in the sample and the absence of a measurable tag effect (Mainstream and Gazey 2007). It should be noted that ageing structures were not collected from all PIT-tagged Mountain Whitefish (see Section 2.1.1.1).

Scale and fin ray structure preparation and ageing procedures followed those described in Mackay *et al.* (1990). Scales were immersed in water and cleaned if dirty, and then placed on a microscope slide for viewing using a dissecting microscope. Mounting procedures for Bull Trout fin rays followed Koch and Quist (2007). Fin rays were fixed in epoxy, sectioned with a jeweler's saw, and mounted on a slide for viewing under a dissecting microscope.

Two experienced individuals independently aged each structure for Mountain Whitefish and Arctic Grayling. One experienced individual aged each Bull Trout structure. A second reader completed random checks on Bull Trout ages.

2.2.2 Standard Analytical Approach

Parameters used as monitoring tools included biological characteristics, catch rate (relative abundance), and population estimates. Methods are described below. Unless otherwise stated, statistical analyses followed procedures described in Sokal and Rohlf (1995).

General statistical protocols were as follows:

1. Statistical significance was accepted at $P \leq 0.05$.
2. Univariate statistical analyses were restricted to samples $n \geq 5$.
3. Data were transformed where appropriate to meet assumptions for parametric statistical analyses.

4. Nonparametric tests were used where assumptions for parametric statistical analyses could not be resolved.

2.2.3 Biological Characteristics

Biological characteristics examined included length and age distribution, body condition-at-age, length-at-age, growth rate, and mortality. When possible, data from individual sections were analyzed and presented separately due to spatial differences in biological characteristics (P&E and Gazey 2003; Mainstream and Gazey 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011). The only exception was analyses of Bull Trout data. For this species all sections were combined for annual comparisons. This approach was adopted because fish of this target species population are migratory and use the entire study area (Burrows *et al.* 2000) and the combined data reduced the issue of small sample size. All age-related analyses were restricted to age data from Mountain Whitefish and Arctic Grayling that were not Floy-tagged during previous studies. These fish were excluded from all analyses due to the potential for negative tag effects (Mainstream and Gazey 2009).

Body Condition

Fulton's Condition Index (*K*), which is an index of the relationship between weight and length of fish, was used as a measure of fish health. To minimize potential problems associated with correlations between fish length and body condition (Cone 1989), samples were stratified by age for comparisons. Fulton's Condition Index formula was as follows:

$$\text{Condition } (K) = (Wt/L^3) \times 100{,}000$$

Where *Wt* represents weight (g) and *L* represents fork length (mm).

Length-at-Age and Growth Rate

Length-at-age relationships were described using the average length of each age-class with the von Bertalanffy growth equation (Busacker *et al.* 1990) as follows:

$$L_t = L_\infty \left[1 - e^{\{-K(t-t_0)\}}\right]$$

Where t represents the age of the fish in years from the starting time t_0, maximum length equals L_∞, K represents the growth coefficient, and e is the base of the natural logarithm. Growth curves were generated using Sigmaplot® 8.0.

Convergence was not possible using the von Bertalanffy growth equation for some samples. For these cases, a best-fit regression model was applied. A linear regression best described the age-length relationship of these samples as follows:

$$Y = a + bX$$

Where *Y* = fork length (mm), *a* = fork length intercept, *b* = slope, and *X* = age (years).

Mean length-at-age, growth rate, and the anabolic constant estimate were test variables used for comparisons of growth. The anabolic constant estimate is the product of the von Bertalanffy growth parameter (*K*) and the asymptotic length parameter L_∞ (Gallucci and Quinn 1979). Standard error of the anabolic constant estimate (ω) was calculated as follows:

$$SE\omega = \sqrt{(a^2 + c^2)\times(b^2 + d^2) + (2\times e\times a\times b\times c\times d)}$$

Where SEω is the standard error of the anabolic constant, *a* is *K*, *b* is the standard error of *K*, *c* is L_∞, *d* is the standard error of L_∞, and *e* is the correlation coefficient between *K* and L_∞.

Annual comparisons of length-at-age were undertaken by examining the difference (mm), or change, between the mean length-at-age in the current year and the overall mean length-at-age. This approach was used to accommodate large differences in fish length between age classes. The overall mean length-at-age represented the mean length-at-age of the total sample for that species and age group collected in the standard section. For Bull Trout the estimate was generated using combined data from all sections. Confidence intervals around the difference estimate were generated following procedures described in Sokal and Rohlf (1995).

Mortality

A "catch curve" of annual mortality of sample populations was developed following Ricker (1975). To reduce the effects of random variations in recruitment, data for individual years were combined for all target species. To address small sample size, data for individual years and sections were combined for Bull Trout. The catch curve mortality approach requires the assumption that the population is in a state of equilibrium (Ricker 1975). This assumption was not tested; therefore, the catch curve results represent "crude" estimates of mortality.

An estimate of instantaneous total mortality (*Z*) was first calculated using least squares regression (age versus natural log number) based on the number of fish in fully vulnerable age classes (descending portion of the age distribution) and converted to survival ($S = e^{-Z}$). Annual mortality was presented based on 1-*S*. Confidence intervals (95%) around the annual mortality estimate were calculated using the standard error of *Z* * ($t_{0.05}$, *n*-2), where *n* equaled the number of age classes used to generate *Z,* and then converting the interval value using the same procedure as for *Z*.

2.2.4 Catch Rate

Catch rate was used to provide an index of fish abundance. Catch rate was calculated by dividing the number of fish enumerated by the distance sampled and represented as number of fish per kilometre. For Mountain Whitefish, the number of fish enumerated equaled the number of fish captured. For Arctic Grayling and Bull Trout, the number of fish enumerated equaled the number of fish captured plus the number of fish observed. The rationale for use of this approach is presented in Mainstream and Gazey (2004). For abundant species such as Mountain Whitefish, large observer bias and sampling error negates the benefit of including observed fish in the catch. For less abundant species, such as Arctic Grayling and Bull Trout, observer bias and sampling error is reduced allowing use of the observed data without compromising sampling accuracy or precision.

The approach used for statistical analyses of catch rate data was dependent on the questions asked and the characteristics of the data. Based on findings by P&E (2002), P&E and Gazey (2003) catch rates were stratified by habitat type and section to reduce sample variation, and to address spatial differences in fish abundance. Catch rates for each habitat type were combined for annual comparisons. Section catch rates were calculated by adding individual habitat type estimates.

The standard deviation of the combined estimate was calculated as follows:

$$SDcp = \sqrt{\left(\left(a^2\right) - \left(\left(\left(\left(\left(b^2 + c^2\right) * d\right) + \left(\left(e^2 + f^2\right) * g\right)\right) / \left(d + g\right)\right)\right)\right)}$$

Where *SDcp* is the standard error of the combined estimate, *a* is absolute value of the combined estimate, *b* is the estimate of CPUE A, *c* is the standard error of CPUE A, *d* is the sample size of CPUE A, *e* is the estimate of CPUE B, *f* is the standard error of CPUE B, *g* is the sample size of CPUE B.

The standard error was calculated as the standard deviation of the combined estimate divided by the square root of the combined sample size.

2.2.5 Index of Recruitment

An index of recruitment was developed for young fish of each target species. Age 0 fish were not effectively sampled by boat electrofisher. The next youngest age class that was regularly encountered in the sample was assumed to represent recruitment. The recruitment age classes used for the analyses were Age 1 for Arctic Grayling and Mountain Whitefish and Age 3 for Bull Trout.

The recruitment index (No. of fish/km) was calculated by dividing the total number of young fish recorded in a section by the total sampled length. Totals were used because low numbers of young fish precluded use of the standard approach (i.e., catch per unit effort by site within each section).

All Age 1 Arctic Grayling and Age 3 Bull Trout collected during the program were aged, and therefore, were available for analysis. A random subsample of Mountain Whitefish was aged. The length data collected from the entire sample was converted to age data using the age-length key procedure described in Isely and Grabowski (2007). The age-length key was constructed using the length frequency probability for each age class of the aged sample from each section, which was then applied to the entire sample from that section.

2.2.6 Population Estimates

A mark-recapture program was conducted on Mountain Whitefish, Arctic Grayling, and Bull Trout over the period August 24 to September 24, 2011 (duration of 32 days). Three sections were sampled (Figure 1.1) by six sequential sessions (Table 2.5).

Table 2.5 Sampling dates by section and session and the study days used for the 2011 Peace River Fish Index Project.

Session	Section		
	One	Three	Five
Actual Sampling Dates			
1	26, 27 Aug	24, 25 Aug	29 Aug, 1 Sep
2	2, 3 Sep	4, 5 Sep	8, 9 Sep
3	6, 7 Sep	8, 9 Sep	12, 13 Sep
4	14, 15 Sep	10, 11 Sep	18 Sep
5	19 Sep	20 Sep	21 Sep
6	22 Sep	23 Sep	24 Sep
Mid or Study Day			
1	3.0	1.0	7.0
2	10.0	12.0	16.0
3	14.0	18.0	20.0
4	22.0	24.0	25.5
5	26.5	27.5	28.5
6	29.5	30.5	31.5

In the text that follows frequent reference is made to the terms "capture probability" and "catchability". Capture probability is defined as the probability of detecting (encountering) an individual fish given that it is alive during a sampling event (Otis *et al*. 1978). For application to the population estimation models discussed here, the sampling event is a sampling day or session (1-2 days, see Table 2.5), dependent on the estimation model used. Catchability is defined as the fraction of the population which is caught by a defined unit of fishing effort (Ricker 1975). Note that under these classical definitions the two terms, as used in this report, are not synonymous. For example, if the number of fish sampled is directly related to effort then sampling sessions with different effort levels on the same population may exhibit the same catchability but will have different capture probabilities.

During the first four sessions marks were intensively applied, but during the final two sessions emphasis was placed on searching for the presence of a mark on fish encountered. Marks were not applied to Mountain Whitefish in the final two sessions (Sessions 5 and 6). Overall, the program was highly successful (in terms of the number of marks applied and recaptured) for Mountain Whitefish but much less so for Arctic Grayling and Bull Trout. Therefore, the methodologies described (diagnostics, population estimation, catchability, and sampling power analyses) were comprehensively applied to Mountain Whitefish. For Arctic Grayling and Bull Trout, only the closed population estimation methodology without empirical diagnostics for model selection could be applied because of sparse data.

2.2.6.1 Factors that Impact Population Estimates

The tagging program has some characteristics that must be considered with reference to the population estimation methodology and limitations of the subsequent estimates. First, the capture of fish may be heterogeneous (i.e., some fish are more likely to be caught than others) because of spatial distribution or the reaction of the fish to electrofishing. Second, marks were applied only to fish greater than 250 mm; thus, any estimates are only applicable to that portion of the population. Third, fish can grow over the life of the study such that fish recruit into the portion of the population greater than 250 mm when the study commenced. However, given the short duration of the study, appreciable growth was not expected. Fourth, marked fish can move to sections where capture probability may be different because of possible differences in sample size (sampling effort), catchability, number of available marks for recapture or the population size. Fifth, capture probability within a section can vary over time because of differences in catchability possibly generated by physical-biological interactions (e.g., samples are taken during the day in the upper 2 m).

In order to investigate these characteristics, we first examined the capture behaviour of the marked Mountain Whitefish. Floy tags have been applied from 2002 to 2004 and PIT tags have been applied over the 2004 to 2011 period. For marks applied prior to 2011, the fish had to be caught again in 2011 and the tag recorded to qualify as a mark release. The proportion of marks recaptured in 2011 by tag type (Floy and PIT) and initial year of release were compared (G-test, Sokal and Rohlf, 1969), as well as the time-at-large for the release types. We also compared the frequency of multiple recaptures following Seber (1982). Length histograms of the fish marked and recaptured were examined to reveal selectivity patterns generated by the presence of a mark. These patterns were further evaluated by combining the measured fish into 25 mm length intervals and conducting tests of independence (G-test) for each section. Growth over the period of the present study was examined by regressing the time at large (days) of a recaptured fish on the increment in growth (difference in length measured at release and recapture).

The movement of fish between sections in 2011 and at-large for over a year (marked in 2002 to 2010 and recaptured in 2011) was assessed through weighting the recaptures by sampling intensity. Within each section are 14 to 15 sites, each with a unique river kilometer (kilometers from the mouth) which allowed for the distance traveled up or downstream to be calculated for recaptured fish.

2.2.6.2 Empirical Model Selection

The large number of Mountain Whitefish recaptures allowed for quantitative model selection using POPAN-5 (UFIT module) software for mark-recapture data (Arnason *et al.* 1998). For the purpose of total survival estimates, the time of sampling was assumed to be the mid-point of the actual sampling dates (Table 2.5). Each section was modeled independently with recaptured fish in other sections treated as removals. For all sections (1, 3, and 5), the model selection was for a closed population (no change in population size over the period of the study).

Apparent survival (represents fish that survive and have not left the study area) of Mountain Whitefish over the study period was estimated with the Cormack-Jolly-Seber (CJS) model using MARK software (White 2006). Because only recaptures are tracked, recruitment cannot be estimated; however, unlike other open population models (e.g., Jolly-Seber), the CJS model allows for time varying capture probability. The CJS model was applied to releases made in each section (1, 3, and 5) and subsequent recapture, regardless of location, in all six sessions. To increase the chance of detecting apparent survival < 1.0, survival was assumed to be constant over time and was scaled to the project duration using the time intervals between sessions as defined in Table 2.5.

The large number of recaptures of Mountain Whitefish also allowed an empirical evaluation of homogeneous, heterogeneous, behaviour (first and subsequent capture events estimated separately), and time-varying capture probabilities by employing MARK (closed population capture-recapture models) software (White 2006) to calculate delta Akaike's information criteria (ΔAIC), adjusted to account for the number of parameters, and the associated model likelihood for each of the sections. The model notation follows that of Otis *et al.* (1978), i.e.,

- M_o - no variation in capture probability among individuals or across sampling sessions,
- M_t - each individual has the same capture probability on any given session, but capture probability can vary from one session to the next,
- M_b - behavioural response in capture probability (initial capture and subsequent recapture probabilities are not the same), and
- M_h - heterogeneous capture probability among individuals.

The MARK program requires the encounter history for every fish be known. A violation occurs when captured fish are returned to the river unmarked as occurred in sampling Sessions 5 and 6. The MARK program also assumes that the sampling intensity of sampling sessions are identical in order for the comparison of ΔAIC's to be valid. Therefore, only the first four sampling sessions were used for this exercise and the few fish that were returned to the river unmarked in these sessions were treated as dead in order to approximate the assumptions MARK requires.

The computation of ΔAIC for the constant capture probability model using MARK may be misinterpreted because variation in sample size results in associated variation in the capture probability; however, the underlying catchability of marks may be consistent throughout the season. If the catchability is constant then the probability that an encountered fish is marked at sequence t (p_t) depends only on the proportion of the population that is marked, i.e.,

(1) $$p_t = \frac{M_t}{M_t + U_t} = \frac{M_t}{N} ,$$

where M_t is the cumulative marks applied that are available for recapture at time t, U_t is the number of unmarked fish in the population at time t and N is the population size that is to be estimated. Note that if catchability varies over time but equally for marked and unmarked fish for each sequence t then p_t does not change and still reflects the proportion of the population that is marked. This is the formulation that is used in the Bayes Sequential model presented below. If the catchability of marked and unmarked fish varies over time unequally then the probability that an encountered fish is marked can be characterized as:

(2) $$p_t = \frac{M_t}{N\exp(b_t)} \text{ with the constraint that } \sum_t b_t = 0,$$

and where b_t is the logarithmic population deviation and will provide a better fit to the data. In the remainder of this document all reference to "time varying catchability" is as characterized by Equation (2). It is important to note that Equation (2) is also consistent with a change in population size (population change and time varying catchability are confounded). The log-likelihoods (L) were computed for these models with an assumed binomial sampling distribution, i.e.,

(3) $$L \propto \sum_t \left[R_t \log_e(p_t) + (C_t - R_t)\log_e(1-p_t) \right],$$

where R_t is the number of recovered tags in the sample of C_t fish taken at time t. Parameter estimates, standard deviations and AIC values were calculated through the maximization of Equation (3) using AD Model Builder (ADMB 2009) to implement the model. For these estimates, each sampling day after the first session was used as a sequence (8 days in each river Sections 1 and 3, and 7 days in Section 5, see Table 2.5).

2.2.6.3 Bayes Sequential Model for a Closed Population

A Bayesian mark-recapture model for closed populations (Gazey and Staley 1986, and Gazey 1994) was applied to the mark-recapture data. The Bayesian model was adapted to accommodate adjustments for movement between river sections, allow for stratified capture probabilities and cope with sparse recaptures characteristic of Arctic Grayling and Bull Trout. The major assumptions are:

1. The population size in the study area does not change over the period of the experiment. If mortality occurs then it can be specified independent of the mark-recapture information. Fish can move within the study area (to different sections); however, the movement is fully determined by the history of recaptured marks.
2. All fish in a stratum (day and section), whether marked or unmarked, have the same probability of being caught.
3. Fish do not lose their marks over the period of the study.
4. All marks are reported when the fish are recaptured. If marks are not detected then the rate can be specified independent of mark-recapture information.

The following data needs to be extracted from the mark-recapture database in order to generate population estimates for the Bayes model:

m_{ti} – the number of marks applied in 2011, or marked in a previous year and recaptured in 2011 during day t in section i,

c_{ti} – the number of fish examined for marks during day t in section i,

r_{ti} – the number of recaptures in the sample c_{ti}, and

d_{ti} – the number of fish removed or killed in the recaptures r_{ti}.

A fish had to be greater than or equal to 250 mm to be a member of m_{ti}. A fish was counted as examined (a member of c_{ti}) only if the fish was landed and examined for the presence of a mark and was greater than or equal to 250 mm in length. A fish was counted as a recapture (r_{ti}) only if it was a member of the sample (c_{ti}), was a member of marks applied (m_{ti}) and was recaptured in a session later than the release session. A fish was counted as removed (d_{ti}) if it was not returned to the river or the fish was deemed to be unlikely to survive.

The number of marks available for recapture, adjusted for movement, was determined by first estimating the proportion of marks released in section i moving to section j (p_{ij}). Note by definition:

$$\sum_j p_{ij} = 1.$$

Assuming that the movement of marked fish is determined by the recapture history corrected for the sampling intensity then:

(4) $$\hat{p}_{ij} = \frac{\dfrac{w_{ij}}{\sum_t c_{tj}}}{\sum_j \dfrac{w_{ij}}{\sum_t c_{tj}}}$$

where w_{ij} is the total number of recaptures that were released in section i and captured in section j over the entire study. The maximum number of releases available for recapture during day t in section j (m^*_{tj}) is then:

(5) $$m^*_{tj} = \sum_i \hat{p}_{ij} m_{ti} \, .$$

The usual closed population model assumptions (e.g., Gazey and Staley 1986) may be invalidated by natural mortality, unaccounted fishing mortality, the emigration of fish from the study area, and non-detection of a mark when the fish was sampled. Thus, the number of marks available for recapture at the start of day t in section i (M_{ti}) consists of the releases in each of the sections corrected for removals (mortality and emigration) summed over time, i.e.,

(6) $$M_{ti} = \sum_{v=1}^{t-h} (m^*_{vi} - d_{vi}) \exp\left\{ \frac{v+h-t}{365} Q \right\}$$

where Q is the instantaneous annual rate of removal and h is the number of lags or mixing days (nominally set to three days). The number of fish examined during day t in the i'th region (C_{ti}) does not require correction, i.e.,

(7) $$C_{ti} = c_{ti}$$

The recaptures in the sample, C_{ti}, however, need to be corrected for the proportion of undetected marks (u), i.e.,

(8) $$R_{ti} = (1+u)r_{ti}$$

The corrected marks available, sample and recaptures (Equations 6, 7, and 8) are the input information required by the Gazey and Staley (1986) to form the population estimates.

The estimation of population size was accomplished with a Microsoft Excel© spreadsheet model that consists of macros coded in Visual Basic. The procedure requires the execution of two passes (macros update and estimate). First (execute macro update), the mark-recapture data are assembled by sections under the selection criteria of minimum time-at-large (days) and minimum length (mm) specified by the user. For the second pass (execute macro estimate), the user must specify the sections to be included in the estimate, annual instantaneous mortality rate, the proportion of undetected marks and the confidence interval percentage desired for the output. The model then assembles the adjusted mark-recapture data (Equations 6, 7, and 8) and follows Gazey and Staley (1986) using the replacement model to compute the population estimates. Output includes the posterior distributions, the Bayesian mean, standard deviation, median, mode, symmetric confidence interval, and the highest probability density (HPD) interval.

Population estimates were generated for the three sections using marks applied at a start-date of 24 August 2011, a minimum length of 250 mm, an annual instantaneous removal rate (represents natural mortality, unobserved removals and emigration) of 0.0, and an undetected mark rate of 0%. Annual instantaneous mortality rates of 0.2, 0.4, and 0.6 and undetected mark rates of 1, 3, and 5% were tried in order to reveal the sensitivity of the population estimates to failures in the closed model assumptions. The total population estimate for the study area was obtained by summing the section estimates. The confidence interval for the total study area estimate was calculated invoking a normal distribution under the central limit theorem with a variance equal to the sum of the variances for the sections. For Arctic Grayling and Bull Trout, highly skewed posterior distributions for the population estimates precluded the application of the central limit theorem. Instead, the compound posterior distributions were calculated following Gazey and Staley (1986).

2.2.7 Catchability

One of the key quantities of interest is catchability. If catchability is constant across years and river sections then indices of abundance such as catch rate (No. fish per unit effort, CPUE) are comparable. Handling time to process a fish (e.g., netter dipping, dumping the fish in the hold) can cause systematic bias in the relationship between CPUE and abundance (Hilborn and Walters 1992). Catchability coefficients (the parameter relating an abundance index to the actual abundance, Ricker 1975) were calculated under the assumptions of a closed population and that abundance indices are proportional to the population size. If these assumptions are true then the coefficients should remain constant over study-years and river sections; which is a test of this potential systematic bias.

An estimate for the catchability coefficient for the *i*'th section was calculated following Ricker (1975) as:

(9) $$\hat{q}_i = \frac{\sum_t C_{ti}}{E_i \cdot N_i}$$

where C_{ti} is from Equation (7), E_i is electrofishing effort (measured as hours of electrofishing or distance traveled) and N_i is the Bayes closed population estimate (i.e., no change over the study period) for section *i,* calculated following section 2.2.6.3 above. Given the number of fish sampled and effort data, the variance of catchability coefficient is:

(10) $$Var(\hat{q}_i) = \left(\frac{\sum_t C_{ti}}{E_i} \right)^2 Var\left(\frac{1}{N_i} \right)$$

where the reciprocal of estimated abundance is distributed normally and can be estimated using the following expression (Ricker 1975, p 97):

(11) $$Var\left(\frac{1}{N_i} \right) = \frac{\sum_t R_{ti}}{\left(\sum_t M_{ti} C_{ti} \right)^2}.$$

The catchability coefficient also was examined using catch rate weighted by length of habitat sampled, as described in Section 2.2.4 above. This was undertaken to illustrate application of catch rate as a monitoring tool. The weighted estimate of catch rate was plotted against the population estimate for that section and the relationship quantified using simple linear regression. The slope of the relationship, which represented the catchability coefficient, was then compared to the catchability coefficient estimate generated using the recapture and effort data (see Equation 9).

2.2.8 Effort Needed to Detect Change

In order to explore the precision that may be obtained under alternative sampling intensities, a simple power analysis was conducted on Mountain Whitefish sampled from Section 1 where a consistent program has been performed each year over the 2002 to 2011 period. We assumed that the estimate of the Bayesian mean ($\overline{N}$) was the actual population size and adjusted the data for an altered sampling factor for any sequence as follows:

(12) $$M'_t = \left[1 - \left(1 - \frac{M_t}{\overline{N}}\right)^f\right] \cdot \overline{N}$$

(13) $$C'_t = \left[1 - \left(1 - \frac{C_t}{\overline{N}}\right)^f\right] \cdot \overline{N}$$

(14) $$R'_t = R_t \cdot \frac{M'_t}{M_t} \cdot \frac{C'_t}{C_t}$$

where f is the sampling factor (e.g., $f = 2$ represents a doubling of the sampling effort), M_t is the number of marks applied at the start of the t^{th} sampling sequence, C_t is the total number of fish examined for marks and R_t is the number of recaptured marks. The prime notation represents the data generated for a specified sampling factor. Since the number of fish sampled is small in relation to the population size, a sampling factor of 2 nearly doubles the marks applied and quadruples the recoveries.

For the purposes of this analysis we defined precision to be half of the 80% highest probability density (HPD) expressed as a percentage of the mean. If the posterior distribution was perfectly symmetrical, then our precision definition would equate to the plus/minus 80% confidence interval.

2.2.9 Data Management System and Update Database

Microsoft® Access 2000 was used to enter, check, and store the raw fish and habitat data collected during 2011. This information was used to update the Peace River Fish Index Project database.

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3.0 RESULTS

This section provides a summary of the general characteristics of the fish community and a comparison to previous results, where appropriate. For simplicity the information has been grouped into seven component sections: sampling conditions, fish community characteristics, biological characteristics, catch rate, recruitment, population estimates, and catchability. Appendices B to E present all raw data.

Additional information presented in this section includes examination of Mountain Whitefish age and ageing technique. Appendix F presents all raw data for analyses associated with that task.

3.1 SAMPLING CONDITIONS

Sampling conditions during the field program were examined to ascertain if one or more parameters affected sampling effectiveness. Summaries for selected parameters are presented in this section, and when appropriate, comparisons are made to historical data. Raw data for all measured parameters are presented in Appendix B.

3.1.1 Discharge

Mean daily discharge of the Peace River was high during most of the 2011 field program (Figure 3.1). Mean daily discharge was 1,405 m^3/s with a range of 875 m^3/s to 1,807 m^3/s. Hourly discharge fluctuated widely during each 24 h period on most sampled days. For the majority of the 2011 field program, daily discharge was much higher (approximately 30% higher) than the historical average daily discharge (2001 to 2010)

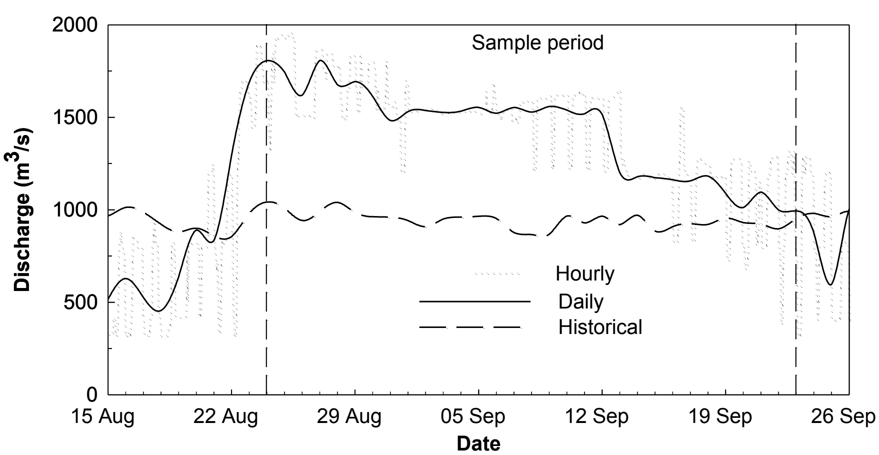

Figure 3.1 Peace River daily and hourly discharge at PCN Dam with comparison to historical average daily discharge recorded from 2001 to 2010, 2011 Peace River Fish Index Project.

There were no large changes in Peace River discharge caused by inputs from the Halfway River and other tributaries. During the field program Halfway River discharge was approximately 30 m^3/s (Water Survey of Canada Station 07FA006) and Moberly River discharge was approximately 2 m^3/s (Water Survey of Canada Station 07FB008).

3.1.2 Water Clarity

Water clarity of the Peace River was moderate to high during the field program (Table 3.1, Figure 3.2). Average daily values ranged from 39 cm to 70 cm at the start of the program, and then continuously increased until values exceeded 200 cm. Average water clarity during field program was highest in Section 1 (173.3 cm) and lowest in Section 3 (138.7 cm). Work by P&E (2002) indicated that water clarity of 50 cm was the threshold at which there was a negative effect on catchability. As such, the overall effectiveness of the fish collection program in 2011 was not affected by low water clarity.

Table 3.1 Water clarity (cm) during the 2011 Peace River Fish Index Project.

Section	Mean (±SE)	Range
1	173.3 ± 6.15	50 – 210
3	138.7 ± 6.42	20 – 210
5	[illegible]	[illegible]

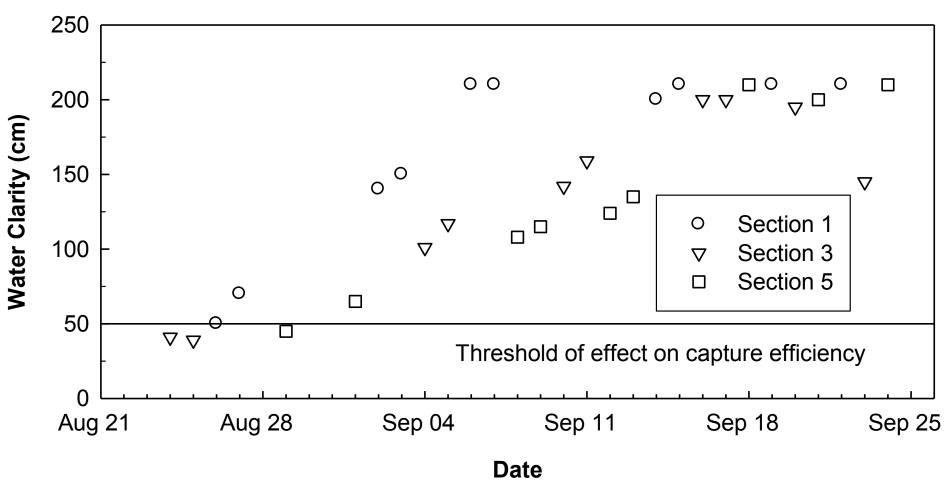

Figure 3.2 Mean daily water clarity in Sections 1, 3, and 5, 2011 Peace River Fish Index Project.

3.1.3 Water Temperature

Water temperatures during the field program ranged from 10.1°C to 13.7°C during the field program (Table 3.2, Figure 3.3). Mean daily water temperature did not differ between sections; however, mean daily water temperature declined during the field program. Water temperatures in each section remained at approximately 12°C from the beginning of the study until 13 September, after which they declined to approximately 10.5°C until the end of the program. Temperatures were well above the 7°C threshold, which is the temperature below which Mountain Whitefish initiate spawning (Northcote and Ennis 1994).

Table 3.2 Water temperature (°C) during the 2011 Peace River Fish Index Project.

Section	Mean (±SE)	Range
1	11.5 ± 0.12	10.1 – 13.2
3	11.6 ± 0.11	10.3 – 13.4
5	11.6 ± 0.12	10.0 – 13.7

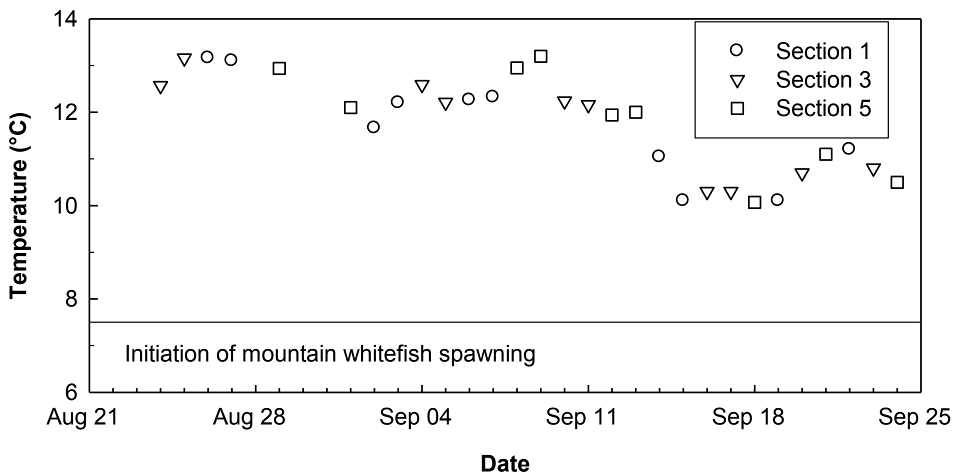

Figure 3.3 Mean daily water temperatures in Sections 1, 3, and 5, 2011 Peace River Fish Index Project.

3.2 GENERAL CHARACTERISTICS OF THE FISH COMMUNITY

In total, 16,152 fish representing 16 species were recorded in 2011 (Table 3.3). The species assemblage included 11 sportfish, 3 suckers, and 2 cyprinids. Mountain Whitefish were very numerous and dominated the sample (14,370 fish; 89.0%). The two other target species were not abundant. In total, 219 Arctic Grayling (1.4%) and 330 Bull Trout (2.0%) were recorded. After Mountain Whitefish, Longnose Sucker was the most prominent species (605 fish; 3.8%). The results for the three target species were generally similar to findings of previous studies. Differences between the present study and previous investigations included the presence of Lake Trout, Lake Whitefish, Yellow Perch, and Flathead Chub, as well as higher numbers of Walleye and Northern Pike.

Table 3.3 Number and percent composition of fish species, 2011 Peace River Fish Index Project.

Family	Common Name	Scientific Name	Number	Percent
Salmonidae	Arctic Grayling	*Thymallus arcticus*	219	1.4
	Bull Trout	*Salvelinus confluentus*	330	2.0
	Kokanee	*Oncorhynchus nerka*	92	0.6
	Lake Trout	*Salvelinus namaycush*	4	<0.1
	Lake Whitefish	*Coregonus clupeaformis*	7	<0.1
	Mountain Whitefish	*Prosopium williamsoni*	14,370	89.0
	Rainbow Trout	*Oncorhynchus mykiss*	278	1.7
Gadidae	Burbot	*Lota lota*	1	<0.1
Esocidae	Northern Pike	*Esox lucius*	19	0.1
Percidae	Walleye	*Sander vitreus*	76	0.5
	Yellow Perch	*Perca flavescens*	1	<0.1
Catostomidae	Largescale Sucker	*Catostomus macrocheilus*	99	0.6
	Longnose Sucker	*Catostomus catostomus*	605	3.8
	White Sucker	*Catostomus commersonii*	29	0.2
Cyprinidae	Flathead Chub	*Platygobio gracilis*	1	<0.1
	Northern Pikeminnow	*Ptychocheilus oregonensis*	21	0.1
Total			**16,152**	**100**

The majority of species (10 of 16) were recorded in all three sections (Table 3.4). Exceptions included less abundant species (i.e., Lake Trout, Burbot, Northern Pike, Walleye, Yellow Perch, and Flathead Chub) that occurred in only one or two sections. These findings were similar to those of previous studies.

Table 3.4 Spatial distribution of fish species, 2011 Peace River Fish Index Project.

Family	Name	Section		
		1	3	5
Salmonidae	Arctic Grayling	●	●	●
	Bull Trout	●	●	●
	Kokanee	●	●	●
	Lake Trout		●	●
	Lake Whitefish	●	●	●
	Mountain Whitefish	●	●	●
	Rainbow Trout	●	●	●
Gadidae	Burbot		●	
Esocidae	Northern Pike		●	●
Percidae	Walleye		●	●
	Yellow Perch			●
Catostomidae	Largescale Sucker	●	●	●
	Longnose Sucker	●	●	●
	White Sucker	●	●	●
Cyprinidae	Flathead Chub			●
	Northern Pikeminnow	●	●	●

3.3 ARCTIC GRAYLING

3.3.1 Biological Characteristics

In total, 157 Arctic Grayling were sampled for biological characteristics. Fork lengths of sampled populations ranged from 146 mm to 405 mm and represented fish Age 1 to Age 5. Numbers of aged Arctic Grayling were as follows – 20 from Section 1, 70 from Section 3, and 45 from Section 5.

<u>Spatial Comparisons</u>

Arctic Grayling sampled from each section exhibited different age and length distributions (Figure 3.4). The small sample in Section 1 was dominated by Age 1 and Age 2 fish (80% of sample). The sample in Section 3 was dominated by Age 2 and Age 3 fish (72% of sample). The sample in Section 5 was dominated by Age 2 fish (51% of sample). No Age 0 fish were recorded during the study.

There was limited difference in Arctic Grayling growth between sections based on von Bertalanffy growth curves (Figure 3.4) and length-at-age (Table 3.5). Asymptotic length ($L\infty$) was 375 mm in Section 1, 351 mm in Section 3, and 383 mm in Section 5.

Table 3.5 Mean length-at-age of sampled Arctic Grayling, 2011 Peace River Fish Index Project.

Age	Section 1		Section 3		Section 5	
	n	Mean Fork Length (± SE)	*n*	Mean Fork Length (± SE)	*n*	Mean Fork Length (± SE)
0						
1	8	177.4 ± 1.49	11	181.8 ± 1.24	9	170.7 ± 2.12
2	8	285.3 ± 2.86	22	285.4 ± 1.92	23	272.6 ± 2.16
3	4	334.3 ± 4.30	29	335.7 ± 0.74	8	324.8 ± 3.51
4			7	317.6 ± 4.09	5	353.4 ± 7.23
5			1	395.0		

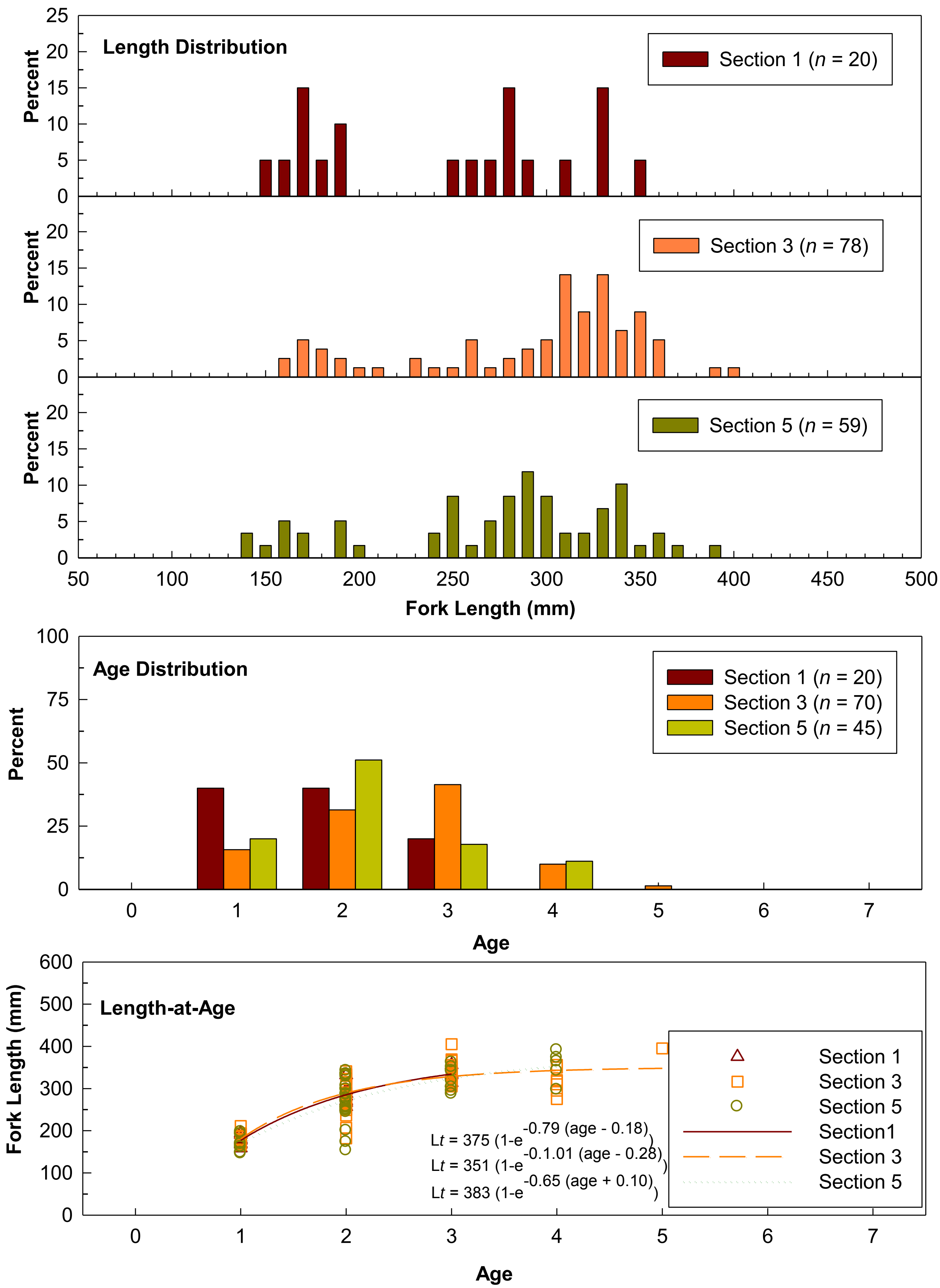

Figure 3.4 Length and age distributions and length-at-age relationships of sampled Arctic Grayling, 2011 Peace River Fish Index Project.

Body condition-at-age of Arctic Grayling was similar among sections (Table 3.6).

Table 3.6 Mean body condition (*K*) of sampled Arctic Grayling, 2011 Peace River Fish Index Project.

Age	Section 1		Section 3		Section 5	
	n	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)
0						
1	6	1.16 ± 0.04	2	1.15 ± 0.07	5	1.15 ± 0.03
2	8	1.21 ± 0.04	13	1.18 ± 0.03	17	1.13 ± 0.02
3	4	1.17 ± 0.04	22	1.23 ± 0.02	6	1.13 ± 0.05
4			6	1.25 ± 0.03	5	1.25 ± 0.08
5						

Annual Comparisons

Annual comparisons are restricted to data from Section 3 and Section 5 due to insufficient data from Section 1. Annual comparisons demonstrate large variation in age class strength, which resulted in variable age (Figure 3.5) and length distributions (Figure 3.6). In Section 3, there has been strong representation by Age 1 fish in 2003, 2006, 2007, and 2009 (> 40% of sample), which resulted in a strong Age 2 class the following year, including 2010. This resulted in strong representation from Age 3 fish in 2011. In Section 5, strong Age 1 representation has been recorded in 2004, 2005, 2009, and 2010; however, 2011 is the first time that this has resulted in a strong Age 2 class the following year.

In both sections, samples collected in most years were dominated by younger (≤ Age 2), smaller (≤ 300 mm fork length) fish. Exceptions to this pattern occurred in Section 3 in 2011 and in Section 5 during 2007 and 2008 when older fish (≥ Age 3) accounted for similar or greater percentage of the sample than younger fish.

Comparisons of Arctic Grayling growth curves (Figure 3.7) and anabolic constants (Figure 3.8) indicated no consistent annual trends in growth. Partitioning growth by age indicated annual differences in growth for all age groups in both Section 3 and Section 5 (Figure 3.9). These results indicated high annual variation in growth without distinct of continuous trends. Some differences were significant based on 95% confidence intervals.

There have been no obvious trends in Arctic Grayling body condition over time in Section 3 and Section 5 (Figure 3.10). It should noted that body condition of all four age classes in Section 3 and Section 5 were the lowest or near lowest values recorded during the index project.

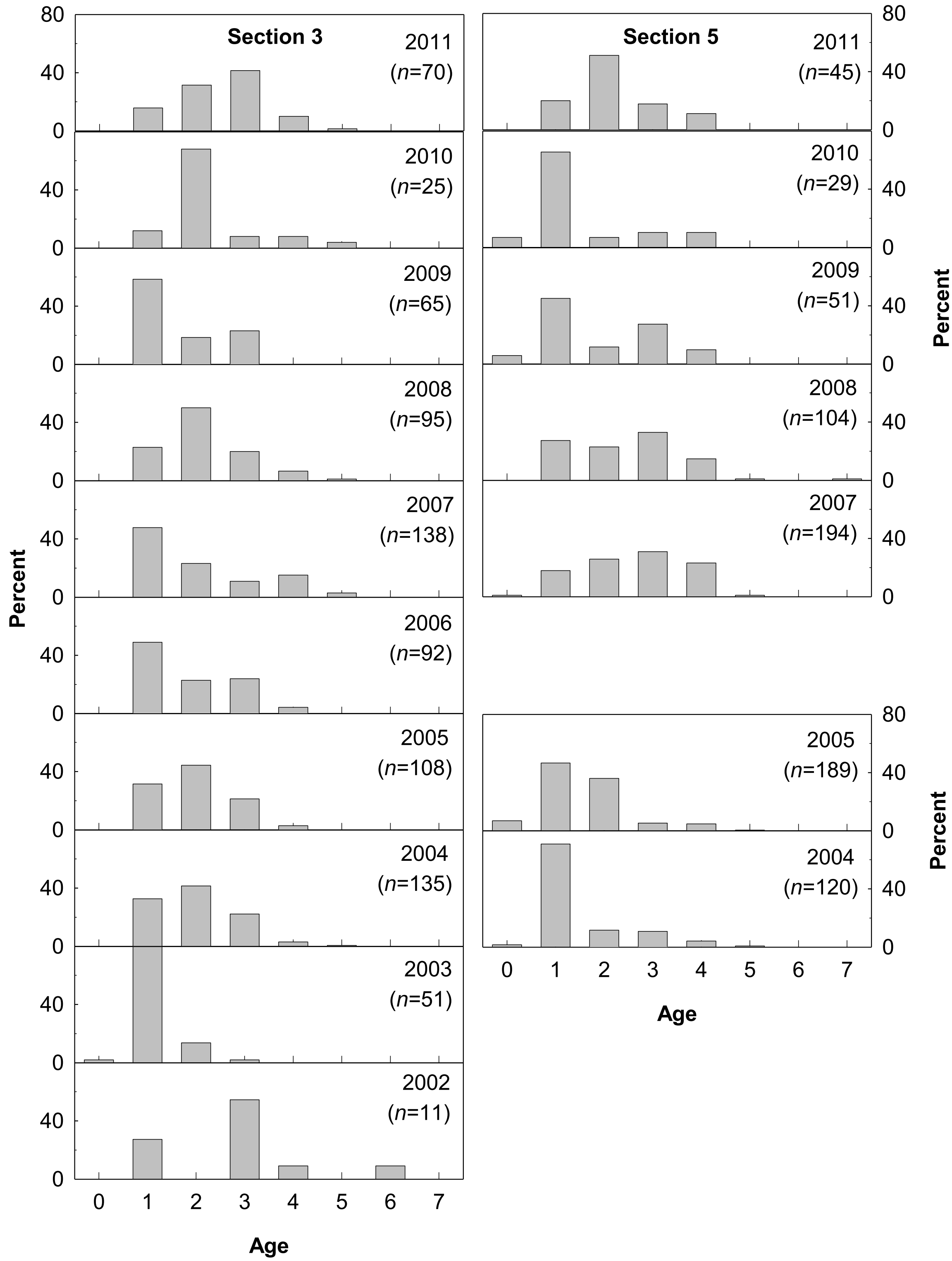

Figure 3.5 Age distributions of Arctic Grayling sampled during the Peace River Fish Index Project, 2002 to 2011.

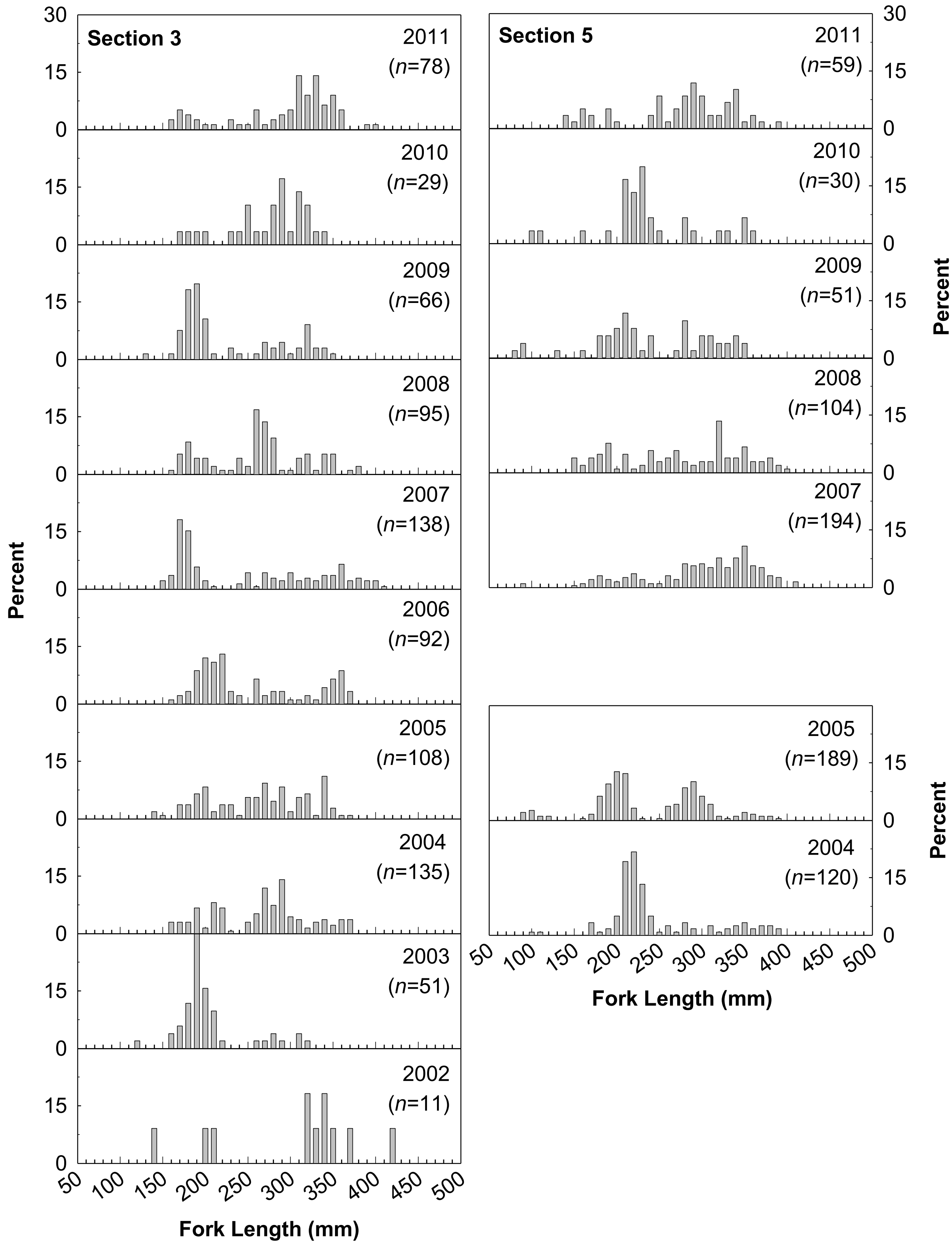

Figure 3.6 Length distributions of Arctic Grayling sampled during the Peace River Fish Index Project, 2002 to 2011.

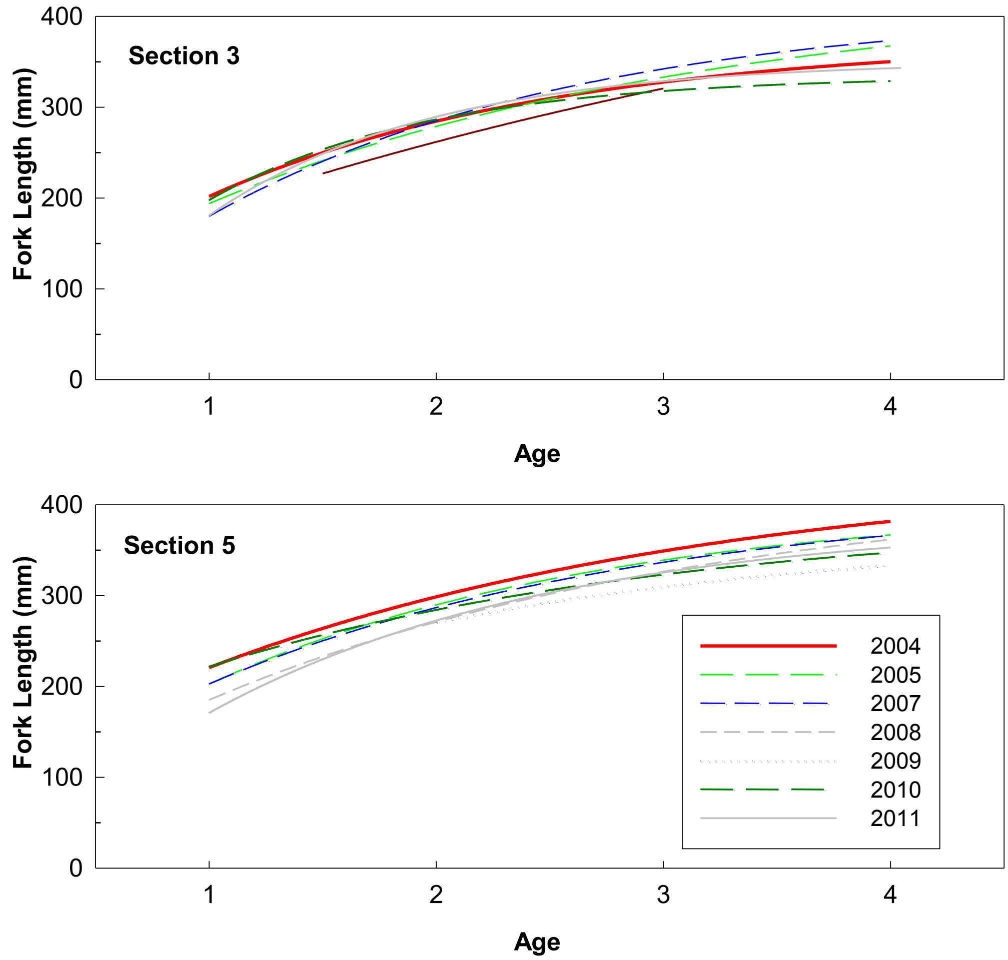

Figure 3.7 Growth curves of Arctic Grayling sampled from the Peace River Fish Index Project, 2004, 2005, 2007, 2008, 2009, 2010, and 2011 (Section 3 data for 2002, 2003, and 2006 omitted due to lack of data or nonconvergence using the von Bertalanffy growth model; analyses

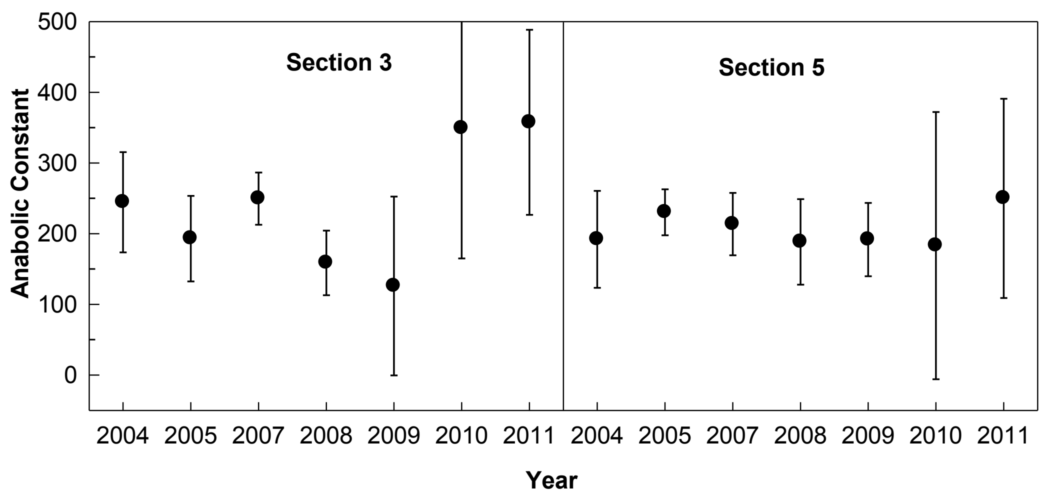

Figure 3.8 Anabolic constants of Arctic Grayling sampled during the Peace River Fish Index Project, 2004, 2005, 2007, 2008, 2009, 2010, and 2011 (data for Age 1 to Age 4; vertical lines represent 95% confidence intervals).

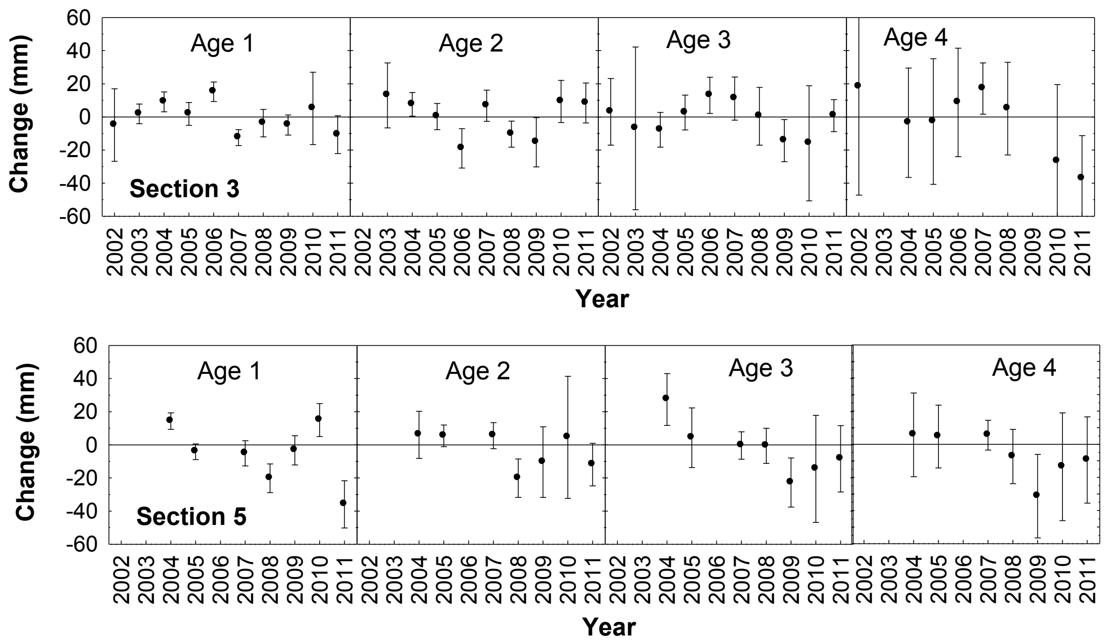

Figure 3.9 Change in mean length-at-age of Arctic Grayling sampled during the Peace River Fish Index Project, 2002 to 2011 (change defined as difference between annual estimate and estimate for entire sample; vertical lines are 95% confidence intervals).

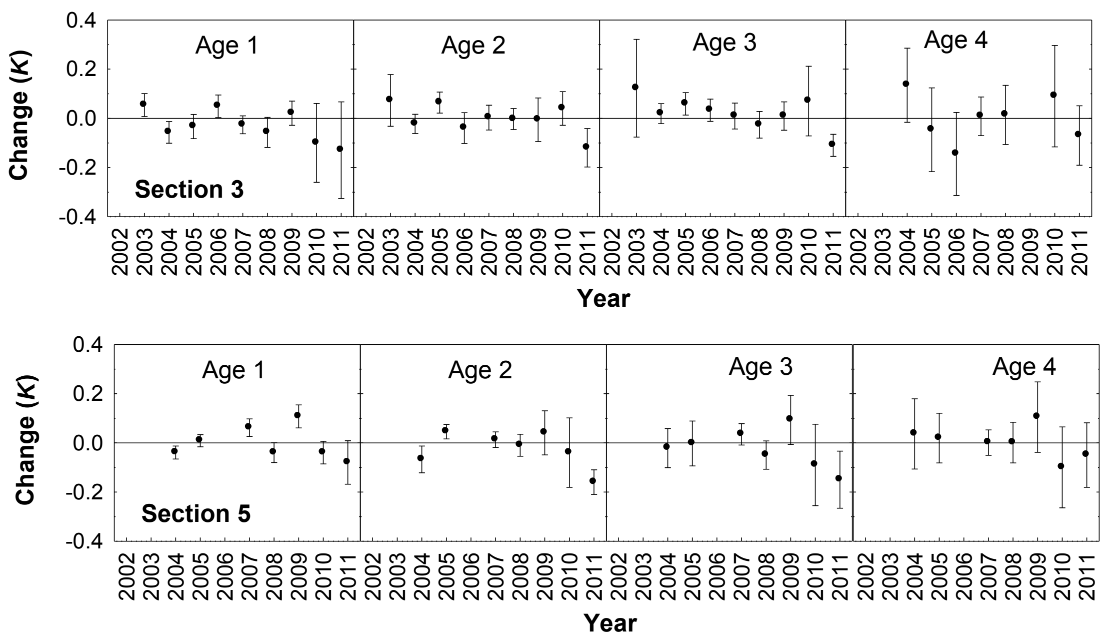

Figure 3.10 Change in mean body condition-at-age of Arctic Grayling sampled during the Peace River Fish Index Project, 2002 to 2011 (vertical lines are 95% confidence intervals).

Mortality

Inspection of catch curves for Arctic Grayling (all years combined) indicated that the fish become fully

long

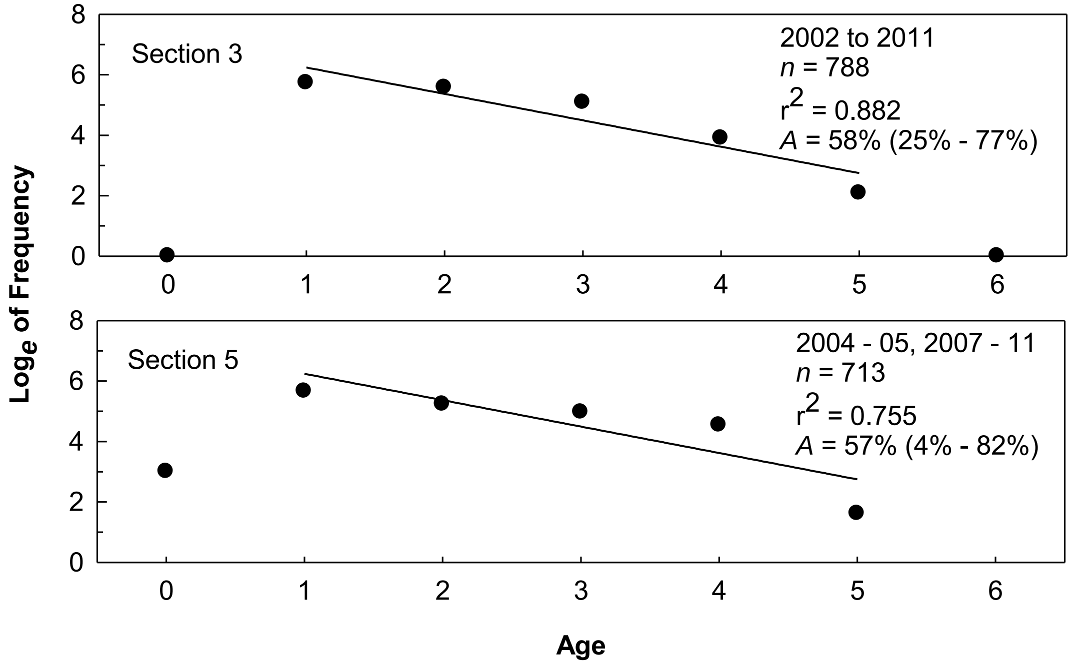

Figure 3.11 Catch curve annual mortality of Arctic Grayling sampled during the Peace River Fish Index Project (combined data from 2002 to 2011; percentages in brackets represent 95% confidence intervals).

3.3.2 Catch Rate

Spatial Comparisons

Catch rates of Arctic Grayling in 2011 were < 1.5 fish/km (Figure 3.12). Catch rates differed by section and habitat, as has been established by previous fish index studies. Arctic Grayling were scarce in Section 1, and were more numerous in Section 3 and Section 5. In Section 3 catch rates were higher in SFC habitat (1.27 fish/km) compared to SFN habitat (0.74 fish/km). In Section 5 catch rates were lower in SFC habitat (0.70 fish/km) compared to SFN habitat (1.14 fish/km).

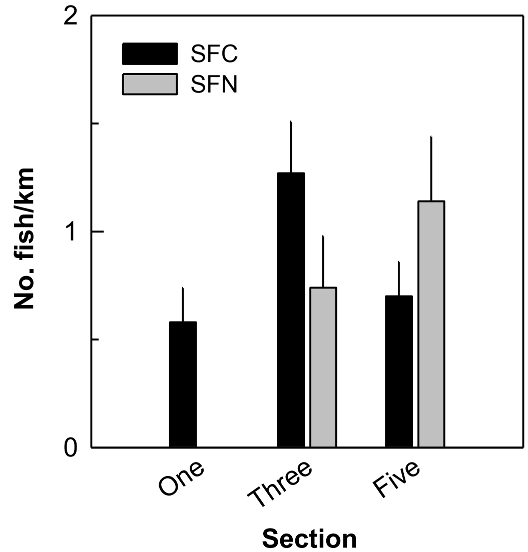

Figure 3.12 Mean catch rates of Arctic Grayling stratified by section and habitat type, 2011 Peace River Fish Index Project (vertical lines represent standard error; see Table 2.1 for sample sizes and Table 2.2 for definitions of habitat type).

Annual Comparisons

Arctic Grayling catch rates exhibited large annual variability within Section 3 and Section 5; annual catch rates were consistently very low in Section 1 (Figure 3.13). In Section 3, catch rates varied from a low of 0.15 fish/km in 2002 to a high of 2.12 fish/km in 2007. Peaks in abundance were recorded in 2004 and 2007, followed by subsequent declines. The average catch rate in 2011 (1.04 fish/km) represents a reversal of the declining trend that started in 2008. In Section 5, Arctic Grayling annual catch rates were also highly variable (range of 0.79 fish/km to 4.64 fish/km). Section 5 was not sampled during all years, but the pattern of annual abundance is generally similar to Section 3. The average catch rate in 2011 (0.9

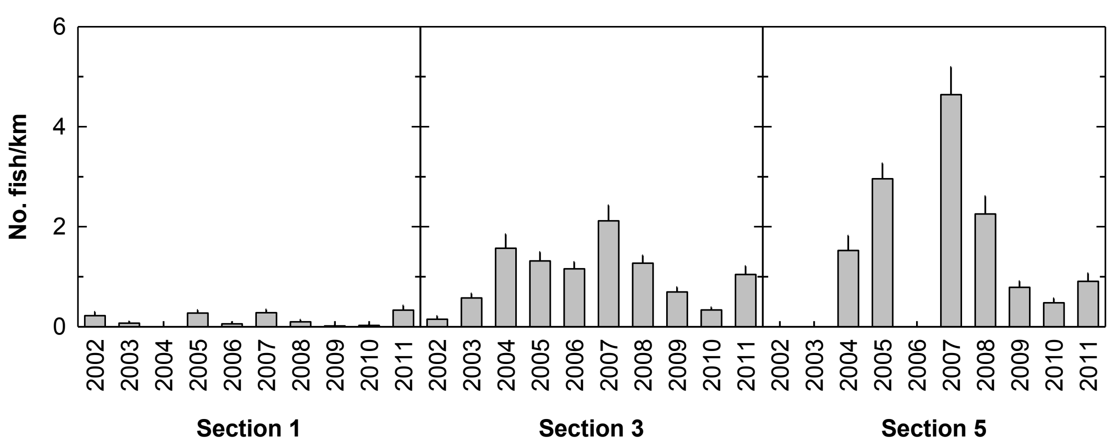

Figure 3.13 Mean catch rates of Arctic Grayling during the Peace River Fish Index Project, 2002 to 2011 (based on combined weighted means and standard errors for SFC and SFN habitats; vertical lines represent standard errors; Section 5 not sampled in 2002, 2003, and 2006).

3.3.3 Recruitment

Until 2011 the contribution of Age 1 Arctic Grayling has been zero in Section 1 until 2011 (Figure 3.14). Age 1 Arctic Grayling were recorded in Section 1. In Sections 3 and 5, Age 1 Arctic Grayling were recorded during all years of study, but annual recruitment has varied within each section. In Section 3 before 2011, the Arctic Grayling recruitment index ranged from a high of 2.86 fish/km in 2007 to a low of 0.13 fish/km in 2010. The recruitment index in 2011 (0.59 fish/km) represents an increase. With the exception of 2002, 2008, 2010, and 2011 recruitment ranged from 1.65 fish/km to 2.30 fish/km. In Section 5, Arctic Grayling annual recruitment was more variable. Recruitment values were high in 2004

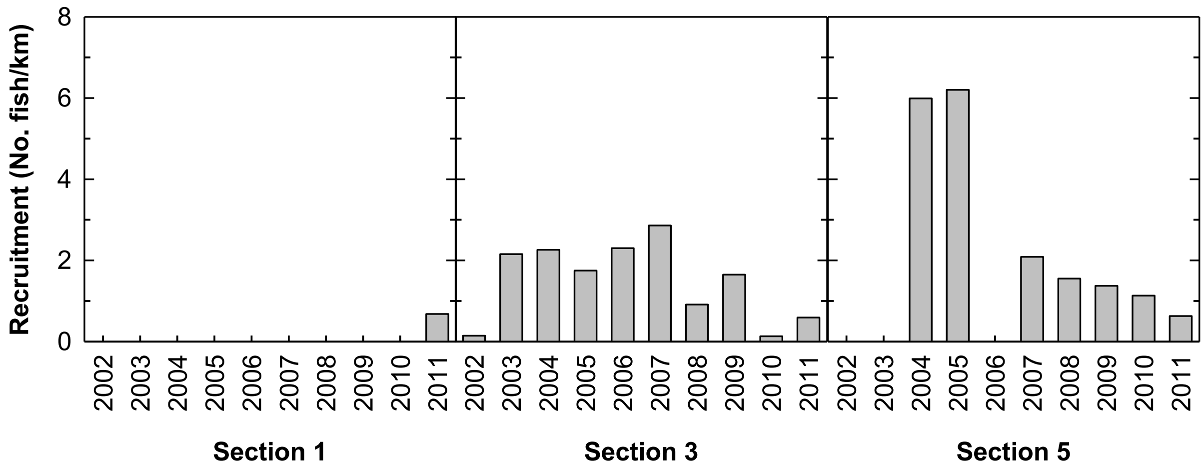

Figure 3.14 Recruitment indices of Age 1 Arctic Grayling during the Peace River Fish Index Project, 2002 to 2011 (Section 5 not sampled in 2002, 2003, and 2006).

3.4 BULL TROUT

3.4.1 Biological Characteristics

In total, 227 Bull Trout were sampled for biological characteristics. Fork lengths of sampled populations ranged from 187 mm to 866 mm and represented fish Age 2 to Age 14. Numbers of aged Bull Trout were as follows – 33 from Section 1, 111 from Section 3, and 56 from Section 5.

Spatial Comparisons

Length and age distributions of Bull Trout were generally similar among sections (Figure 3.15). No fish younger than Age 2 were encountered in any section and subadult fish (estimated as Ages 2 and 5) dominated in all sections (≥ 50% of each sample). Adult Bull Trout (estimated as ≥ Age 6) also were present in each section.

The von Bertalanffy growth equation could not be applied to the Bull Trout sample in any section due to non-convergence of growth curves, which was likely caused by the paucity of older fish. As such, linear regression was used to describe Bull Trout growth (Figure 3.15). These growth curves and length-at-age data from Table 3.7 indicated that subadult fish in all three sections grow at a similar rate (approximately 75 mm per year).

Spatial differences in sample populations were not apparent from mean length-at-age (Table 3.7) and mean body condition-at-age (Table 3.8).

Annual Comparisons

Age and length distributions of the combined sample (Sections 1, 3, and 5) remained stable across years (Figure 3.16 and Figure 3.17, respectively). In all years Age 0 and Age 1 fish were largely absent. Age distributions were dominated by subadults (Age 2 to Age 5) and adult fish (≥ Age 6) were poorly represented. An important caveat should be placed on these results, which is the absence of adult fish from the index sections, likely caused by use of tributaries for spawning during the study period. Therefore, the results do not reflect the actual age structure of Bull Trout that inhabit the Peace River.

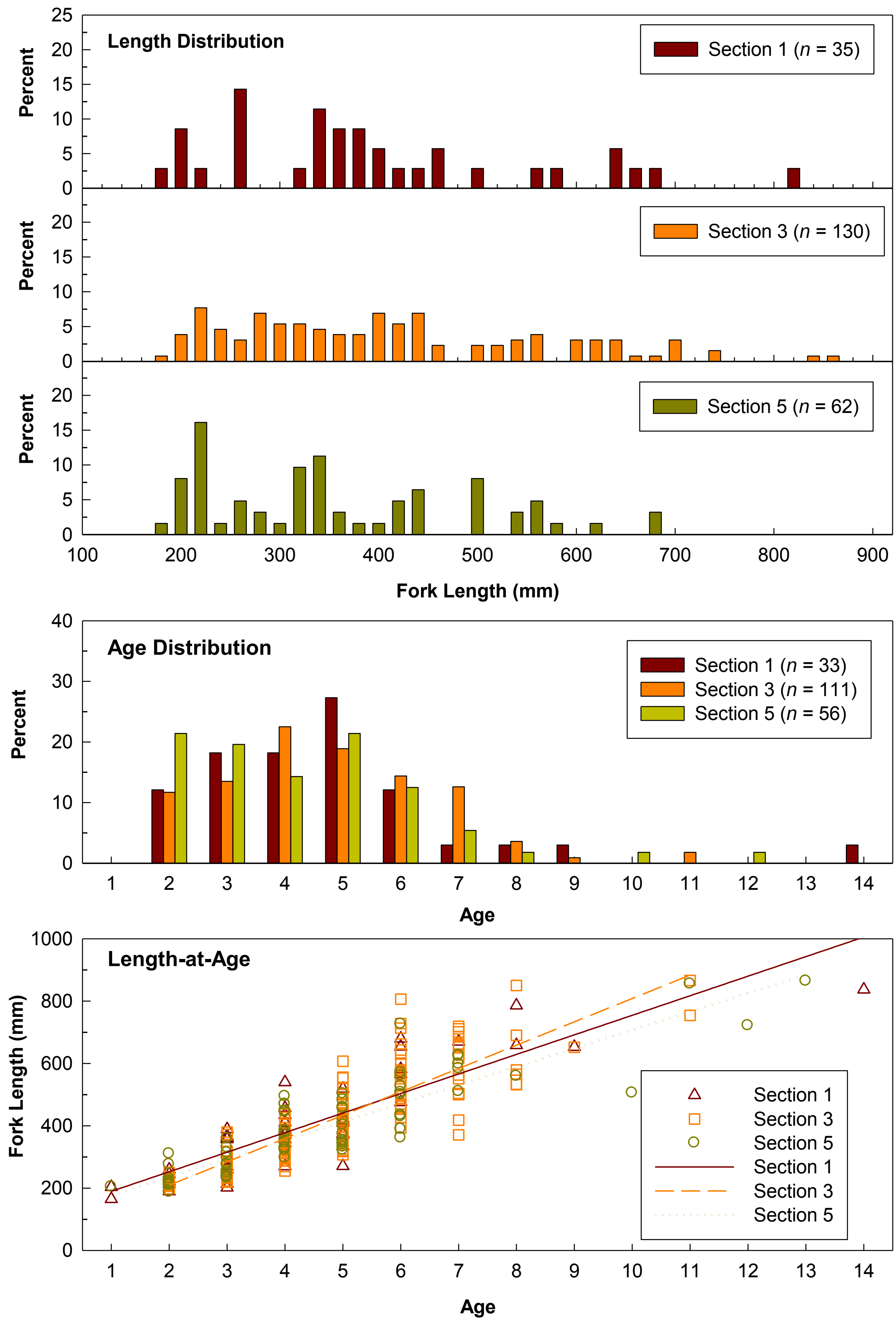

Figure 3.15 Length and age distributions and length-at-age relationships of sampled Bull Trout, 2011 Peace River Fish Index Project.

Table 3.7 Mean length-at-age of sampled Bull Trout, 2011 Peace River Fish Index Project.

Age	Section 1		Section 3		Section 5	
	n	Mean Fork Length (± SE)	*n*	Mean Fork Length (± SE)	*n*	Mean Fork Length (± SE)
0						
1						
2	4	222.8 ± 7.34	13	222.8 ± 1.12	12	229.0 ± 2.73
3	6	276.8 ± 11.32	15	272.5 ± 3.32	11	260.3 ± 3.60
4	6	366.2 ± 10.21	25	334.0 ± 2.01	8	358.5 ± 7.06
5	9	388.1 ± 7.54	21	410.5 ± 3.56	12	388.0 ± 4.93
6	4	576.0 ± 20.89	16	532.0 ± 5.23	7	464.4 ± 11.79
7	1	670.0	14	607.4 ± 7.75	3	577.3 ± 19.91
8	1	659.0	4	623.5 ± 38.15	1	559.0
9	1	653.0	1	652.0		
10					1	505.0
11			2	810.0 ± 39.60		
12					1	721.0
13						
14	1	837.0				
15						

Table 3.8 Mean body condition (*K*) of sampled Bull Trout, 2011 Peace River Fish Index Project.

Age	Section 1		Section 3		Section 5	
	n	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)
0						
1						
2	2	1.03 ± 0.05	6	1.04 ± 0.03	5	0.98 ± 0.04
3	5	1.14 ± 0.03	10	1.01 ± 0.03	4	1.07 ± 0.05
4	4	1.12 ± 0.07	16	0.97 ± 0.01	8	0.94 ± 0.02
5	7	1.11 ± 0.02	15	0.99 ± 0.02	8	0.92 ± 0.03
6	3	1.01 ± 0.01	13	1.04 ± 0.04	6	0.95 ± 0.01
7	1	1.21	11	1.06 ± 0.05	1	0.89
8			1	1.10		
9	1	1.37	1	1.08		
10						
11			2	1.03 ± 0.07		
12					1	0.89
13						
14	1	1.08				
15						

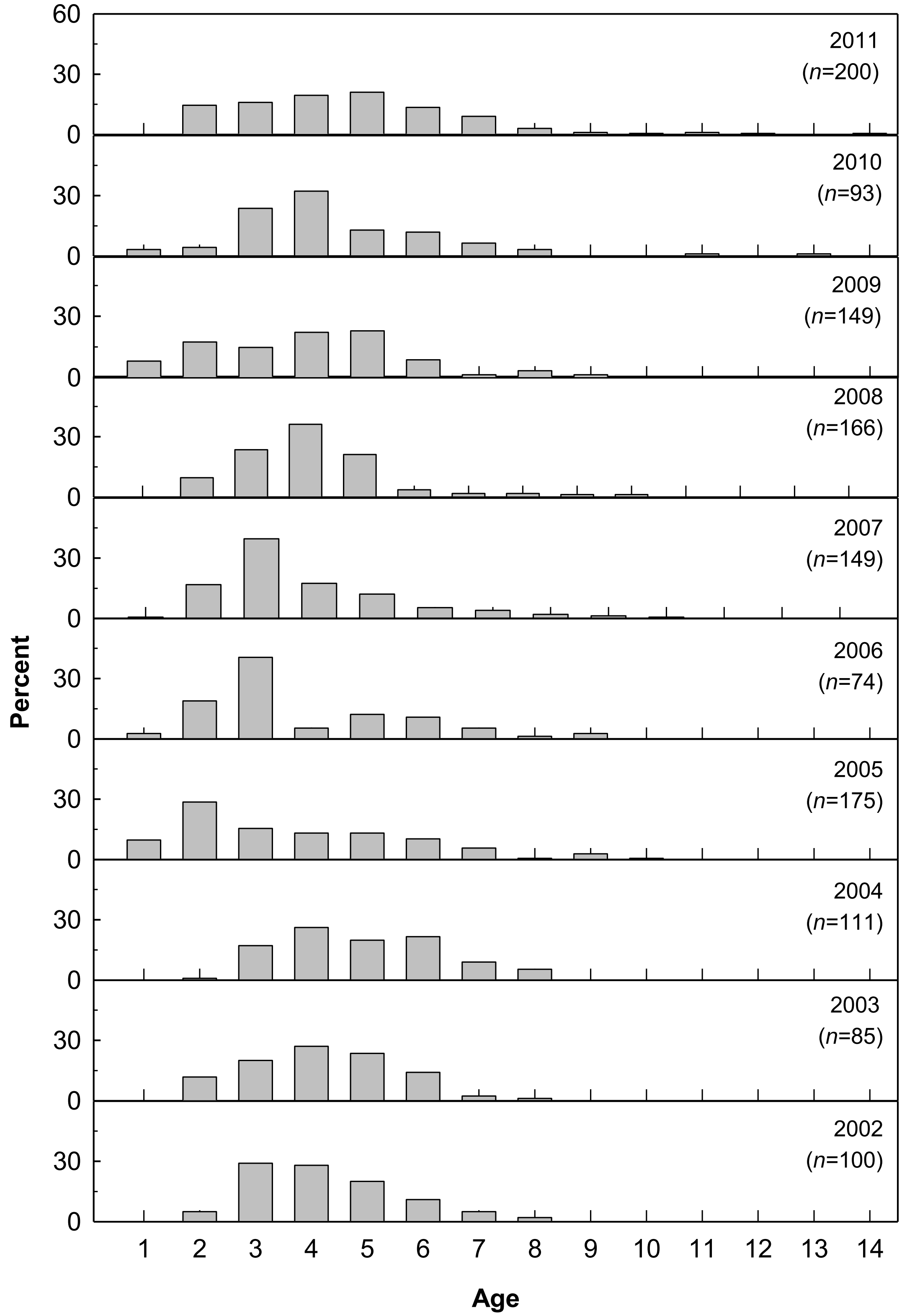

Figure 3.16 Age distributions of Bull Trout sampled during the Peace River Fish Index Project, 2002 to 2011 (data for all sections combined).

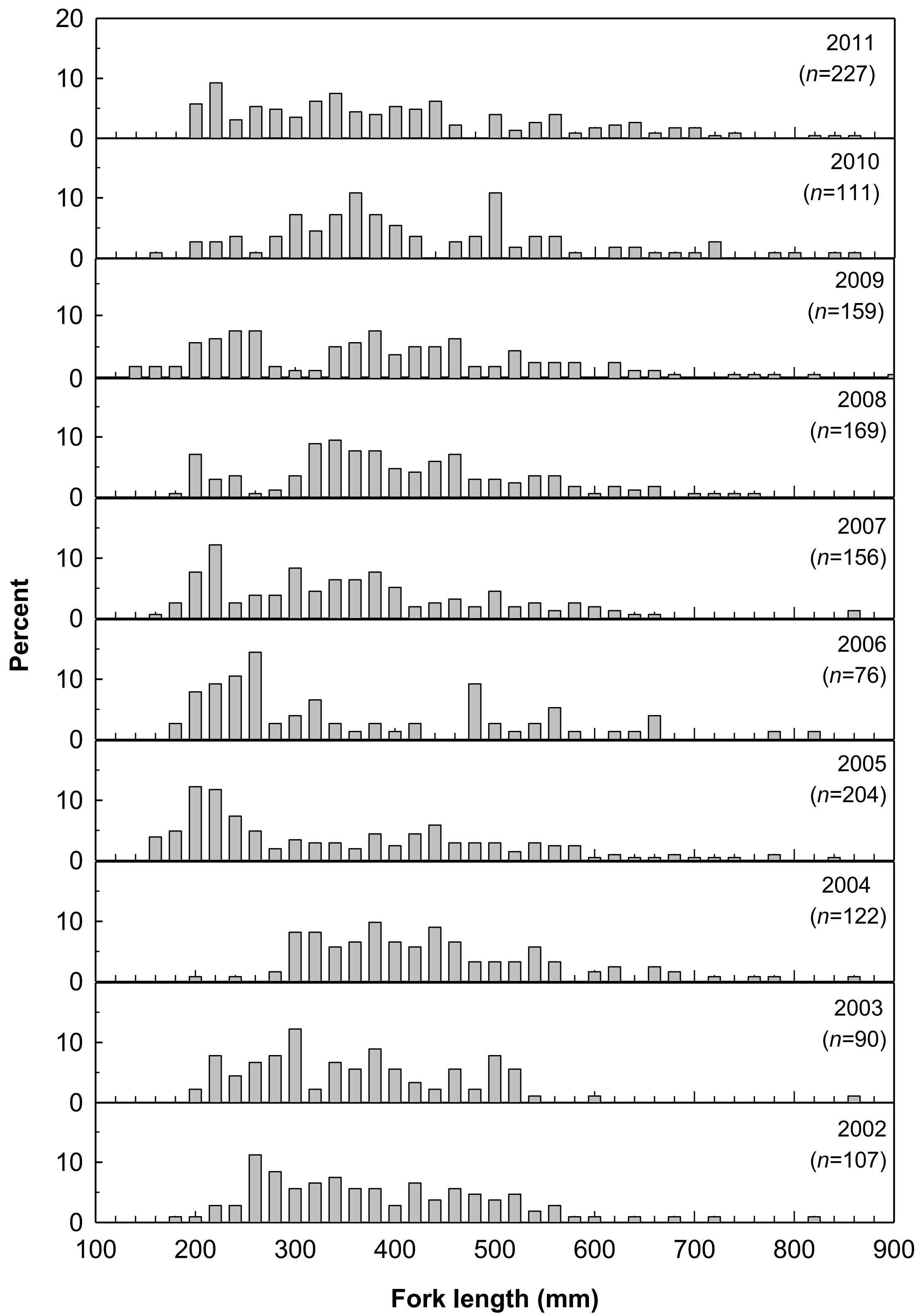

Figure 3.17 Length distributions of Bull Trout sampled during the Peace River Fish Index Project, 2002 to 2011 (data for all sections combined).

Annual differences in growth were not examined using the von Bertalanffy growth model. However, annual growth rates of subadult fish (Ages 2 to 6) could be compared using the length-age slopes (Figure 3.18). Annual growth of subadult fish was approximately 75 mm per year. There was variation around this [illegible] nost years.

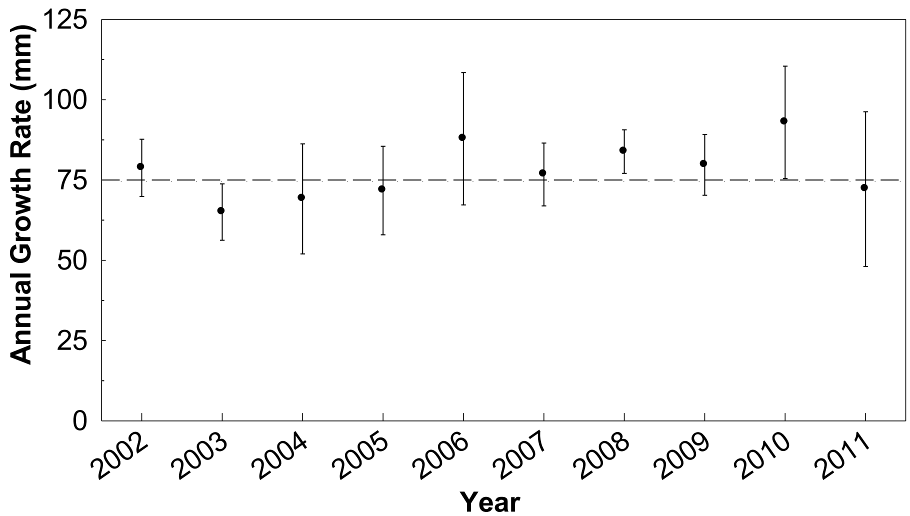

Figure 3.18 Growth rates of Bull Trout sampled during the Peace River Fish Index Project, 2002 to 2011 (analyses based on mean length-at-age; restricted to subadults [Age 2 to Age 6]; data from all sections combined).

Partitioning the results by age also indicated no substantive changes in length at age over time (Figure 3.19). No annual changes in body condition were apparent from the data (Figure 3.20).

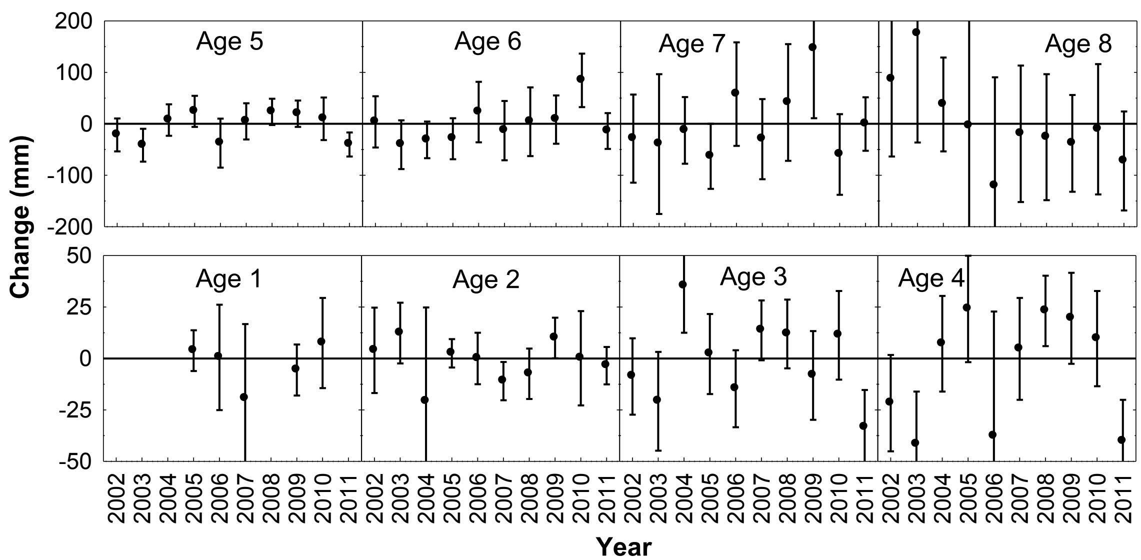

Figure 3.19 Change in mean length-at-age of Bull Trout sampled during the Peace River Fish Index Project, 2002 to 2011 (data from all sections combined; lines are 95% confidence intervals).

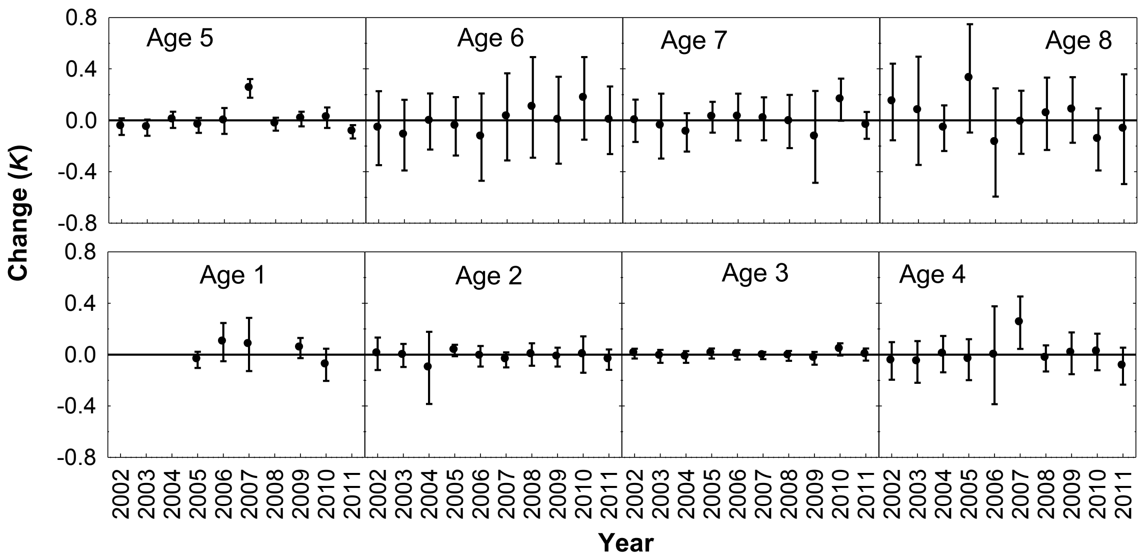

Figure 3.20 Mean body condition-at-age of Bull Trout sampled during the Peace River Fish Index Project, 2002 to 2011 (all sections combined; lines are 95% confidence intervals).

Mortality

Inspection of the catch curve for Bull Trout (all years and sections combined) indicates that the fish become fully vulnerable at Age 3 (Figure 3.21). The apparent annual mortality was 42%. As for the population age structure, the results should be interpreted with caution because of the scarcity of adult fish during the study period.

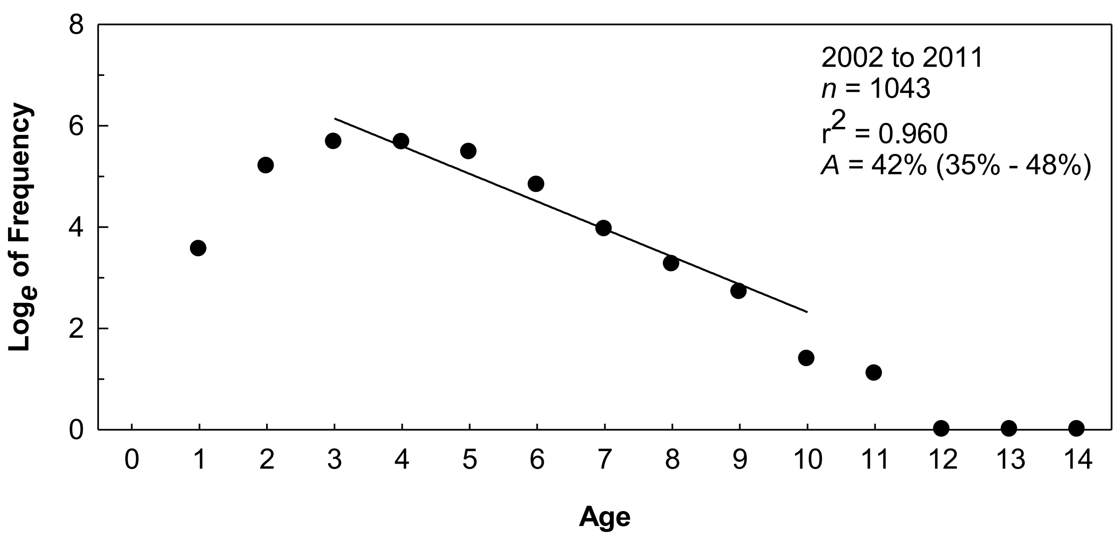

Figure 3.21 Catch curve annual mortality of Bull Trout sampled during the Peace River Fish Index Project (combined data from 2002 to 2011; percentages in brackets represent 95% confidence intervals).

3.4.2 Catch Rate

Spatial Comparisons

Bull Trout mean catch rates were low in Section 1 and Section 5 (≤ 1.00 fish/km) (Figure 3.22). Catch rates were higher in Section 3 (> 1.50 fish/km). Bull Trout catch rates were higher in SFC compared to SFN habitat types in Section 1 and Section 5, but in Section 3 catch rates were higher in the SFN habitat type compared to the SFC ha

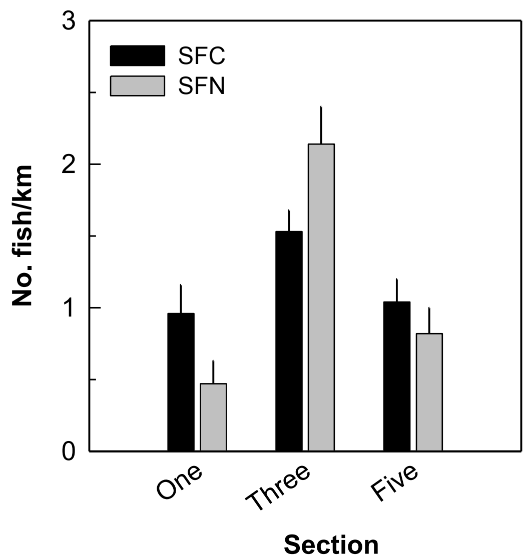

Figure 3.22 Mean catch rates of Bull Trout stratified by section and habitat type, 2011 Peace River Fish Index Project (vertical lines represent standard error; see Table 2.1 for sample sizes and Table 2.2 for definitions of habitat type).

Annual Comparisons

Bull Trout catch rates have been consistently below < 2.00 fish/km in all sections during all sample years (Fig

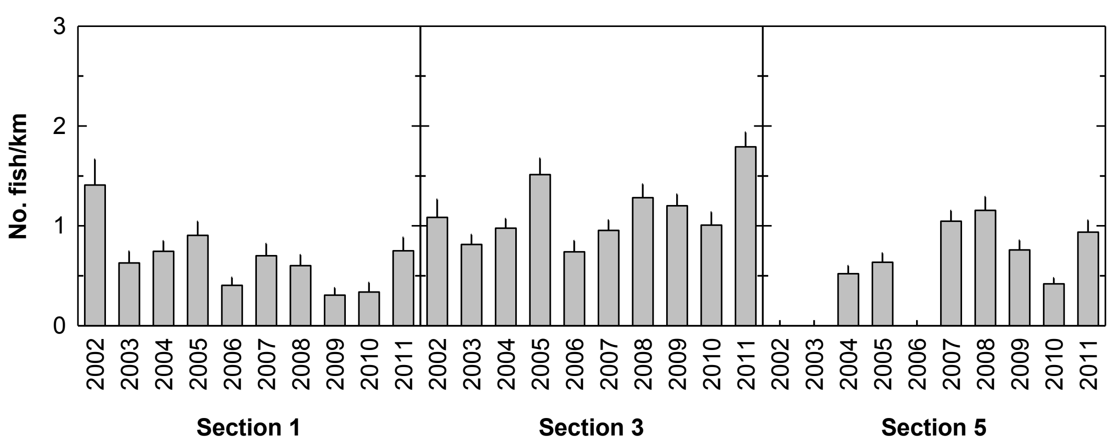

Figure 3.23 Mean catch rates of Bull Trout during the Peace River Fish Index Project, 2002 to 2011 (based on combined weighted means and standard errors for SFC and SFN habitats; vertical lines represent standard errors; Section 5 not sampled in 2002, 2003, and 2006).

3.4.3 Recruitment

Age 3 Bull Trout were recorded in each section during all years of the study when sampling occurred, but the recruitment index was at or below 1.5 fish/km (Figure 3.24). Recruitment of this age class has varied annually in Sections 1 and 5, but has been relatively stable in Section 3. The annual trend of Bull Trout recruitment is consistent among sections. The recruitment index gradually increased from 2004 to 2007,

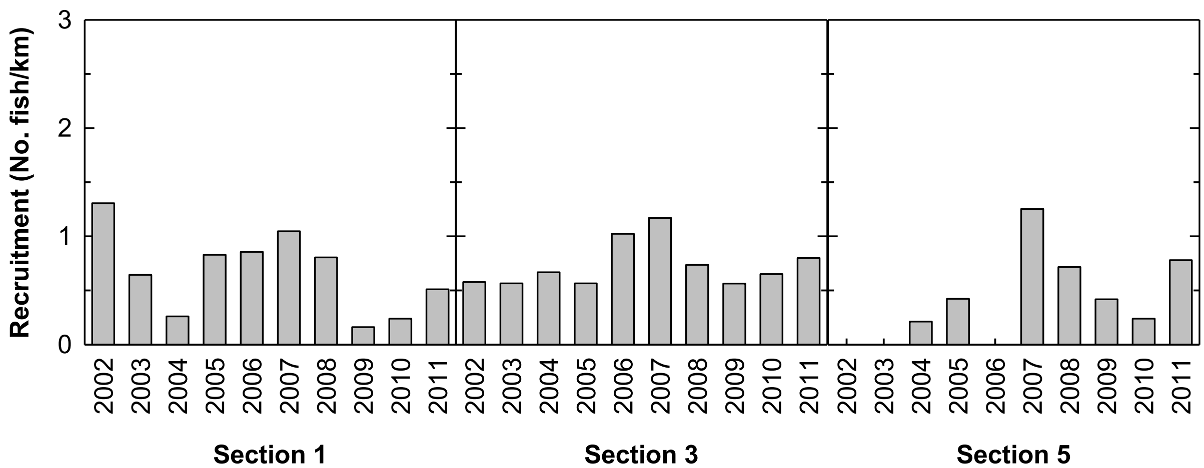

Figure 3.24 Recruitment index of Age 3 Bull Trout in Sections 1, 3, and 5 during the Peace River Fish Index Project, 2002 to 2011 (see Section 2.2.5 for definition of age groups; Section 5 not sampled in 2002, 2003, and 2006).

3.5 MOUNTAIN WHITEFISH

3.5.1 Biological Characteristics

In total, 10,673 Mountain Whitefish fish were available for analyses. Fork lengths ranged from 75 mm to 525 mm with ages ranging from Age 1 to Age 12. A random sample of 578 Mountain Whitefish was aged for biological characteristics analyses (5.4% of the total). Numbers of aged Mountain Whitefish were as follows – 204 from Section 1, 206 from Section 3, and 168 from Section 5

Spatial Comparisons

A comparison of length and age distributions of Mountain Whitefish indicated that there were spatial differences in sampled populations (Figure 3.25). All three samples exhibited a truncated length distribution with a large modal peak. The mode peak shifted by section -- 290 mm in Section 1, 320 in Section 3, and 340 in Section 5. A smaller secondary modal peak was also recorded in each section, and this peak also exhibited a shift (200 mm in Section 1 to 240 in Section 5). This pattern was not demonstrated by the age distribution. Age 4 to Age 6 fish dominated in each section (42% to 54% of sample), Younger and older fish accounted for the remainder of the sample in each section.

The inconsistency between the length and age distribution samples (i.e., the lack of a shift towards older fish in Sections 3 and 5) may have been due to the higher growth rate of older fish recorded in Sections 3 and 5 compared to Section 1 (Figure 3.25; Table 3.9). Visual examination of growth curves and length-at-age results suggested spatial differences in growth. Younger fish (≤ Age 4) tended to be larger in Section 1 compared to those in Sections 3 and 5, and the reverse was true for older fish. Differences in length-at-age suggest a lower growth rate of sampled Mountain Whitefish in Section 1 compared to Sections 3 and 5. This pattern was similar to results recorded during previous studies.

Table 3.9 Mean length-at-age of sampled Mountain Whitefish, 2011 Peace River Fish Index Project.

Age	**Section 1**		**Section 3**		**Section 5**	
	n	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**
0						
1	3	172.0 ± 8.35	4	152.5 ± 3.64	6	135.5 ± 1.29
2	25	211.2 ± 0.71	18	216.8 ± 1.15	15	216.8 ± 1.78
3	21	254.9 ± 0.55	16	249.4 ± 0.54	20	249.3 ± 0.96
4	62	284.1 ± 0.22	75	277.4 ± 0.19	36	278.8 ± 0.28
5	42	306.6 ± 0.35	37	295.2 ± 0.56	35	302.9 ± 0.53
6	17	315.5 ± 1.19	21	321.0 ± 0.97	18	330.0 ± 0.82
7	12	333.3 ± 1.35	9	354.2 ± 2.52	20	353.5 ± 1.31
8	15	356.0 ± 1.74	15	365.5 ± 1.36	7	397.3 ± 2.66
9	4	352.0 ± 2.01	5	389.0 ± 5.75	6	404.0 ± 6.41
10	1	370.0	3	407.0 ± 2.33	4	425.8 ± 1.71
11	1	427.0	3	446.3 ± 10.60	1	480.0
12	1	421.0				
13						
14						
15						

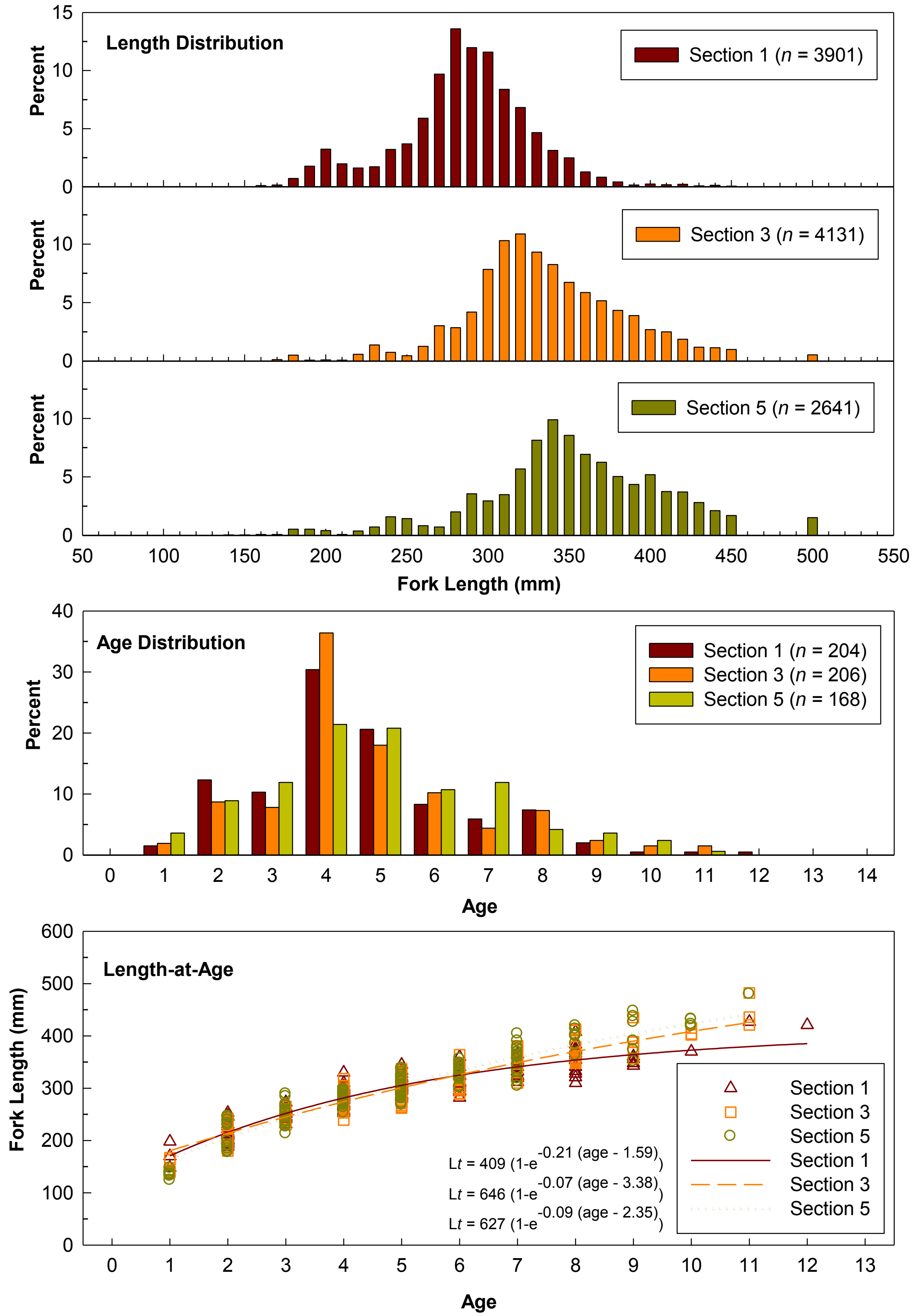

Figure 3.25 Length and age distributions and length-at-age relationships of sampled Mountain Whitefish, 2011 Peace River Fish Index Project.

The body condition-at-age results did not suggest large spatial differences in growth (Table 3.10).

Table 3.10 Mean body condition (*K*) of sampled Mountain Whitefish, 2011 Peace River Fish Index Project.

Age	Section 1		Section 3		Section 5	
	n	**Mean Body Condition (± SE)**	***n***	**Mean Body Condition (± SE)**	***n***	**Mean Body Condition (± SE)**
0						
1	2	1.04 ± 0.07	3	1.07 ± 0.03	6	0.95 ± 0.06
2	23	1.05 ± 0.01	17	1.05 ± 0.02	15	0.98 ± 0.02
3	19	1.10 ± 0.02	15	1.02 ± 0.02	18	1.08 ± 0.01
4	59	1.08 ± 0.01	74	1.04 ± 0.01	25	1.06 ± 0.02
5	42	1.05 ± 0.02	35	1.03 ± 0.01	26	1.06 ± 0.01
6	17	1.06 ± 0.03	20	1.00 ± 0.01	14	1.02 ± 0.02
7	12	1.11 ± 0.02	9	0.98± 0.02	17	1.01 ± 0.02
8	14	1.08 ± 0.03	14	1.00 ± 0.02	5	0.99 ± 0.04
9	3	1.09 ± 0.08	4	0.94 ± 0.06	3	0.93 ± 0.02
10	1	0.99	3	0.94 ± 0.03	3	1.04 ± 0.11
11	1	1.11	3	0.98 ± 0.06	1	0.94
12	1	0.95				
13						
14						
15						

<u>Annual Comparisons</u>

Age and length distributions within each section generally remained stable between 2002 and 2011 (Figure 3.26 and 3.27). Section 1 age and length distributions were primarily unimodal and exhibited weak contributions of younger fish (≤ Age 1) and rapid declines in the percentage of fish older than Age 7. Younger (Age 1 and Age 2) and older fish (≥ Age 7) were better represented in length and age distributions of Sections 3 and 5. Large changes in age and length distributions have been recorded during the program; however, the 2010 and 2011 data were unique. In 2010 substantial contribution of Age 1 Mountain Whitefish was recorded in in Section 1 (approximately 10% of the sample). In 2011, age and length distributions of Mountain Whitefish in Sections 3 and 5 were similar to those recorded in Section 1. This included a pronounced unimodal peak and truncated length distribution and low contributions of younger and older fish to the age distribution.

Comparisons of Mountain Whitefish growth curves indicated no consistent trends over time in any of the sections (Figure 3.28). Comparisons of anabolic constants and associated 95% confidence intervals indicated small differences in Mountain Whitefish growth within each section (Figure 3.29).

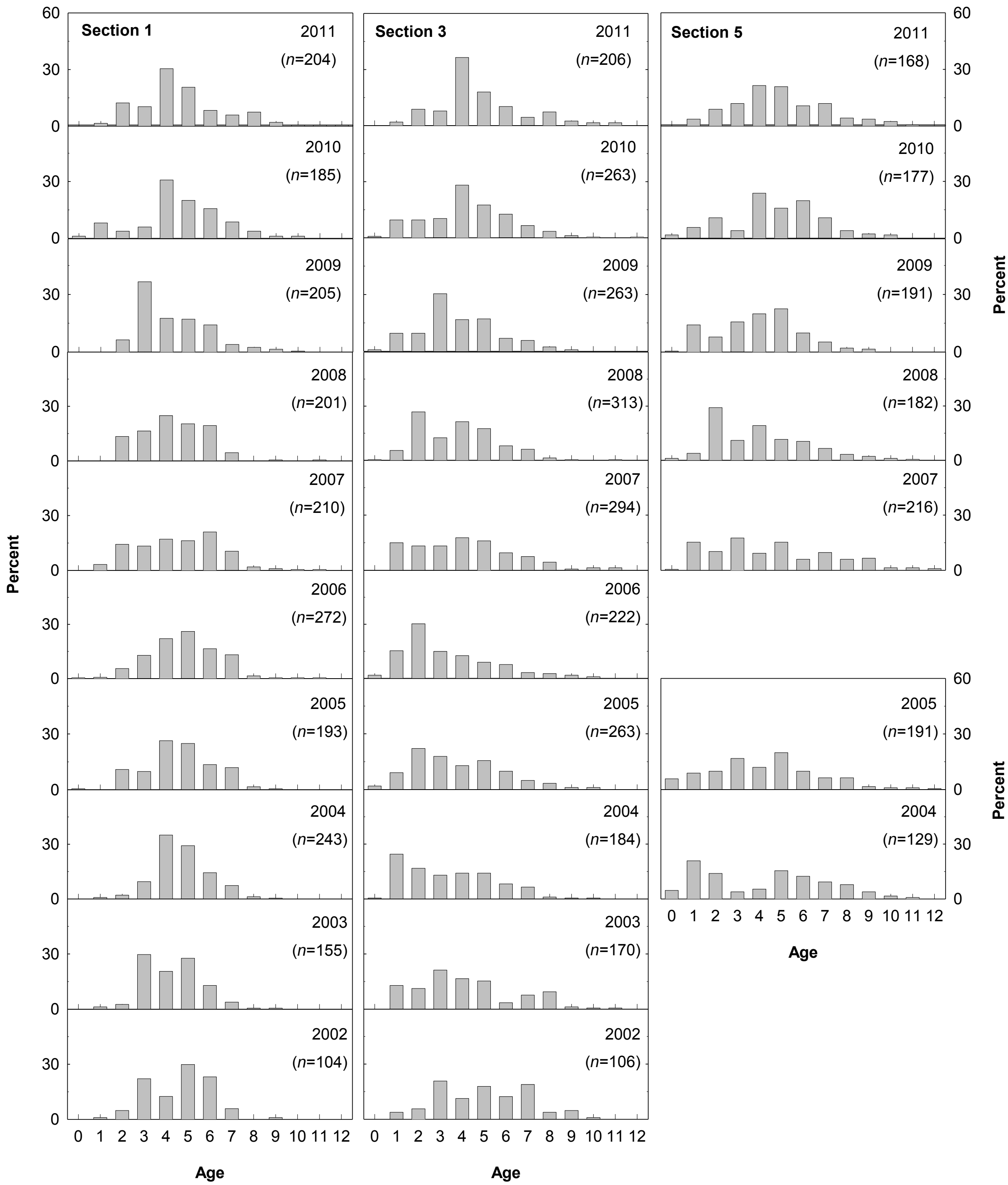

Figure 3.26 Age distributions of Mountain Whitefish sampled during the Peace River Fish Index Project, 2002 to 2011.

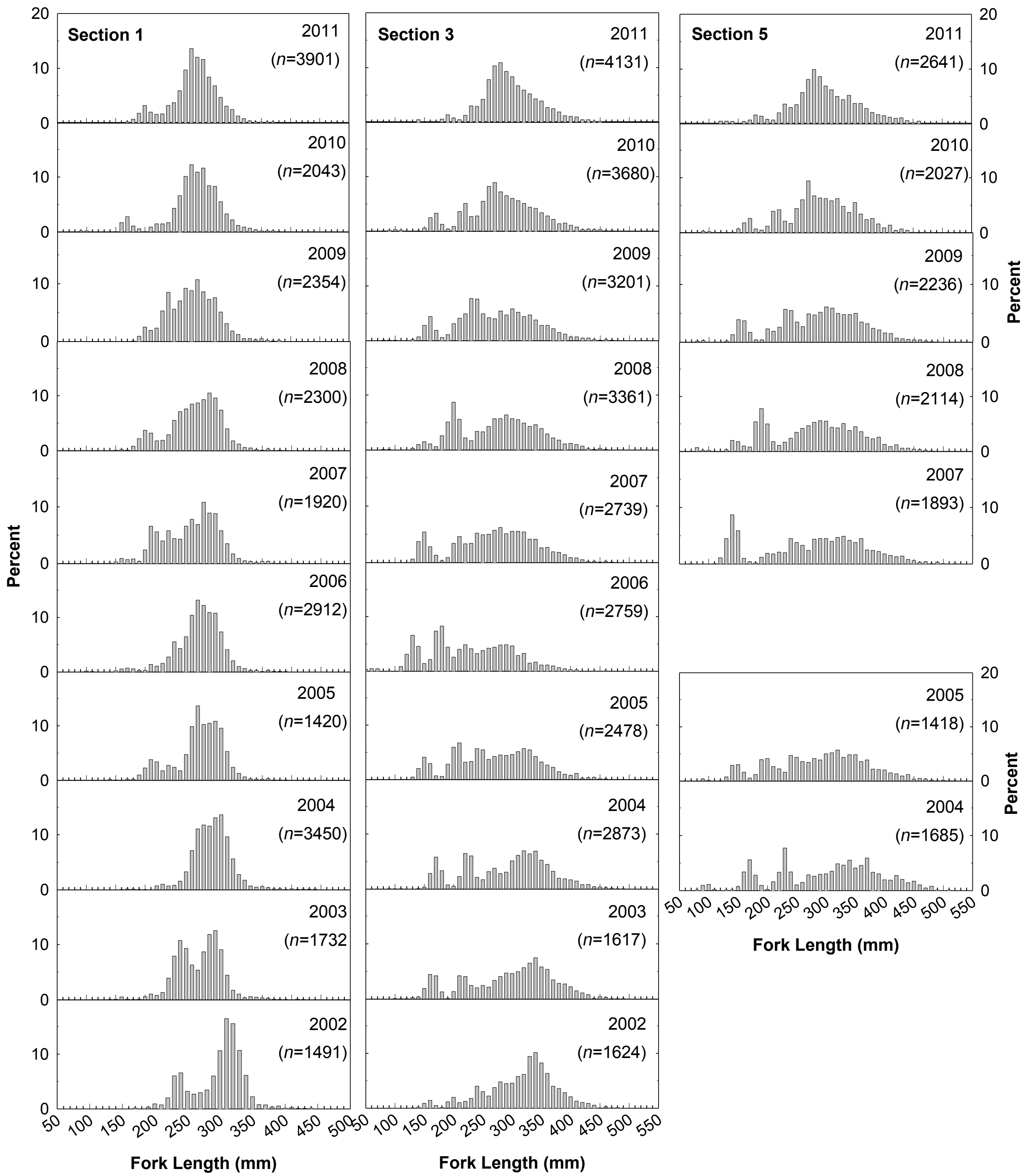

Figure 3.27 Length distributions of Mountain Whitefish sampled during the Peace River Fish Index Project, 2002 to 2011.

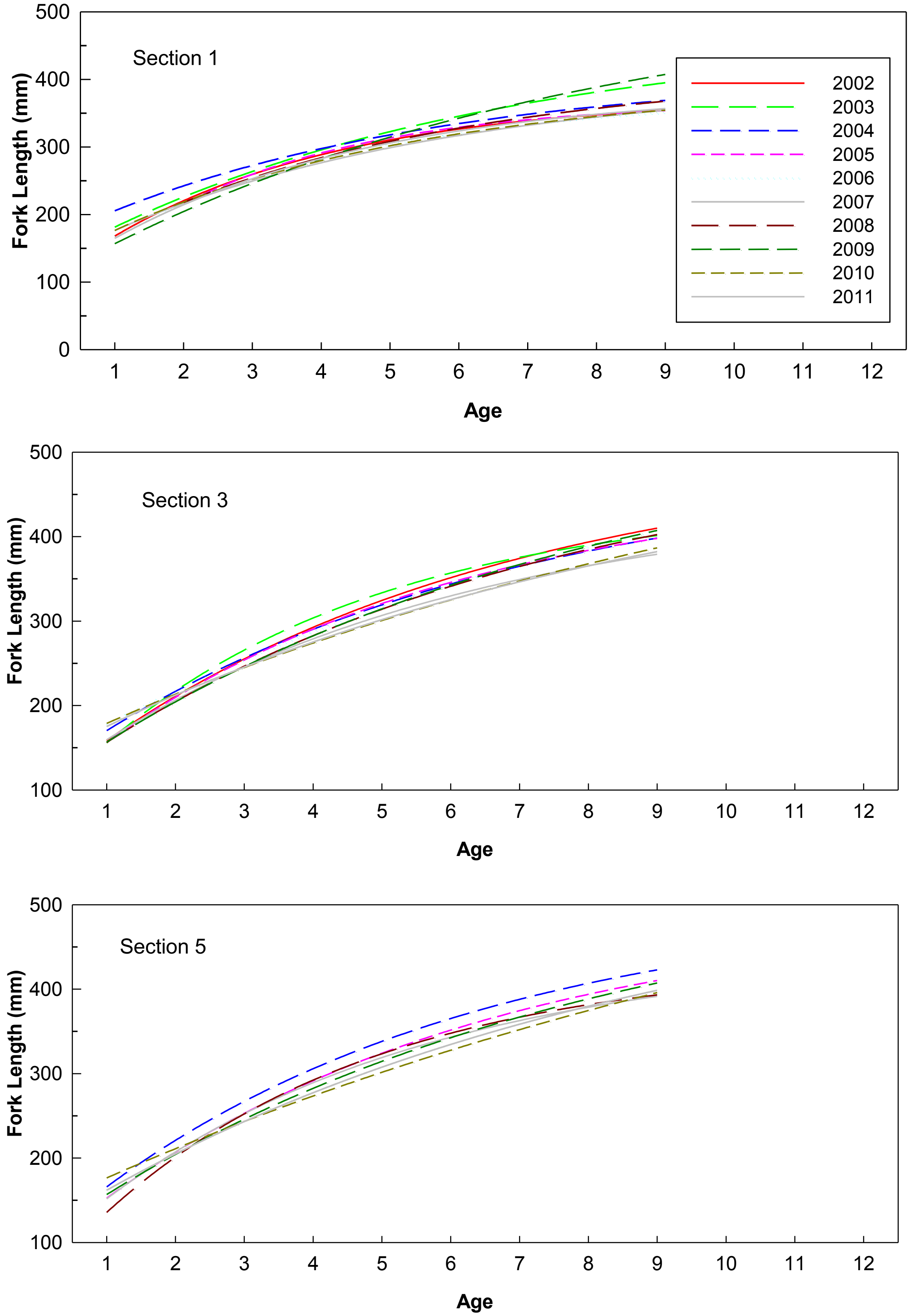

Figure 3.28 Comparisons of growth curves of Mountain Whitefish sampled during the Peace River Fish Index Project, 2002 to 2011 (growth curves restricted to Ages 1 to 9).

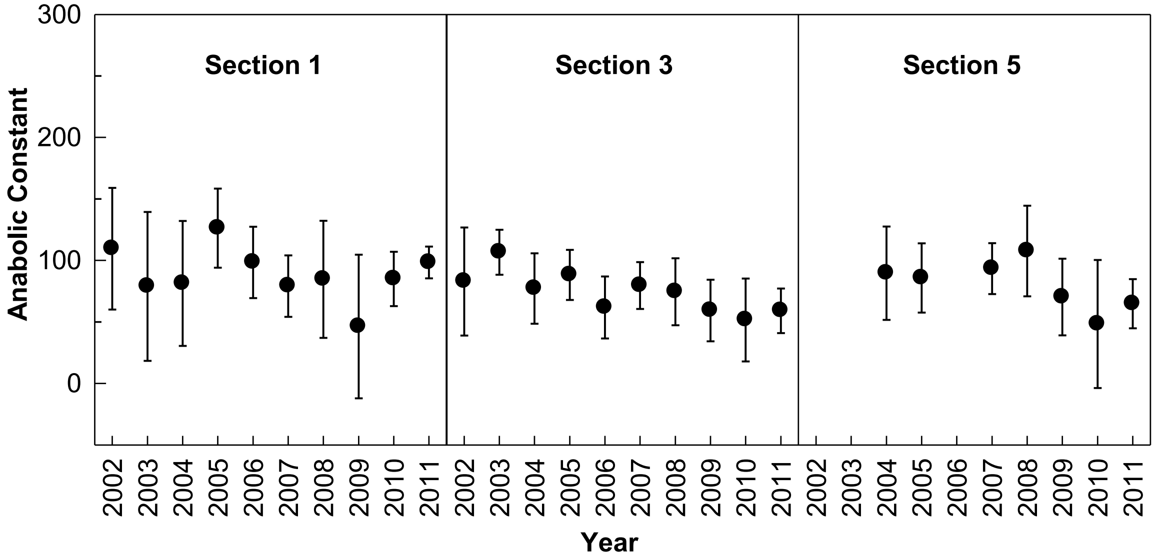

Figure 3.29 Anabolic constants of Mountain Whitefish sampled during the Peace River Fish Index Project, 2002 to 2011 (analyses restricted to Ages 1 to 9; vertical lines represent 95% confidence intervals).

Comparisons of change of annual mean length-at-age of Mountain Whitefish suggested trends for some age classes (Figure 3.30). No distinct patterns were apparent for Age 1 and Age 2 fish in each section. Starting in 2003 there was a general downward trend in mean length-at-age of fish from Age 3 to Age 6 in all three sections, but in 2011 that trend was reversed for most age classes. The 95% confidence intervals indicated significant differences between some estimates in all three sections. A visual examination of Mountain Whitefish body condition-at-age estimates and associated 95% confidence intervals did not indicate temporal trends in any section (Figure 3.31). However, Mountain Whitefish body condition in 2011 was consistently below the long term mean for most ages in all three sections. This apparent decrease may have been caused by one or more factors such the 2011 flow regime, water temperature and water clarity.

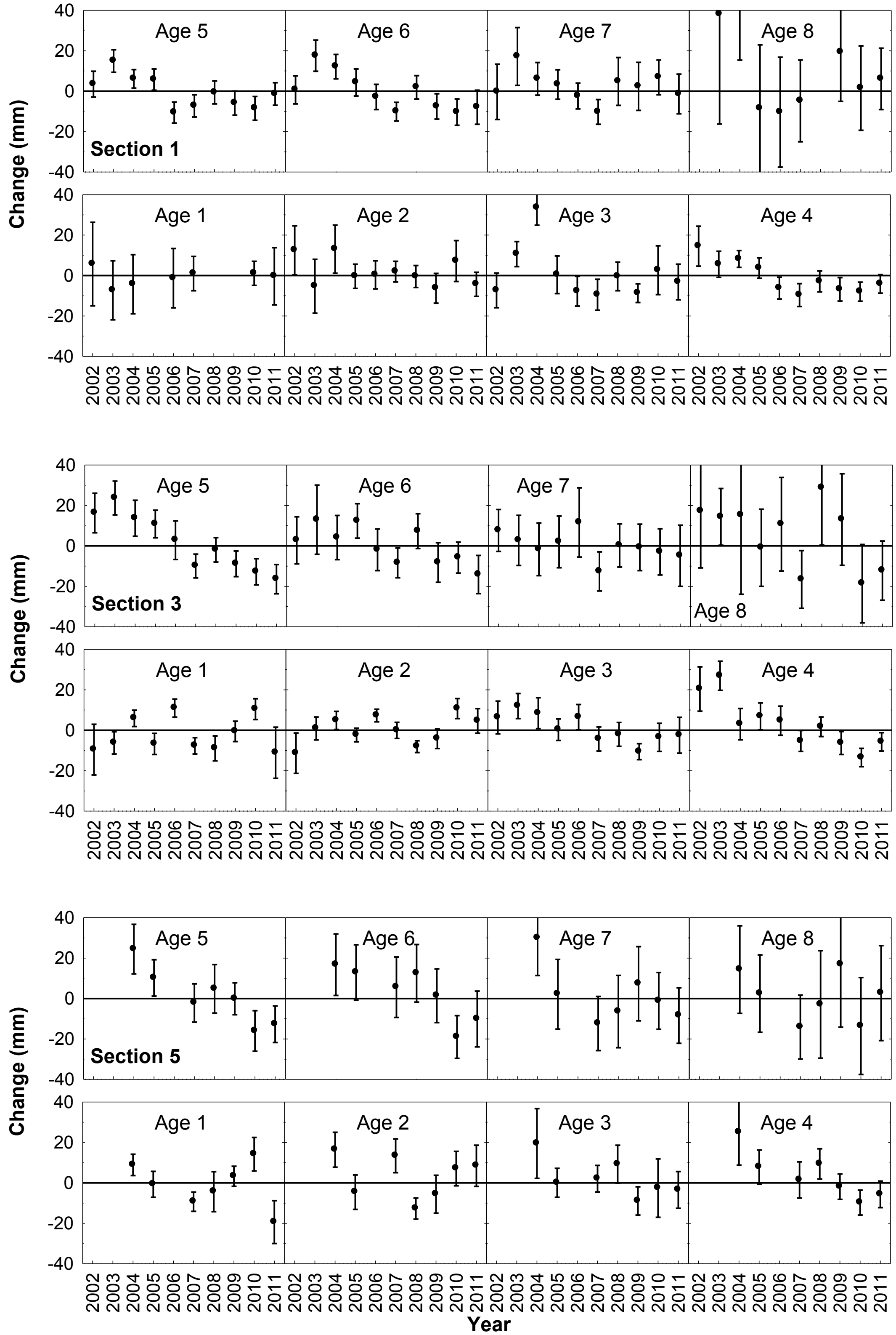

Figure 3.30 Change in mean length-at-age of Mountain Whitefish during the Peace River Fish Index Project, 2002 to 2011 (vertical lines are 95% confidence intervals).

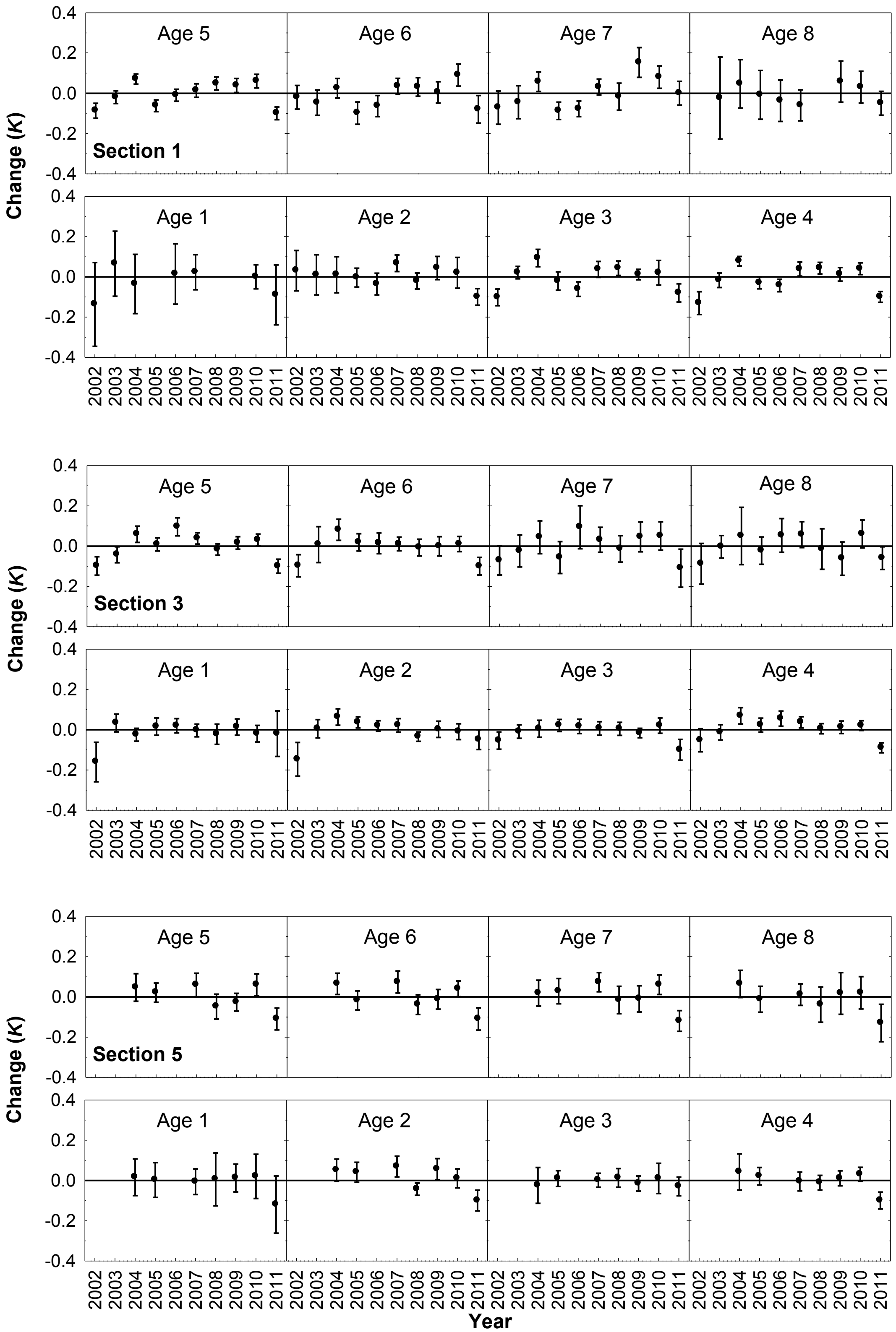

Figure 3.31 Change in mean body condition-at-age of Mountain Whitefish during the Peace River Fish Index Project, 2002 to 2011 (vertical lines are 95% confidence intervals).

Mortality

The catch curve of Mountain Whitefish in each section indicated that fish were fully recruited at Age 1 (Sections 3 and 5) or Age 3 (Section 1), but the downward trend in catch did not commence until Age 5 (Figure 3.32). The apparent annual mortality was highest in Section 1 (56%), intermediate in Section 3 (44%), and lowest in Section 5 (39%). Based on 95% confidence intervals, annual mortality in Section 1 was significantly higher compared to Sections 3 and 5.

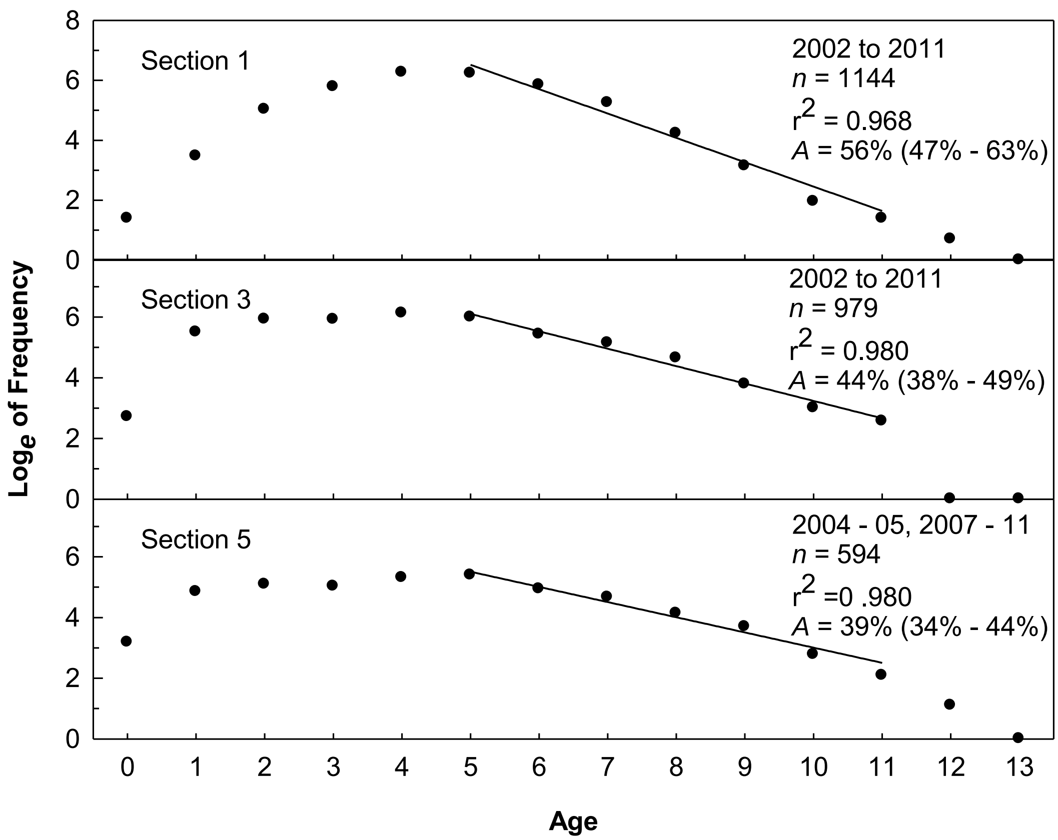

Figure 3.32 Catch curve annual mortality of Mountain Whitefish sampled during the Peace River Fish Index Project (combined data from 2002 to 2011; percentages in brackets represent 95% confidence intervals).

3.5.2 Catch Rate

Spatial Comparisons

Average catch rates of Mountain Whitefish were high in all sections (values ranged from 35 fish/km to 105 fish/km). There were differences between sections and between habitats within each section (Figure 3.33). Highest catch rates were recorded in Section 1, intermediate catch rates were recorded in Section 3, and lowest catch rates were recorded in Section 5. In each section, mean catch rates were higher in SFN habitats compared to mean catch rates in SFC habitat. The greatest difference occurred in Section 1 (105.3 fish/km versus 54.7 fish/km, respectively).

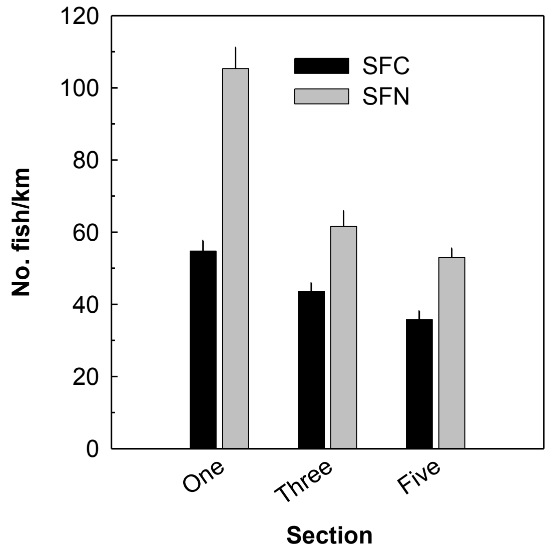

Figure 3.33 Mean catch rates of Mountain Whitefish stratified by section and habitat type, 2011 Peace River Fish Index Project (vertical lines represent standard error; see Table 2.1 for sample sizes and Table 2.2 for definitions of habitat type).

Annual Comparisons

The 2011 Mountain Whitefish catch rates were the highest recorded for each section since the start of the Peace River Index Project (Figure 3.34). Catch rates of Mountain Whitefish have differed between years in some sections. In Section 1, the downward trend that commenced after a high of 65.1 fish/km in 2004 had stabilized around 45.0 fish/km since 2007, before jumping to 76.4 fish/km in 2011. In Section 3, Mountain Whitefish catch rates have cycled from lows in 2002 and 2006 to highs in 2005, 2008, and 2011. Catch rates in Section 3 have ranged from 21.8 fish/km to 51.3 fish/km. Mountain Whitefish abundance in Section 5 has not changed substantively during the period of record; average catch rates

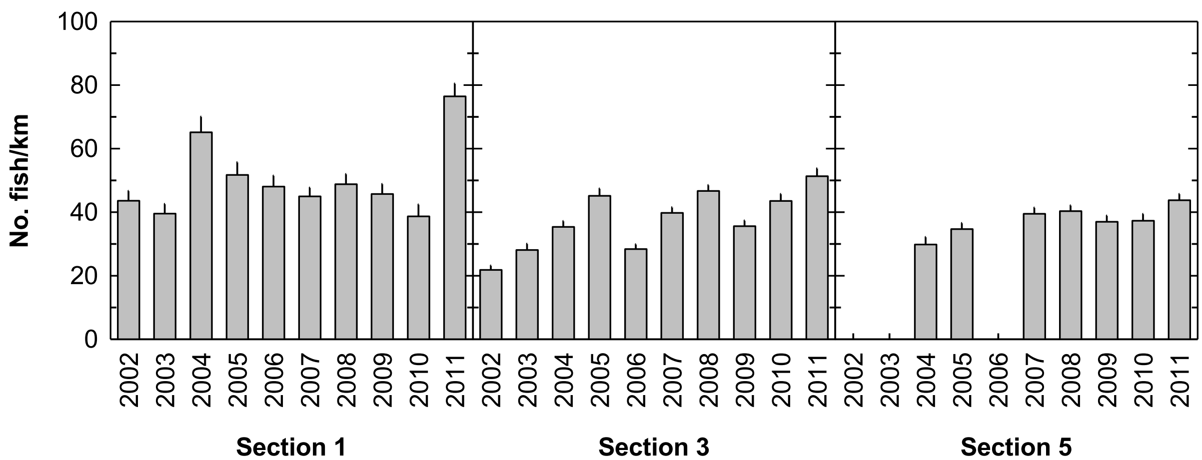

Figure 3.34 Mean catch rates of Mountain Whitefish during the Peace River Fish Index Project, 2002 to 2011 (based on combined weighted means and standard errors for SFC and SFN habitats; vertical lines represent standard errors; Section 5 not sampled in 2002, 2003, and 2006).

3.5.3 Recruitment

Recruitment of Age 1 Mountain Whitefish has varied annually and has differed between sections (Figure 3.35). During most years recruitment indices were much lower in Section 1 compared to Sections 3 and 5. An exception to this pattern occurred for the first time in 2010, when recruitment values among all three sections were similar (range of 7.5 fish/km to 13.4 fish/km). Recruitment was similar amongst the three sections in 2011; however, values were low (≤ 3.1 fish/km).

Recruitment indices in Section 3 were variable. Lows were recorded in 2002 and 2008 (< 6.0 fish/km), while a peak in recruitment was recorded in 2005 (37.2 fish/km). Section 5 recruitment values were 20% lower than those recorded in Section 3 in 2004 and 2005, but since that time they have been generally similar to values recorded in Section 3. Of note is the annual pattern of recruitment. Increasing and decreasing trends are identical and occur on the same year in Sections 3 and 5. In Section 1 the pattern is

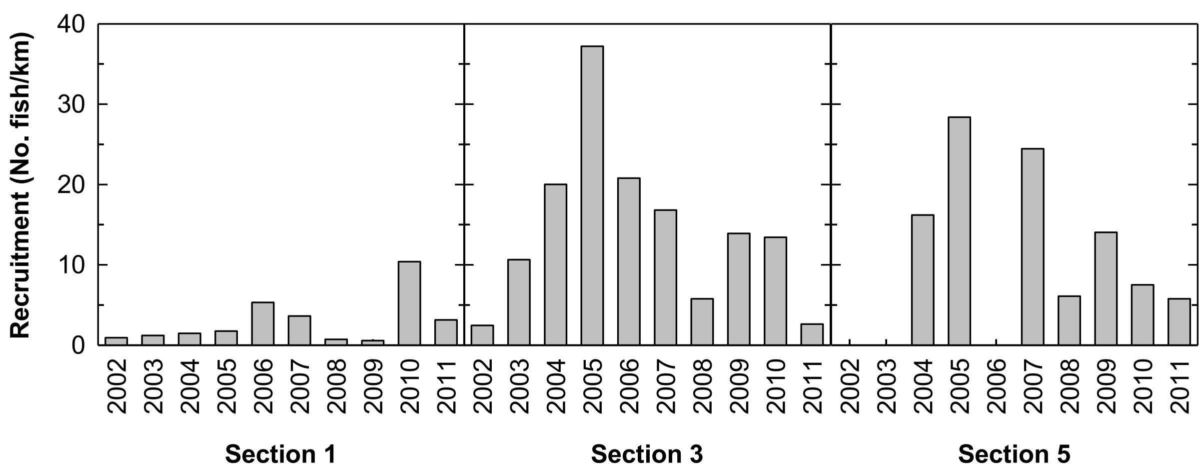

Figure 3.35 Recruitment index of Age 1 Mountain Whitefish in Sections 1, 3, and 5 during the Peace River Fish Index Project, 2002 to 2011 (see Section 2.2.5 for definition of age groups; Section 5 not sampled in 2002, 2003, and 2006).

3.6 POPULATION ESTIMATES

Detailed population estimation results are in Appendix E. A summary of the pertinent results follows.

3.6.1 Mountain Whitefish

Mountain Whitefish had sufficient number of encounters and recaptures of marked fish to evaluate many characteristics that may impact or help to explain the behaviour of population estimates. Consistent with past studies, fish marked with pit tags in recent years (2010 and 2011) were slightly less catchable in 2011 than fish marked in earlier years. However, there was not sufficient power for a significant rate of recapture by year of release to be detected in river Sections 3 and 5. The rate of recovery was significantly different in Section 1. Also consistent with past studies, small fish (< 275 mm) appear to be slightly under-represented in the recapture record. However, there was not sufficient power for a significant difference in size of unmarked fish in comparison to the recapture of marked fish to be detected. Examination of multiple recaptures did not provide any evidence of heterogeneous capture probability. Growth over the study period was small (< 0.5 mm over the study period) and not statistically significant; thus, the number of unmarked fish entering the population (≥ 250 mm) through growth during the study period (termed growth recruitment) was small. Limited growth also allowed length measurement error to be evaluated (standard deviation of 2.4 mm for each measurement). Mountain Whitefish exhibited little movement between river sections and within a section most fish were recaptured at the same site-of-release. The 95% confidence limits of apparent survival for all river sections included 1.0 (i.e., no mortality occurred over the study period).

The evaluation of alternative closed population models using the encounter history of individual fish with consistent sampling intensity through program MARK resulted in the identification of time varying capture probability model as the best fit to the data followed by the constant capture probability model based on AIC in all sections. In all sections, the heterogeneous capture probability model provided the poorest fit to the data. Sensible estimates could not be obtained for the behaviour model.

Despite the constant sampling effort, the sample size (marked and unmarked) collected in each sequence exhibited significant variation. The more direct test of time varying catchability using ADMB (Equations 1 to 3) resulted in a slightly better fit with time varying catchability in Section 5; however, in Sections 1 and 3 the constant catchability model fit the data better. In general, the logarithmic population deviation estimates show no apparent trends or large deviations with the exception of the 9 September and 12 September sampling dates in Section 5. Population estimates were very similar (within 3%) regardless of the model (constant catchability or time varying catchability).

The sequential posterior probability plots through the application of the Bayes sequential model for a closed population (the sequential posterior probability plots should stabilize about a common mode if the model assumptions hold) revealed convergent distributions in all sections. Sensitivity analysis through the application of mortality (annual instantaneous rates of 0.2 to 0.6) and undetected mark rate (1 to 5%) had little (< 5% change) impact on the population estimates.

A summary of the 2011 population estimates for the Bayes sequential model are given in Table 3.11. Bar plots of the population estimates for the 2002 to 2011 studies with sections common to 2011 are provided in Figure 3.36. Population estimates from previous studies (prior to 2011) that were deemed to have substantive assumption violations or to measure a different population are labeled in the figure as suspect. In 2004 the population estimates appeared valid; however, very low water likely concentrated the fish from locations that were not sampled in other years. Similarly, the population estimates for 2010 are largest on record and coincide with a low water level. The population estimates in 2011 are the second largest on record. The reliability of 2011 estimates is discussed in Section 4.4.2 (Reliability of Estimates).

Table 3.11 Population estimates by section for Mountain Whitefish, 2011 Peace River Fish Index Project.

Section	Bayesian Mean	MLE	95% Highest Probability Density		Standard Deviation	CV (%)
			Low	High		
One	26,671	26,460	23,540	29,940	1,632	6.1
Three	18,710	18,620	17,080	20,400	840	4.5
Five	15,542	15,400	13,620	17,540	998	6.4
Total	60,923		56,828	65,018	2,089	3.4

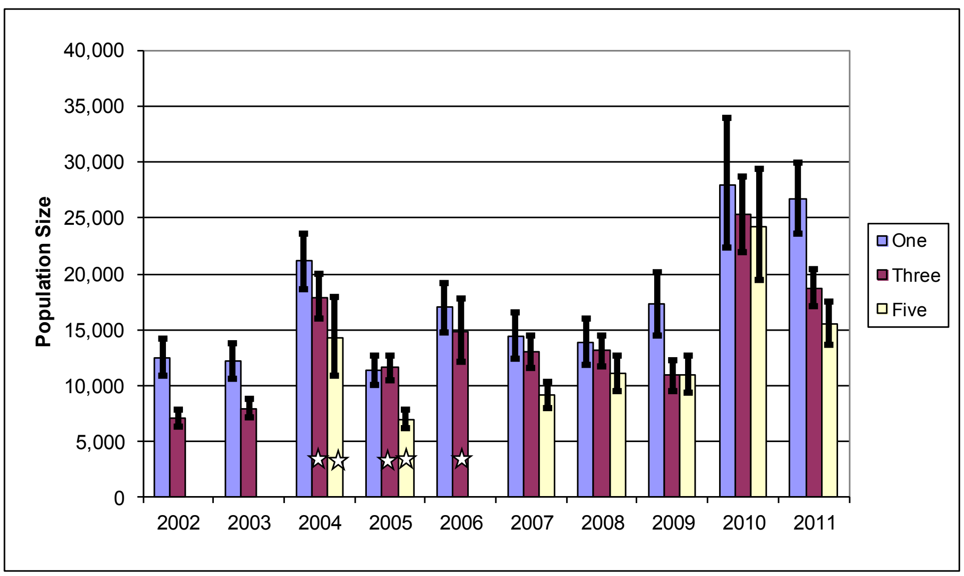

Figure 3.36 Mountain Whitefish population estimates from 2002 to 2011, Peace River Fish Index Project (vertical lines represent 95% confidence intervals; star indicates suspect population estimate).

3.6.2 Arctic Grayling

No Arctic Grayling were recaptured in Section 1; thus population estimates were not computed for this section. A summary of the 2011 population estimates for the Bayes sequential model are given in Table 3.12 for Sections 3 and 5. A bar plot of the historical population estimates of sections common to 2011 are provided in Figure 3.37.

Table 3.12 Population estimate in Sections 3 and 5 for Arctic Grayling, 2011 Peace River Fish Index Project.

Section	Bayesian Mean	MLE	95% Highest Probability Density		Standard Deviation	CV (%)
			Low	High		
Three	230	172	91	428	94	40.9
Five	66	58	41	97	15	23.1
Total	296	240	151	492	95	32.2

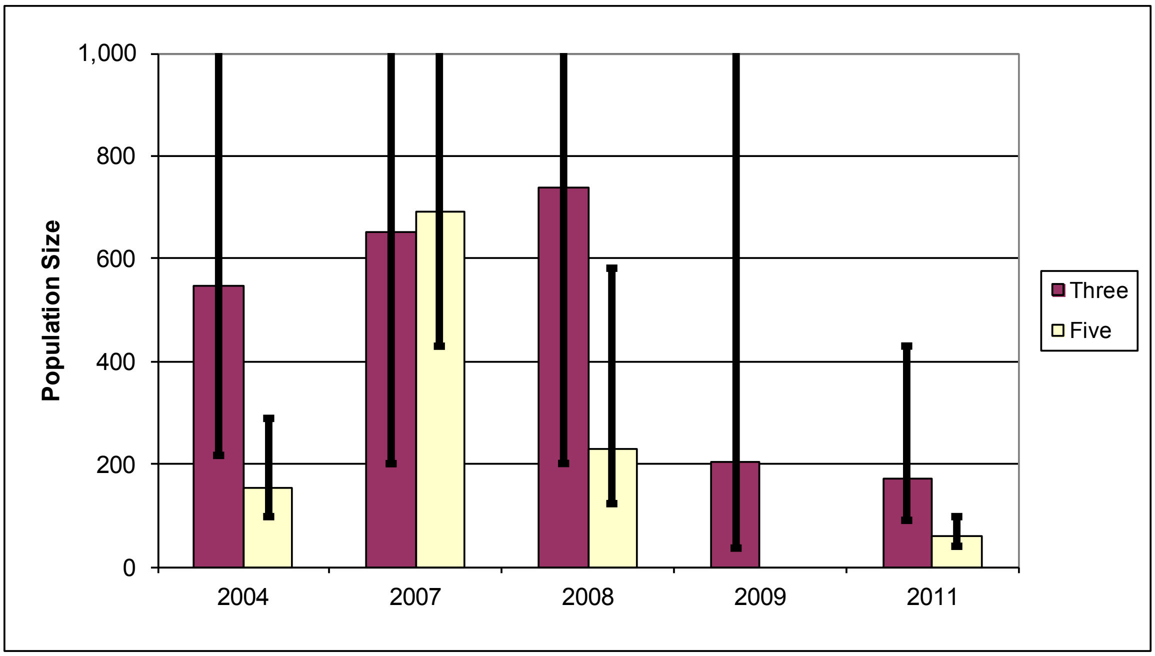

Figure 3.37 Arctic Grayling population estimates by section for 2004, 2007, 2008, 2009, and 2011, Peace River Fish Index Project (vertical lines represent 95% confidence intervals).

3.6.3 Bull Trout

A summary of the 2011 population estimates for the Bayes sequential model are given in Table 3.13. Because of sparse recoveries in Sections 1 and 5, the posterior distributions were highly skewed and mean estimates were unreliable. Construction of minimum population probability curves inferred a 0.95 probability that the population size was at least 117 and 175 Bull Trout in Sections 1 and 5, respectively. A bar plot of the population estimates for the 2002 to 2011 studies with sections common to 2011 is provided in Figure 3.38.

Table 3.13 Population estimates by section for Bull Trout, 2011 Peace River Fish Index Project.

Section	Bayesian Mean	MLE	95% Highest Probability Density		Standard Deviation	CV (%)
			Low	High		
One	734	176	49	2,504	761	103.7
Three	331	284	177	524	96	29.1
Five	504	266	106	1,226	390	77.3
Total	1,569	969	533	3,178	861	54.8

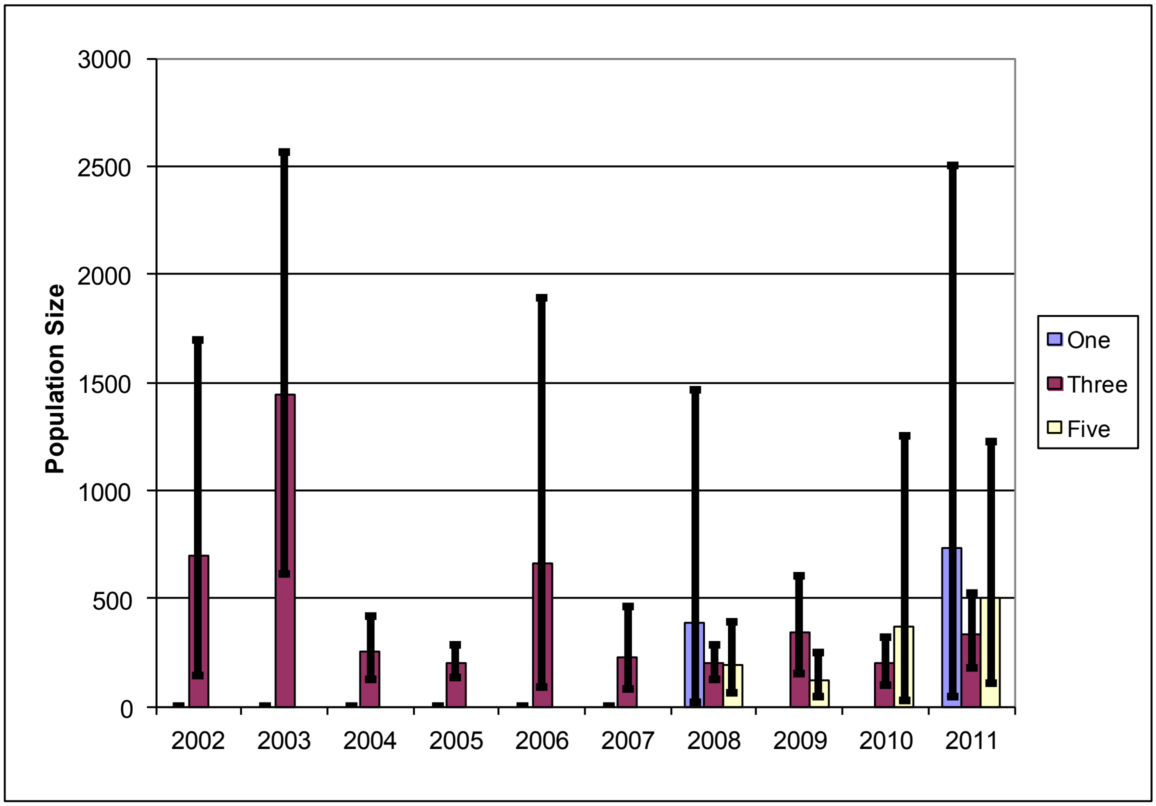

Figure 3.38 Bull Trout population estimates by section from 2002 to 2011, Peace River Fish Index Project (vertical lines represent 95% confidence intervals).

3.7 CATCHABILITY

Mountain Whitefish had sufficient number of recaptures to compute catchability coefficients based on the Bayesian sequential estimates for a closed population. The catchability coefficients and associated population estimates, standard deviation estimates and effort (Equations 9 to 11) by section are listed in Tables 3.14 and 3.15 using effort measured in kilometers traveled or the hours of electrofishing to collect the samples, respectively. Figure 3.39 plots the catchability coefficients using both effort measures and the associated 95% confidence intervals. Note that the coefficients are consistent for all sections within

2011 and are also consistent across years and sections where the population estimates were deemed to be reliable or represent the same population.

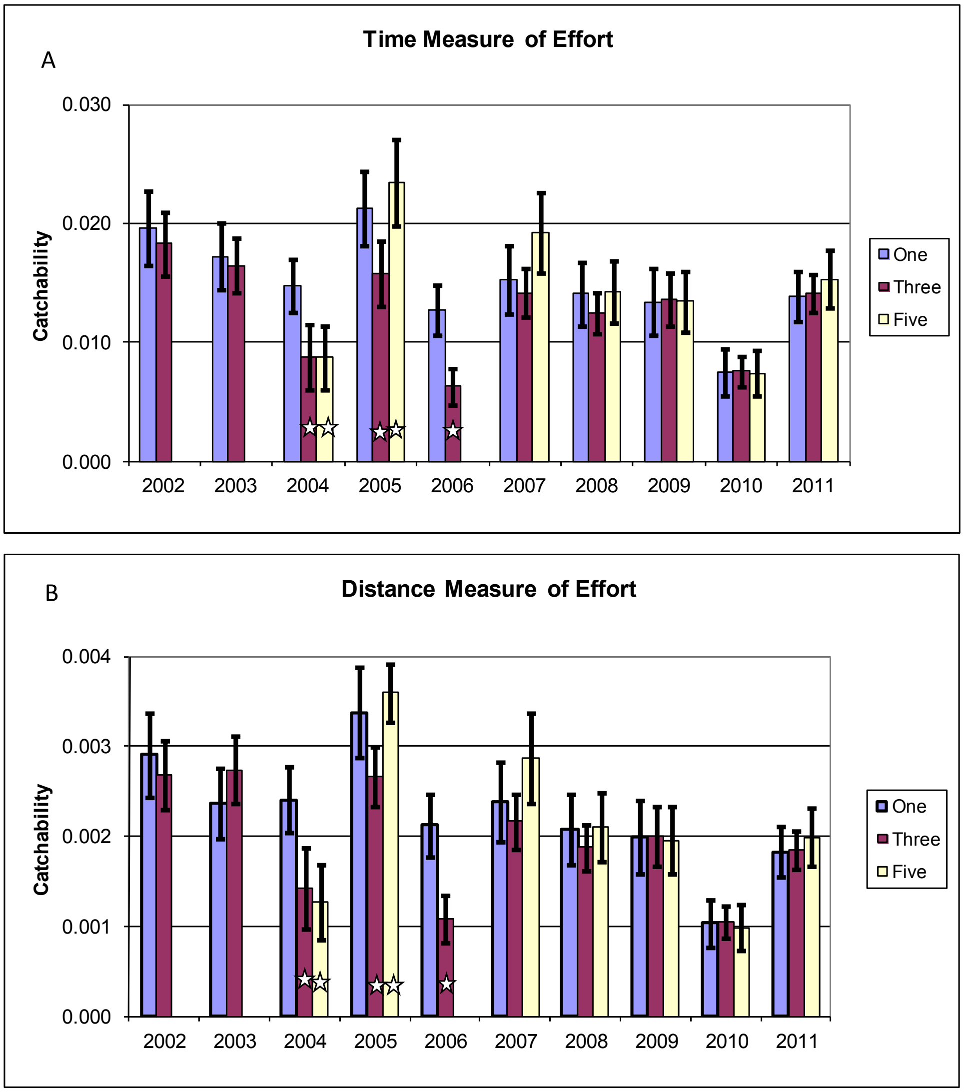

Figure 3.39 Catchability using time (hours – top graph) and distance (km – bottom graph) by section for Mountain Whitefish from 2002 to 2011, Peace River Fish Index Project (vertical lines represent 95% CI; star indicates a suspect population estimate).

Table 3.14 Catchability of Mountain Whitefish by section (effort in kilometres) during the Peace River Fish Index Project, 2002 to 2011.

Statistic	Section					Total
	One	Two	Three	Four	Five	
2002 Study						
Sample	2,845	2,611	2,363	2,105		9,924
Effort	78.13	90.90	124.85	119.34		413.22
Abundance (N)	12,534	10,587	7,066	6,045		36,232
SD(1/N)	5.614E-06	6.493E-06	8.794E-06	1.024E-05		3.998E-06
Catchability (q)	2.905E-03	2.713E-03	2.679E-03	2.918E-03		2.804E-03
SD(q)	2.044E-04	1.865E-04	1.665E-04	1.805E-04		9.602E-05
CV(q)	7.0%	6.9%	6.2%	6.2%		3.4%
2003 Study						
Sample	2,145	1,896	2,546	1,883		8,470
Effort	74.51	86.98	116.80	112.24		390.53
Abundance (N)	12,165	8,911	7,955	7,252		36,283
SD(1/N)	5.876E-06	7.591E-06	7.388E-06	1.039E-05		3.989E-06
Catchability (q)	2.367E-03	2.446E-03	2.740E-03	2.313E-03		2.467E-03
SD(q)	1.692E-04	1.655E-04	1.610E-04	1.743E-04		8.652E-05
CV(q)	7.1%	6.8%	5.9%	7.5%		3.5%
2004 Study						
Sample	3,514		2,972		1,549	8,035
Effort	69.16		116.80		85.18	271.13
Abundance (N)	21,121		17,912		14,409	53,442
SD(1/N)	2.959E-06		7.388E-06		8.969E-06	3.997E-06
Catchability (q)	2.406E-03		1.421E-03		1.262E-03	1.696E-03
SD(q)	1.504E-04		1.880E-04		1.631E-04	1.184E-04
CV(q)	6.2%		13.2%		12.9%	7.0%
2005 Study						
Sample	2,777		3,624		2,132	8,533
Effort	72.34		116.80		85.18	274.32
Abundance (N)	11,370		11,628		6,969	29,967
SD(1/N)	5.496E-06		4.538E-06		9.4737E-06	3.952E-06
Catchability (q)	3.376E-03		2.668E-03		3.592E-03	3.212E-03
SD(q)	2.110E-04		1.408E-04		2.371E-04	1.229E-04
CV(q)	6.2%		5.3%		6.6%	3.8%
2006 Study						
Sample	2,532	2,120	1,887			
Effort	70.39	77.52	117.42			
Abundance (N)	16,973	10,274	14,846			
SD(1/N)	4.112E-06	6.334E-06	6.939E-06			
Catchability (q)	2.119E-03	2.662E-03	1.082E-03			
SD(q)	1.479E-04	1.732E-04	1.115E-04			
CV(q)	7.0%	6.5%	10.3%			

Table 3.14 Concluded.

Statistic	Section					Total
	One	Two	Three	Four	Five	
2007 Study						
Sample	2,565		3,292		2,218	8,075
Effort	74.51		117.22		84.80	276.53
Abundance (N)	14,436		12,985		9,120	36,541
SD(1/N)	5.518E-06		4.663E-06		8.049E-06	3.605E-06
Catchability (q)	2.385E-03		2.163E-03		2.868E-03	2.472E-03
SD(q)	1.900E-04		1.310E-04		2.105E-04	1.053E-04
CV(q)	8.0%		6.1%		7.3%	4.3%
2008 Study						
Sample	2156		2905		1978	7,039
Effort	74.51		118.03		84.98	277.52
Abundance (N)	13,884		13,125		11,053	38,062
SD(1/N)	5.713E-06		4.410E-06		6.983E-06	3.348E-06
Catchability (q)	2.084E-03		1.875E-03		2.106E-03	2.022E-03
SD(q)	1.653E-04		1.085E-04		1.625E-04	8.491E-05
CV(q)	7.9%		5.8%		7.7%	4.2%
2009 Study						
Sample	2555		2575		1825	6,955
Effort	74.51		118.03		84.98	277.52
Abundance (N)	17,253		10,918		10,991	39,162
SD(1/N)	5.058E-06		6.331E-06		7.402E-06	3.658E-06
Catchability (q)	1.988E-03		1.998E-03		1.954E-03	1.980E-03
SD(q)	1.734E-04		1.381E-04		1.590E-04	9.169E-05
CV(q)	8.7%		6.9%		8.1%	4.6%
2010 Study						
Sample	2,102		3,171		2,034	7,307
Effort	72.83		119.46		85.18	277.47
Abundance (N)	27,966		25,285		24,268	77,519
SD(1/N)	3.948E-06		2.804E-06		4.473E-06	2.197E-06
Catchability (q)	1.032E-03		1.050E-03		9.840E-04	1.022E-03
SD(q)	1.140E-04		7.442E-05		1.068E-04	5.787E-05
CV(q)	11.0%		7.1%		10.9%	5.7%
2011 Study						
Sample	3,445		3,902		2,632	9,979
Effort	70.63		112.74		85.10	268.46
Abundance (N)	26,671		18,710		15,542	60,923
SD(1/N)	2.403E-06		2.569E-06		4.381E-06	1.873E-06
Catchability (q)	1.829E-03		1.850E-03		1.990E-03	1.890E-03
SD(q)	1.172E-04		8.893E-05		1.355E-04	6.961E-05
CV(q)	6.4%		4.8%		6.8%	3.7%

Table 3.15 Catchability of Mountain Whitefish by section (effort in hours) during the Peace River Fish Index Project, 2002 to 2011.

Statistic	Section					Total
	One	Two	Three	Four	Five	
2002 Study						
Sample	2,845	2,611	2,363	2,105		9,924
Effort	11.58	14.39	18.31	17.59		61.86
Abundance (N)	12,534	10,587	7,066	6,045		36,232
SD(1/N)	5.614E-06	6.493E-06	8.794E-06	1.024E-05		3.998E-06
Catchability (q)	1.960E-02	1.714E-02	1.827E-02	1.980E-02		1.870E-02
SD(q)	1.379E-03	1.178E-03	1.135E-03	1.225E-03		6.414E-04
CV(q)	7.0%	6.9%	6.2%	6.2%		3.4%
2003 Study						
Sample	2,145	1,896	2,546	1,883		8,470
Effort	12.29	15.31	19.49	18.67		65.76
Abundance (N)	12,165	8,911	7,955	7,252		36,283
SD(1/N)	5.876E-06	7.591E-06	7.388E-06	1.039E-05		3.989E-06
Catchability (q)	1.722E-02	1.652E-02	1.642E-02	1.659E-02		1.669E-02
SD(q)	1.231E-03	1.118E-03	9.651E-04	1.249E-03		5.800E-04
CV(q)	7.1%	6.8%	5.9%	7.5%		3.5%
2004 Study						
Sample	3,514		2,972		1,549	8,035
Effort	11.29		18.87		12.35	42.51
Abundance (N)	21,121		17,912		14,409	53,442
SD(1/N)	2.959E-06		7.388E-06		8.969E-06	6.923E-06
Catchability (q)	1.473E-02		8.791E-03		8.708E-03	1.074E-02
SD(q)	9.208E-04		1.163E-03		1.125E-03	1.308E-03
CV(q)	6.2%		13.2%		12.9%	12.2%
2005 Study						
Sample	2,777		3,624		2,132	8,533
Effort	11.49		19.70		13.06	44.26
Abundance (N)	11,370		11,628		6,969	29,967
SD(1/N)	5.496E-06		4.538E-06		9.4737E-06	3.952E-06
Catchability (q)	2.126E-02		1.582E-02		2.342E-02	2.016E-02
SD(q)	1.328E-03		8.347E-04		1.546E-03	7.620E-04
CV(q)	6.2%		5.3%		6.6%	3.8%
2006 Study						
Sample	2,532	2,120	1,887			
Effort	11.75	13.36	20.27			
Abundance (N)	16,973	10,274	14,846			
SD(1/N)	4.112E-06	6.334E-06	6.939E-06			
Catchability (q)	1.270E-02	1.545E-02	6.270E-03			
SD(q)	8.864E-04	1.005E-03	6.459E-04			
CV(q)	7.0%	6.5%	10.3%			

Table 3.15 Concluded.

Statistic	Section					Total
	One	Two	Three	Four	Five	
2007 Study						
Sample	2,565		3,292		2,218	8,075
Effort	11.63		17.89		12.65	42.17
Abundance (N)	14,436		12,985		9,120	36,541
SD(1/N)	5.518E-06		4.663E-06		8.049E-06	3.605E-06
Catchability (q)	1.528E-02		1.417E-02		1.923E-02	1.623E-02
SD(q)	1.217E-03		8.579E-04		1.411E-03	6.904E-04
CV(q)	8.0%		6.1%		7.3%	4.3%
2008 Study						
Sample	2156		2905		1978	7,039
Effort	11.04		17.75		12.59	41.39
Abundance (N)	13,884		13,125		11,053	38,062
SD(1/N)	5.713E-06		4.410E-06		6.983E-06	3.348E-06
Catchability (q)	1.406E-02		1.247E-02		1.422E-02	1.358E-02
SD(q)	1.116E-03		7.215E-04		1.097E-03	5.694E-04
CV(q)	7.9%		5.8%		7.7%	4.2%
2009 Study						
Sample	2555		2575		1825	6,955
Effort	11.06		17.36		12.36	40.78
Abundance (N)	17,253		10,918		10,991	39,162
SD(1/N)	5.058E-06		6.331E-06		7.402E-06	3.658E-06
Catchability (q)	1.339E-02		1.358E-02		1.343E-02	1.347E-02
SD(q)	1.169E-03		9.390E-04		1.093E-03	6.239E-04
CV(q)	8.7%		6.9%		8.1%	4.6%
2010 Study						
Sample	2,102		3,171		2,034	7,307
Effort	10.09		16.65		11.32	38.06
Abundance (N)	27,966		25,285		24,268	77,519
SD(1/N)	3.948E-06		2.804E-06		4.473E-06	2.197E-06
Catchability (q)	7.450E-03		7.532E-03		7.404E-03	7.462E-03
SD(q)	8.227E-04		5.340E-04		8.037E-04	4.219E-04
CV(q)	11.0%		7.1%		10.9%	5.7%
2011 Study						
Sample	3,445		3,902		2,632	9,979
Effort	9.35		14.80		11.06	35.21
Abundance (N)	26,671		18,710		15,542	60,923
SD(1/N)	2.403E-06		2.569E-06		4.381E-06	1.873E-06
Catchability (q)	1.381E-02		1.410E-02		1.532E-02	1.441E-02
SD(q)	8.849E-04		6.776E-04		1.043E-03	5.308E-04
CV(q)	6.4%		4.8%		6.8%	3.7%

The relationship between Mountain Whitefish population estimate and catch rate weighted for habitat type of Mountain Whitefish is presented in Figure 3.40. With the exception of 2010, which differed substantially from other results, catchabilty for Mountain Whitefish was consistent among years and sections. For these data the catchability estimate using distance as the measure of effort was 0.0024 ± 0.(

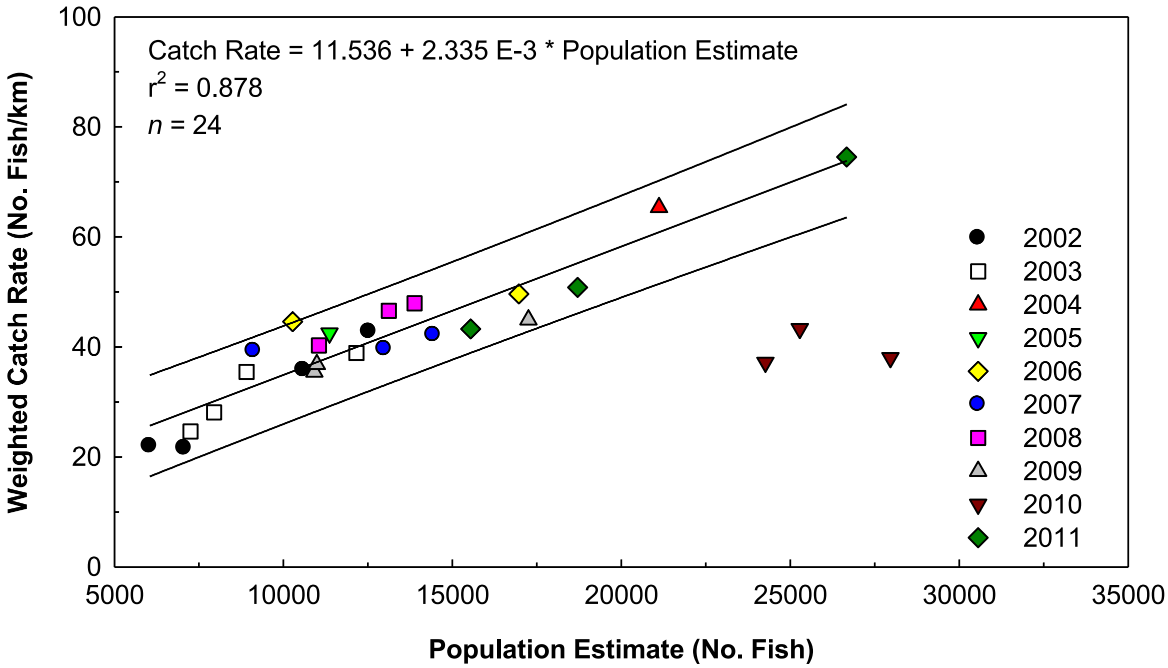

Figure 3.40 Relationship between population estimate and catch rate weighted for habitat of Mountain Whitefish during the Peace River Fish Index Project, 2002 to 2011 (data from 2010 excluded from regression; dashed lines represent 95% prediction intervals; see Section 2.2.7 for selection of data for analysis).

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4.0 DISCUSSION

4.1 SAMPLING CONDITIONS

Field sampling conditions (i.e., discharge, water clarity, and water temperature) were generally similar to conditions during previous studies. Discharge was high and averaged 1,405 m^3/s, water clarity exceeded 100 cm during most of the field program, and water temperatures ranged from 10.0°C to 13.7°C. In 2011 discharge was approximately 30% above the historical average for the index project.

4.2 GENERAL CHARACTERISTICS OF THE FISH COMMUNITY

In total, 16,152 fish representing 16 species were recorded in 2011. The species composition and numerical contribution recorded during the present study was similar to results of previous programs. Unique species not typically observed, but present in the 2011 sample were lake trout, lake whitefish, yellow perch, and flathead chub, as well as higher numbers of walleye and northern pike.

4.3 TARGET SPECIES

4.3.1 Arctic Grayling

In total, 175 Arctic Grayling were sampled for biological characteristics. Similar to results of previous studies, Age 0 fish were not recorded.

Fish from Sections 1, 3 and 5 exhibited similar biological characteristics. Samples were dominated by Age 1 and Age 2 fish. There were no measurable differences between the sections in terms of length-at-age, body condition-at-age, growth, and apparent annual mortality. The results were generally consistent with previous studies.

There continues to be annual shifts in length and age distributions of the Arctic Grayling sample populations, which are related to strong age classes in a particular year. Several parameters (i.e., growth curves, anabolic constants, length-at-age, body condition-at-age) indicated general stability in Arctic Grayling population health over time.

Arctic Grayling catch rates were low in 2011. Arctic Grayling were scarce in Section 1 and fish abundance was similar among Sections 3 and 5. Arctic Grayling catch rates in Sections 3 and 5 increased from 2010 suggesting a reversal of the continued decline since 2007. The biological data did not show any large shift in population structure or health that could explain reversal abundance. As such, the change may reflect natural variation in Arctic Grayling abundance and recruitment from Peace River tributaries.

The contribution of Age 1 Arctic Grayling has been zero in Section 1 for the duration of the program until 2011. In 2011, Age 1 Arctic Grayling were recorded in all three sections. In Sections 3 and 5, Age 1 Arctic Grayling were recorded during all sample years, but annual recruitment has varied. Recruitment increased slightly from previous years in Section 3, but continued a downward trend in Section 5.

4.3.2 Bull Trout

In total, 227 Bull Trout were sampled for biological characteristics. In 2011, length and age distributions of Bull Trout were similar among sections. Fish from Age 2 to 6 dominated and Bull Trout older than Age 7 (adults) were not well represented. Bull Trout population health, in terms of growth and body condition, are similar among sections. Fish grow very quickly and exhibit good body condition.

Age and length distributions of the combined sample (Sections 1, 3, and 5) remained stable across years. Age 1 fish were largely absent. During all sample years, age distributions were dominated by subadults, while adult fish were poorly represented. The absence of adult fish from the index sections was likely caused by use of tributaries for spawning during the study period. As such, the results do not reflect the actual age structure of the Peace River Bull Trout.

Bull Trout catch rates were low in all sections and there were no strong section differences in Bull Trout abundance. In general, catch rates were lowest in Section 1, intermediate in Section 5, and highest in Section 3. Bull Trout catch rates did not differ between SFC habitat and SFN habitat. There has been no large change in Bull Trout catch rates for the duration of the index project.

Age 3 Bull Trout were recruited in each section during all years of the study, but the recruitment index has remained at approximately or below 1.0 fish/km.

4.3.3 Mountain Whitefish

In total, 10,673 Mountain Whitefish were available for analyses. The 2011 results were consistent with previous studies. There were spatial differences in length and age distributions of Mountain Whitefish. Fish in Section 1 exhibited truncated age and length distributions caused by the preponderance of Age 3 to Age 6 fish. Younger fish (Age 1) and older fish (> Age 6) were much less numerous. In contrast, Mountain Whitefish in Sections 3 and 5 exhibited multi-modal length distributions that represented a wider range of ages. The spatial differences recorded in 2011 were consistent with results from previous studies. Section 1 continues to exhibit a unique population structure. The results suggest in migration by younger fish and out migration, or mortality, of older fish.

There were spatial differences in Mountain Whitefish growth and body condition. In Section 1 younger age classes tended to have higher mean lengths and older age classes had lower mean lengths compared to fish in Sections 3 and 5. This resulted in a lower growth rate by Section 1 fish. The annual mortality of Mountain Whitefish also differed between sections. The apparent annual mortality was highest in Section 1, intermediate in Section 3, and lowest in Section 5.

There continues to be small annual differences in Mountain Whitefish age and length distributions based on strengths of younger age classes; however, the spatial differences remain consistent among years. In terms of population health, some parameters (i.e., growth curves, anabolic constants, and body condition-at-age) indicated no strong temporal change in population health. However, Mountain Whitefish body condition in 2011 was below the long term mean for most ages in all sections. This apparent decrease may be due to one or more factors such as the 2011 flow regime, water temperature, and water clarity.

Mountain Whitefish continue to be abundant in Sections 1, 3, and 5. Catch rates in each section in 2011 were the highest recorded during the Peace River Fish Index Project. Mean catch rates (habitat type combined) were 76 fish/km in Section 1, 51 fish/km in Section 3, and 44 fish/km in Section 5. As found by previous index studies, catch rates differed by habitat. Mountain Whitefish were more abundant in SFN habitat compared to SFC habitat.

Catch rates of Mountain Whitefish within each section varied annually. In Section 1, the downward trend recorded in Mountain Whitefish abundance that commenced in 2004 ended in 2007, after which catch rates varied only slightly before the large increase in 2011. Section 3 Mountain Whitefish exhibited cyclic abundance with highs recorded in 2005 and 2008 and 2011. Section 5 Mountain Whitefish exhibited a similar, but weaker cyclic pattern. Annual recruitment of Age 1 Mountain Whitefish differed between sections. During most years recruitment were lower in Section 1 compared to Sections 3 and 5; however, in 2010 Section 1 recruitment was similar to those in Sections 3 and 5. In 2011, there was a decline in Mountain Whitefish recruitment in all three sections (< 3.5 fish/km). The annual pattern of recruitment was the same in Sections 3 and 5. The pattern in Section 1 was similar to that of other sections, but the timing appeared to be delayed by 1 year.

4.4 POPULATION ESTIMATES

Population estimates for Arctic Grayling and Bull Trout were imprecise because of sparse recoveries; therefore, for these two species annual comparisons of estimates and evaluation of assumptions were not possible. The population estimates for Mountain Whitefish were precise. Mountain Whitefish in 2011 were the second largest on record (the population size in 2010 was larger). The population estimates were approximately 1.5 to 2.0 times that estimated for 2002 to 2009 except for 2004.

4.4.1 Evaluation of Assumptions

The factors that affect the population estimates can be evaluated through an assessment of assumptions required for the closed sequential stratified population model.

1. *The population is closed, so the population size does not change over the period of the experiment.*

Very few Mountain Whitefish were recaptured in river sections other than the section of release (1.1%, approximately). Moreover, the population estimation model accounts for fish that move under the assumption that all movement is described by the history of recaptured marks. Only one Arctic Grayling and one Bull Trout were observed to move to a different river section. For Mountain Whitefish, growth over the study period was very small; therefore, any growth recruitment (fish becoming larger than 250 mm during the study) was minimal. Mortality was not expected to be an issue because of the short duration of the study and was further supported by the Cormack-Jolly-Seber (CJS, open population) where estimates of survival of marked fish were not significantly different than 1.0 in any of the river sections. Also consistent with the closed population assumption, inspection of the posterior probability plot sequences generated by the Bayes model revealed that all sections were convergent with no marked trend to larger or smaller population sizes. The available evidence supports either a closed population or small change in the population size over the study period.

2. *All fish in a stratum (day and section), whether marked or unmarked, have the same probability of being caught.*

The study area was stratified into three river sections to account for any differences from marks applied, population size, or spatial catchability. Similarly, the day strata accounted for new marks applied through the study. For Mountain Whitefish, as found in previous studies, there were small differences in capture probabilities by tag type and year of tag application for Mountain Whitefish. However, examination of multiple recaptures and evaluation of heterogeneous capture probability models using MARK did not provide any empirical evidence for heterogeneous effects. In Section 5, the time varying catchability model provided a better fit to the data over the constant catchability model based on AIC. In Sections 1 and 3, the evidence for the constant catchability model was strong. The logarithmic population deviation estimates show no apparent trends or large deviations with the exception of the two sampling dates in Section 5. These two days (only 15% of total recaptures) were responsible for the time varying catchability finding. The Bayesian sequential posterior probability plots of population size were consistent with the AIC and deviation evidence. We conclude that neither population size nor catchability of marks changed appreciably over the study period (the factors are confounded). The available evidence supports the assumption.

3. *Fish do not lose their marks over the period of the study.*

Each captured fish was examined for the presence of an adipose fin clip. No fish had evidence of a PIT tag and a fresh adipose fin clip scar for fish marked during the 2011 study. A total of 0 Arctic Grayling, 23 Mountain Whitefish and 1 Bull Trout had evidence of a PIT/Floy tag and an adipose fin clip scar from marks applied in 2009 and before. As such, the impact on the 2011 population estimates from lost marks should be very small.

4. *All marked fish are reported on recovery.*

It is unlikely that a marked fish would escape detection during thorough investigation during fish processing.

4.4.2 Reliability of Estimates

The assumptions required to produce population estimates appear to hold for the 2011 study. Unlike some study years (e.g., 2008, 2009) of the Peace River Indexing program, the constant catchability assumption for Mountain Whitefish in 2011 does not appear to be deficient. The foremost issue for the reliability of estimates is the weight each sampling sequence should receive for the estimation of population size. The time varying capture probability model assumes uniform reliability of the capture probability computed for each sequence (White 2006). Similarly, the time varying catchability model developed here employs equal weight for the logarithmic population deviations. The constant catchability model used by the Bayesian algorithm updates the posterior distribution of the previous sequence by the information contained in the current sampling sequence (Gazey and Staley 1986 showed that the sequential mark-recapture experiment can be characterized as a sequential Bayes algorithm updated by the binomial kernel). In other words, if the expected (mean) probability of sampling a marked fish is the fraction of the marked population then the sequential Bayes model weights each sampling sequence by the information contained in the sample regardless of variations in catchability. From a practical perspective, the population estimates were very similar (within 3%) regardless of model (constant capture probability, time varying capture probability, constant catchability, or time varying catchability) or estimation program (MARK, ADMB, or Excel Bayes).

In our opinion, the Bayes population estimates are accurate. Moreover, invalidation of the assumption that the catch rate is directly related to abundance requires population estimates under the null hypothesis of constant catchability. The remarkable consistency of the computed catchability coefficients over all sections in 2011 and across years despite the large change in population size speaks to the consistency of the population estimates.

Because there is little movement of fish between the river sections, sampling intensity can be isolated to a section. Figure 4.1 plots the precision as a function of electrofishing effort (hours) for Mountain Whitefish in Section 1. For reference, the 2011 effort expended is also plotted. The plots indicate that an effort reduction in Section 1 may risk substantive loss of power. Future project planning should focus on the addition or removal of sections rather than amend the sampling intensity of a section. For Arctic Grayling and Bull Trout, there was not sufficient data to generate a reliable power curve.

This is the first study year in which Arctic Grayling population estimates in river Sections 3 and 5 had reasonable precision (CV = 32% overall). For Bull Trout, population estimates are available, but the overall precision is poor (CV = 55%). There was not sufficient data to forecast effort levels needed for reliable population estimates for either species.

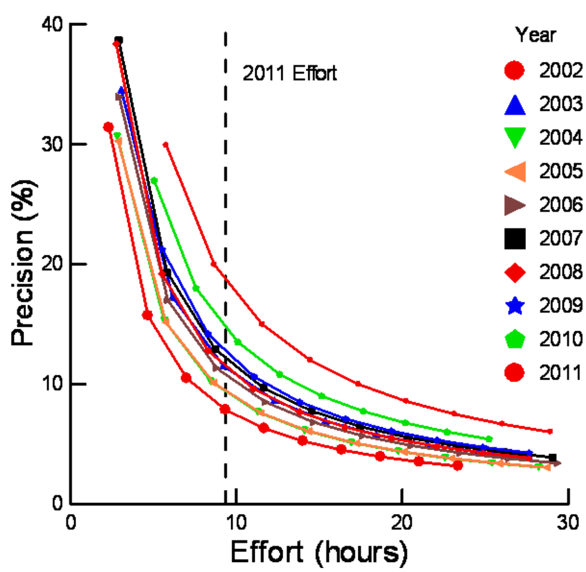

Figure 4.1 Precision (percentage of the mean) of the population estimate of Section 1 at various effort levels for Mountain Whitefish by year during the Peace River Fish Index Project, 2002 to 2011.

4.5 CATCHABILITY

Catchability coefficients were calculated under the assumptions of a closed population and that abundance indices are proportional to the population size. If these assumptions are true then the coefficients should remain constant over study years and river sections. Moreover, three caveats have been developed in past Peace River Indexing Programs for the application of catch rate as an index of abundance for Mountain Whitefish:

1. Sampling protocols (methods, equipment, and approach) must be consistent,
2. Water clarity must remain above 50 cm; and,
3. The target population must remain closed during the sampling period.

The 2011 program complied with the above caveats. The estimated catchability coefficients were also consistent across years and sections where the population estimates were deemed to be reliable or represent the same population. In other words, the catchability remained constant despite the large population size.

The catchability coefficient estimates for 2010 were not consistent with estimates for other years. The 2010 catchability coefficients in Sections 1, 3, and 5 are similar to those estimated in 2004 for Sections 3 and 5, and in 2006 for Section 3 (see Figure 3.39). Note that 2004 and 2006 had the largest population estimates prior to 2010 (see Figure 3.36). The populations for those years and sections were deemed either to be unreliable or they represented populations augmented by immigrants. Assuming the occurrence of low water levels, a potential source of immigrants would be dewatered side channels.

The patterns of PCN Dam monthly discharge during each year from 2002 to 2011 support the hypothesis that low water levels cause augmentation of populations (Figure 4.2). PCN Dam discharge during the index project sample period was near minimum flow only in 2004, 2006, and 2010. In 2011, it was near minimum for an extended period immediately preceding the sample period. Therefore, we believe the population estimates for 2010 and other years included immigrants from dewatered side channels or from recently dewatered side channels.

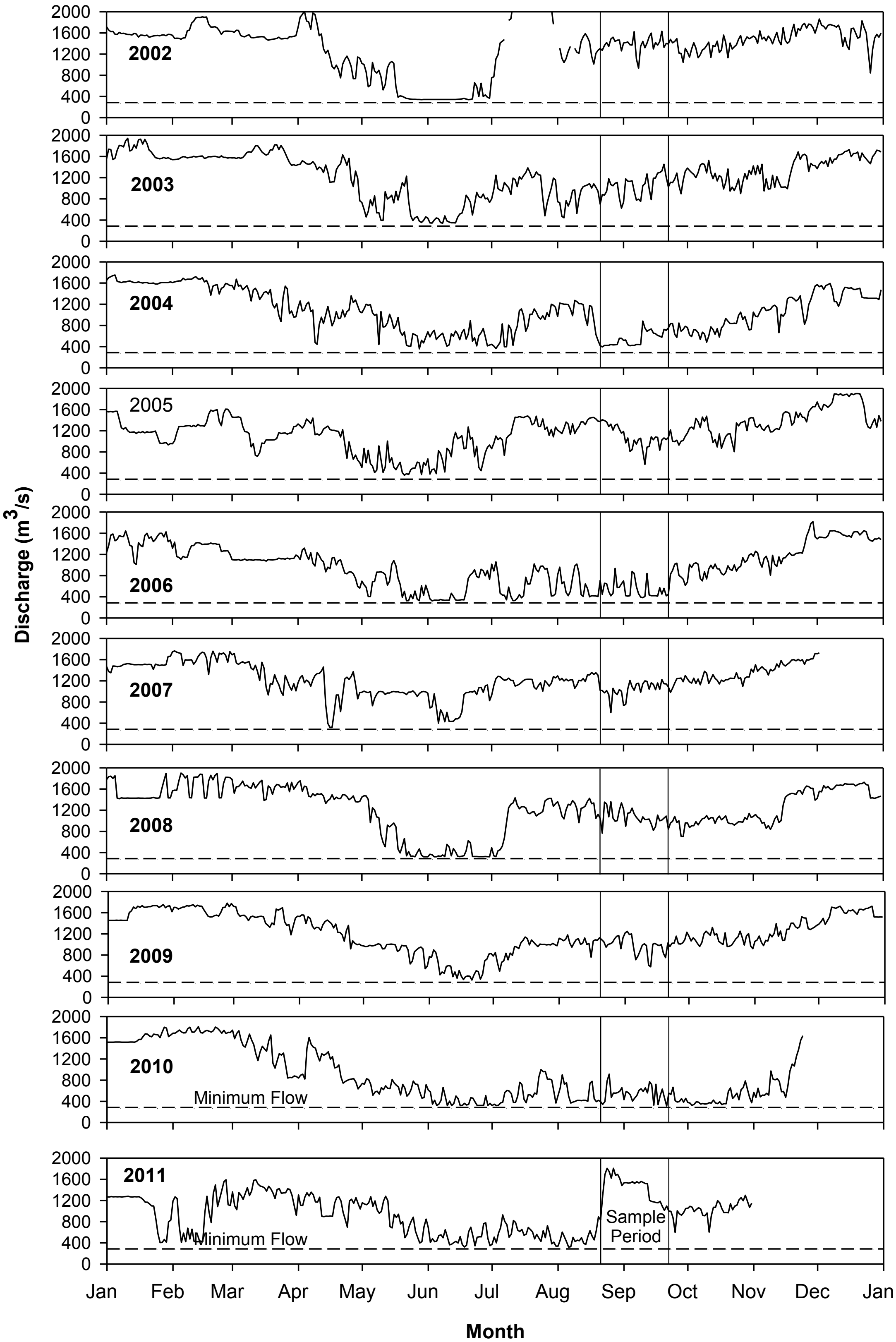

Figure 4.2 Mean daily discharge releases from the PCN Dam, Peace River Fish Index Project 2002 to 2011 (Based on preliminary discharge data provided by BC Hydro).

If catch rates were hyperstable, then high population sizes for those years and sections should be consistently associated with lower catchability, but this was not the case (Figure 4.3). The absence of this relationship for Section 1 in 2004 and Section 1 in 2006, suggests that hyperstable catch rates may not be the primary factor influencing catchability (see Figure 3.39). An alternate hypothesis may be reduced catchability. Low water clarity was the reason provided for reduced catchability in Sections 3 and 5 in 2004, but water clarity was high for problem sections in 2006 and 2010. The one consistent sample condition in all sections in 2004, 2006, and 2010 was low water level. Low water level may have caused a spatial shift of fish to deeper water making them less vulnerable to capture by boat electrofisher. Anecdotal field observations support this idea. However, lower catchability was not recorded for Section 1 in

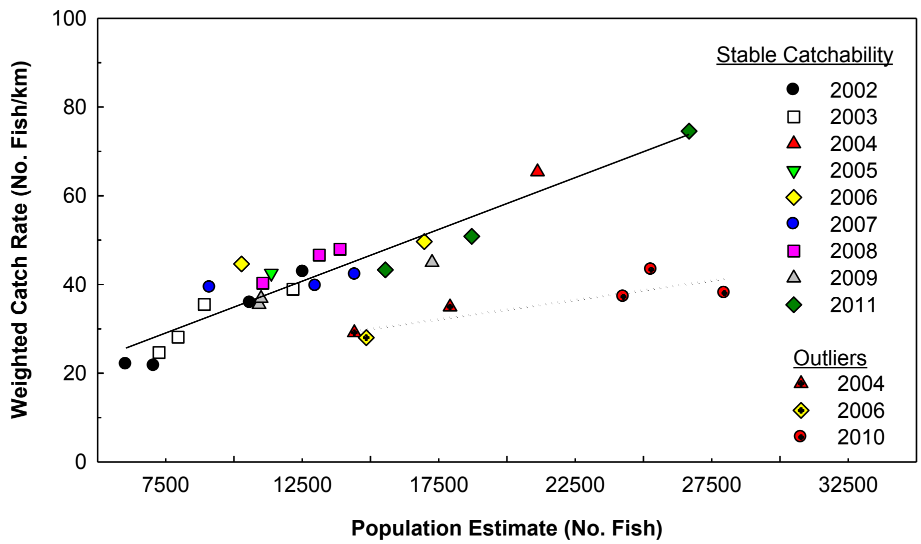

Figure 4.3 Relationships between population estimate and catch rate of Mountain Whitefish based on two data sets, Peace River Fish Index Project 2002 to 2011 (Data grouped based on apparent reliability of catchability coefficients).

Attempts can be made to describe the relationship between population estimates and catch rates if low catchability is caused by changes to catchability and not hyperstable catch rates (Figure 4.3). Reasons for changes to catchability likely are complex and will require more work. In particular, factors need to be investigated that influence differences in catchability between Section 1 and Sections 3 and 5.

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5.0 CONCLUSIONS

5.1 SUMMARY

The stated overall objective of the Large River Fish Community Indexing Program to date was to establish fish monitoring protocols that can be used reliably across the Peace River and Columbia River watersheds to provide an index of the general status of the fish community. The Peace River Fish Community Indexing Program has been integrated into the Peace Water Use Plan (WUP), and as such, the goal has shifted from evaluation of monitoring protocols to monitoring of target fish populations in order to evaluate the effectiveness of the Peace River management plans. Implementation of projects under the management plans commenced in 2008 and will continue to at least 2018.

The 2011 Peace River Fish Index Project fulfilled its primary objectives, which were to extend time series data and to build upon previous investigations. The Peace River Fish Index Project, as currently designed, has the sensitivity to identify changes in biological characteristics and abundance of Mountain Whitefish. The program's ability to detect change in the two remaining target species populations (Arctic Grayling and Bull Trout) is limited, primarily due to low fish numbers.

5.2 LIMITATIONS IN DESIGN AND METHODOLOGY

Previous years' results of the Peace River Fish Index Project have identified limitations associated with current study design and sample methodology. These issues are as follows:

1. Floy tags have a detrimental effect on fish health. This effect will continue to confound the monitoring results as long as floy-tagged fish remain a large component of sample populations.
2. Water clarity alters catchability, thereby hindering use of catch rate as an index of abundance. This prevents comparisons of catch rate data collected during high and low water clarity.
3. During some years, one or more unknown factors cause Mountain Whitefish to move or cause changes to within section catchability, which invalidates results of the closed population estimate model.
4. Arctic Grayling catch rates decline during the field sampling program, which may invalidate the catch rate data. The decline may be caused by sampling effects, fish movement, or altered catchability.
5. Adult Bull Trout are not fully present in study sections during the field program due to movements to and from spawning tributaries. This influences adult Bull Trout availability between years and between sections, which hinders interpretation of biological data, catch rates, and population estimates.
6. Low Peace River water level during or immediately preceeding the sample period appears to influence population size independent of changes to annual recruitment. The effect occurs when discharge of PCN Dam approaches minimum flow. The causal mechanism likely is displacement of fish from side channels that dewater at low flows.

7. Low water level may alter catchability, but not across all sections within a sample year. This prevents comparisons of catch rate data collected during periods of high level and low water level.
8. Mountain Whitefish ages derived from interpretation of scales underestimates actual Mountain Whitefish age. This negative bias affects the outcome of analyses of Mountain Whitefish biological characteristics will hinder construction of an age structured mark-recapture (ASMR) synthesis model for Mountain Whitefish.

5.3 DATA GAPS

As the Peace River WUP management plans are implemented the goal of the Peace River Fish Index Project will be to monitor target fish populations in order to evaluate the effectiveness of the WUP management plans. In order to achieve this goal consideration should be given to the following data gaps that that are inherent to the current design of the program and suggestions provided to address these data gaps.

1. The Peace River Fish Index Project samples large-sized fish in nearshore habitats. The design limits the ability to quantify recruitment of young fish into the target populations. The age structure mark recapture model may assist in addressing this data gap. Another technique includes development of a dedicated small fish program, similar in design to the pilot study completed during the 2005 program.
2. The Peace River Fish Index Project samples target fish populations within specific index sections. If these sections do not encompass portions of the Peace River that are targeted for restoration under the WUP management plans, the effects on the fish community may be difficult to detect. This issue can be resolved by ensuring that index sections are correctly located in the Peace River.
3. The Peace River Fish Index Project samples three target species populations – Arctic Grayling, Bull Trout, and Mountain Whitefish. If one or more of these species population are not targeted by the WUP management plans (e.g., rainbow trout) then the effects will not be monitored. This issue can be resolved by ensuring that Peace River Fish Index Project includes species targeted by the WUP management plans.

5.4 RECOMMENDATIONS

5.4.1 Monitoring Protocols

Based on the findings of the 2011 Peace River Fish Index Project we recommend the following:

1. Repeat the standard program to extend the time series data. Sample Sections 1, 3, and 5 to extend sampling history. The continuous record of consistent and rigorous sampling is a valuable baseline for the target populations. Adding years to the data set will increase its value.
2. Maintain the current study design and sampling protocols.
3. Address the issue of under estimation of Mountain Whitefish age derived from scales by development of a "correction factor" using incremental growth data for known aged marked fish that are recaptured (Gazey 2012). This approach allows use of historical index data, but may require an additional 2 to 3 years of growth data before it can be implemented.

5.4.2 Monitoring Objectives

The ultimate purpose of the Fish Index Project is to assist in the evaluation of the effectiveness of Peace River management plans, designed to improve fish habitat and productivity, by monitoring target fish populations. In preparation for implementation of the Peace River Side Channel Plan, BC Hydro commissioned a study to inventory and evaluate Peace River side channels to determine suitability for physical works to restore or maintain habitats at a base flow of 283 m^3/s (NHC *et al.* 2010). The document short-listed eleven side channels as candidate sites and provided conceptual restoration plans for each site.

The following are recommendations to adjust the current Fish Index Project in order to assist in the evaluation of the effectiveness of Peace River Side Channel Plan.

1. Continue the standard program in Sections 1, 3, and 5 and maintain the current study design and sampling protocols. The adult cohort of Peace River fish populations, which is targeted by the Fish Index Project, is sufficiently mobile to allow monitoring of side channel restoration effects without requiring spatial adjustment to the current sections.
2. Large-fish species expected to respond to side channel restoration (i.e., for spawning or rearing) should be added to the list of existing target species. Standard sampling protocols should be applied to those species (i.e., measurement of biological characteristics and fish numbers).

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APPENDICES A to E

(Attached CD)