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PEACE RIVER FISH COMMUNITY INDEXING PROGRAM - PHASE 7 STUDIES

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EXECUTIVE SUMMARY

B.C. Hydro initiated a Large River Program in the Peace River and Columbia River watersheds to help define the effects of dam and reservoir operations on fish communities. The ultimate goal was to develop monitoring tools that provided a reliable index of the fish community status. Phases 1 and 2 of the Peace River Fish Community Indexing Program focused on development of suitable monitoring tools. The primary objectives of Phases 3 to 6 were to test whether the results were repeatable using the recommended approach and to extend the time series data. The objectives of Phase 7 remained the same.

The study area encompassed a 92 km portion of the Peace River from downstream of the Moberly River confluence to just downstream of the PCN Dam. Repeated sampling (six sessions) within three sections (1, 3, and 5) occurred from 22 August to 24 September, 2007. Sampling methods included standard boat electrofishing of near-shore fish habitats.

Sampling Conditions

Mean daily discharge was approximately 1000 cms at the beginning of the field program and gradually increased for the duration of the session. Water temperatures remained above 8.5^{o}C and water clarity was well above 50 cm after the beginning of the program. As such, sampling conditions did not negatively affect the results of the 2007 program.

Fish Community Characteristics

Fish community characteristics documented in 2007 were similar to findings of previous investigations. Fifteen large-fish species were recorded and mountain whitefish was numerically dominant. Most species were widely distributed. Exceptions included cool-water sportfish species such as burbot, northern pike, walleye, and yellow perch, which were restricted to downstream sections.

Biological Characteristics

In total, 365 Arctic grayling were sampled for biological characteristics: 10 in Section 1 and 142 in Section 3, and 213 in Section 5. The fork length of sampled populations ranged from 96 mm to 446 mm and represented fish Age 0 to Age 5. The growth and body condition of Arctic grayling was similar among Sections 3 and 5. There was a significant difference in mean length of Age 1 fish between Sections 3 and 5, which was consistent with previous investigations. The apparent annual mortality of the Arctic grayling sample population was 59%.

There were annual differences in length and age distributions of Arctic grayling in Sections 3 and 5. There has been an increase in the numerical importance of larger, older fish since 2005. There were annual differences in the growth of Age 1 Arctic grayling. Lengths of Age 1 fish in 2004 and 2006 were significantly larger than lengths of Age 1 fish in 2003, 2005, and 2007.

In total, 118 bull trout were sampled for biological characteristics; 34 from Section 1, 73 from Section 3, and 59 from Section 5. Fork lengths ranged from 164 mm to 865 mm with ages ranging from Age 1 to Age 10. Length and age distributions of bull trout were similar among sections. Younger fish dominated (Age 3 fish was the most prominent group) and bull trout older than Age 6 were not well represented. Comparisons of mean length-at-age and age-specific body condition indicated few differences between sections, which was consistent with previous investigations. The apparent annual mortality of the bull trout sample populations was 41%.

In general bull trout age and length distributions remained stable between 2002 and 2007. In all sections in most years subadults dominated (Age 2 to Age 5). The absence of older fish during most years likely was caused by use of spawning tributaries by the adult cohort during the study period and did not reflect the actual age structure of the Peace River population.

In total, 8094 mountain whitefish fish were measured; 2449 from Section 1, 3428 from Section 3, and 2217 from Section 5. Fork lengths ranged from 74 mm to 520 mm with ages ranging from Age 0 to Age 13. There were spatial differences in length and age distributions of mountain whitefish in 2007, which was consistent with findings during previous investigations. Fish in Section 1 exhibited a truncated length distribution caused by the preponderance of Age 4 to Age 6 fish. Younger fish (Age 1) and older fish (> Age 6) were largely absent. In contrast, mountain whitefish in Sections 3 and 5 exhibited multi-modal length distributions that represented a wide range of ages. Similar to findings during previous investigations there were spatial differences in growth and body condition. Older age-classes in Section 1 had significantly lower mean lengths compared to fish in Sections 3 and 5. Body condition of younger fish (Age 1 to Age 4) was higher in Section 1 compared to Sections 3 and 5. The opposite was the case for Age 5 to Age 9 fish. The apparent annual mortality was highest in Section 1 (62%), intermediate in Section 3 (46%), and lowest in Section 5 (39%).

Length and age distributions in 2007 were consistent with previous studies. There were annual differences in mountain whitefish growth. Growth rates of younger fish (Age 2 to Age 4) varied, but appeared to be in general decline. In contrast, growth rates of older mountain whitefish (Age 5 to Age 8) remained stable.

Annual comparisons of mean length-at-age of mountain whitefish suggest strong year effects for some age classes. The results for anabolic constants suggested a decline in growth between 2002 and 2004, and then generally stable growth from 2005 to 2007. Annual differences in body condition were evident for younger (Age 2 to 4) and older (Age 5 to 8) mountain whitefish. In Section 1, body condition of both groups increased from 2002 to 2004, declined in 2005, and then increased in 2007. In Section 3, body condition of both groups increased from 2002 to 2004, and then remained stable. No changes were recorded in Section 5.

Catch Rate

The results of Phase 7 demonstrated that established sampling protocols were appropriate to generate reliable data and findings were consistent with previous investigations. In general, catch rates differed between species, section, and habitat. Catch rates for Arctic grayling and bull trout were low in all sections and were much less than those of mountain whitefish. Arctic grayling and bull trout catch rates tended to be higher in SFC habitats compared to SFN habitats, while the reverse was true for mountain whitefish. Mean catch rates differed between sections. Arctic grayling were scarce in Section 1, but were relatively numerous in Sections 3 and 5. Bull trout exhibited a low abundance in all three sections. Catch rates of mountain whitefish were higher in Sections 1 and 3 compared to Section 5.

Mean catch rates of target species populations changed between years. Arctic grayling catch rates in Sections 3 and 5 continued to increase since the beginning of structured sampling in 2002. Mountain whitefish catch rates in Section 1 in 2007 represented a continued decline from the high recorded in 2004. In Section 3, mountain whitefish catch rates in 2007 rebounded from the drop recorded in 2006. Results from Section 5 did not suggest a substantive change in mountain whitefish abundance. Bull trout catch rates remained low in 2007, which was consistent with previous studies.

The relative contribution of younger and older fish to sample populations within each section varied annually. For Arctic grayling in Section 3, the relative contribution of younger fish has been stable since 2002, but the contribution of older fish has varied considerably. In Section 5, the relative contribution of younger Arctic grayling has decreased; the opposite occurred for older Arctic grayling. The relative contribution of younger bull trout was low and variable in all sections; however, there has been an increase since 2004. Trends in the relative contribution of younger mountain whitefish differed between sections over the period of record. Values in Section 1 increased after the low recorded in 2004. In Sections 3 and 5 values for younger fish were generally stable after 2004. The relative contribution of older mountain whitefish was generally stable in all sections.

Sampling Effects

The anabolic constants derived from incremental growth of Floy and PIT marked mountain whitefish were different for the 2005, 2006, and 2007 studies. The incremental growth of PIT marked fish were not different from the age-length derived intervals for unmarked fish for 2005 and 2006; but it was lower than the age-length derived intervals for unmarked fish in 2007. In addition, the anabolic constants of Floy and PIT marked mountain whitefish decreased over the three studies indicating lower growth rates. The apparent decline in growth of marked fish over time and the lower growth of PIT marked fish compared to unmarked fish in 2007 may have been an artifact of sample methodology or adverse effects of PIT marks on mountain whitefish growth.

Population Estimates

Overall, the program was highly successful for mountain whitefish but much less so for Arctic grayling and bull trout. Population estimates were made using a Bayesian sequential closed population model and with an open Jolly-Seber model for the three species. Population estimates for Arctic grayling and bull trout were not available in Section 1 because no marked fish were recaptured.

Population estimates for mountain whitefish were 14,436 fish in Section 1, 12,985 in Section 3, and 9120 fish in Section 5. Population estimates for Arctic grayling in Sections 3 and 5 were 1648 fish and 783 fish, respectively. For bull trout the population estimates were 231 fish in Section 3 and 303 fish in Section 5. For Arctic grayling and bull trout, the estimate precision was poor.

Sampling in control sections immediately upstream and downstream of each standard section recorded very limited numbers of marked fish ($n = 2$). As such, short distance movements by substantial numbers of marked fish out of standard sections did not occur during the 2007 field program and it is unlikely that short distance movements during the sample period influenced capture probabilities.

For mountain whitefish, the large number of marks applied and recaptured and the structured sequential sampling design allowed the following findings:

1. Empirical evaluation of the assumptions required for population estimation.
2. Population estimates must be stratified by river section.
3. Verification that catchability is constant between sections (where compliance with the closed population assumption allows for rigorous comparison and where water clarity is not an issue).
4. The population vulnerable to sampling in 2004 was different than that in other study years.
5. Sampling effort should be standardized (sample with same array of sites, intensity and period) if high precision is required.

Catchability

The catchability estimate for mountain whitefish remained robust despite a range of conditions encountered among sample years and sections. As such, catch rate can be used as an index of absolute abundance. Fifteen data points are now available to quantify the relationship.

Three caveats should be acknowledged regarding use of catch rate as an index of abundance as follows:

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

Recommendations

The stated primary goal of the Large River Program is to establish fish monitoring protocols that can be used reliably to provide an index of the general status of the fish community. The findings of the Peace River Phase 2 to 7 programs indicated that the monitoring protocols are suitable to meet this goal particularly for mountain whitefish.

During each year of study, results were reviewed to identify issues of concern and recommendations were made to address those issues. The tasks of each subsequent study were limited to the main objective of refining sampling protocols. The Peace River Fish Community Program will continue to adhere to this overriding objective. To this end we recommend the following for the Phase 8 program:

General

1. Repeat the standard program to extend the time series data.
2. Maintain the current study design and sampling protocols with the following adjustments:
    a. Continue the control fish program to provide a random sample of fish to evaluate non-tag effect sampling activities on target fish populations. Parameters examined should include growth and body condition.
    b. Use the collected data to evaluate monitoring program activities on mountain whitefish population health.

Population Estimates

1. Sample Sections 1, 3, and 5 to extend the sampling history. The continuous six year record of consistent and rigorous sampling is a valuable baseline for the mountain whitefish population. Adding years to the data set will increase its value.

2. Conduct a mark-recapture "robust design" analysis for mountain whitefish to allow estimates of survival and the total population size which includes the population that is not subject to sampling each year.
3. Build an age-structured model that will serve to synthesize catch-per-unit-of-effort, age and abundance information. If such models are to be maintained and used for the evaluation of dam operation impacts there will be a need to collect long term information on population dynamics (e.g., mortality and stock-recruitment functional form). The continued application of long-lasting marks (e.g., PIT tags) will assist in this endeavor.

These recommendations do not address a number of data gaps/issues that may compromise the ability to interpret the ecological significance of the indexing data. Data gaps/issues identified during the present and previous investigations are as follows:

1. Develop a catchability coefficient for low water clarity conditions.
2. Collect data (i.e., fish movements, angler harvest, and river productivity) in order to interpret ecological meaning of the indexing information.
3. Collect information to quantify recruitment of younger-aged fish into the target fish populations (i.e., dedicated small fish sampling program).

As recommended during previous investigations, consideration should be given to expanding the scope of the Peace River Fish Community Indexing Program in order to address these data gaps/issues.

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

Rick Pattenden	Senior Biologist and Coauthor
Chantal Pattenden	Senior Technician
Todd Sherstone	Technician
Jessica Parker	Technician
Trisha Boorman	Technician
Dawn Cowie	Technician

Bill Gazey of W.J. Gazey Research was responsible for the population estimate and tagging effects components of the study and co-authored the report.

M. Miles and Associates Ltd. were responsible for initiating the water level recorders.

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1.0 INTRODUCTION

1.1 BACKGROUND

In 2001, B.C. Hydro initiated a Large River Program in the Peace River and Columbia River watersheds to help define the effects of dam and reservoir operations on fish communities. The ultimate goal of the program was to establish cost-effective monitoring protocols for the Columbia River and Peace River systems to provide reliable indices of fish population characteristics.

The program was designed to proceed in phases. In Phase 1 (2001/02) sampling was undertaken to update basic information on fish populations and to test methodological assumptions. Efforts during Phases 2 (2002/03), 3 (2003/04), 4 (2004/05), 5 (2005/06) and 6 (2006/07) built on the previous findings to refine sampling and analytical protocols. Phase 7 (2007/08) was a continuation of this work.

Mainstream Aquatics Ltd. (Mainstream) and its study team completed Phases 1 to 6 of the Peace River component of the Large River Program. In July 2007, Mainstream was contracted by B.C. Hydro to complete Phase 7 of the program. Similar to the 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 and tagging effects components.

1.2 OBJECTIVES

The objectives of Phase 7 were similar to those of previous phases and were as follows:

1. To conduct a boat electrofishing sampling program to monitor annual changes in population abundance, distribution, and biological characteristics of target species.
2. Sample upstream and downstream control sections associated with each standard section to monitor potential emigration of marked fish and to collect control samples (very low numbers of fish marked in 2007 were recorded in control samples [*n* = 2]; therefore, these data are not evaluated in the report).
3. Populate an existing MS ACCESS® electronic database for storing, organizing, and retrieving fish population and fish habitat data.
4. Prepare a concise technical report to document field-sampling protocol, the findings and recommendations of the Phase 7 investigations.
5. Participate in a Large River Program workshop with other Phase 7 investigators, regulatory agency representatives, selected scientists, and B.C. Hydro staff to disseminate results and to discuss recommendations for further actions.

1.3 TARGET SPECIES

Three target species were investigated during Phase 7:

- 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). It included a 90 km portion of the Peace River from downstream of the Moberly River confluence (Km 53) to downstream of the PCN Dam (Km 145). Sampling occurred in three previously sampled standard sections: Section 1, Section 3, and Section 5 (Table 1.1; Appendix A). Standard sections varied in total length from 8.2 km to 11.4 km.

Table 1.1 Standard sections of the Phase 7 Peace River Fish Community Indexing Program, 2007.

Area	Section	Location[a]	Section Length (km)	Sampled[b] Length (m)	Percent of Section Sampled[c]
Hudson Hope	1	Km 137.0 to 145.2	8.2	12,057	54.2
Downstream of Halfway River	3	Km 89.8 to 99.2	9.4	19,467	65.5
Downstream of Moberly River	5	Km 53.4 to 64.8	11.4	14,196	51.8

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

Two control sections were located immediately adjacent to each standard section. These were designated as upper or lower controls based on location (Table 1.2; Appendix A).

Table 1.2 Control sections of the Phase 7 Peace River Fish Community Indexing Program, 2007.

Area	Section	Location[a]	Section Length (km)	Sampled[b] Length (m)
Hudson Hope	1CL	Km 134.1 to 140.0	5.9	5108
	1CU	Km 146.5 to 147.1	0.6	1077
Downstream of Halfway River	3CL	Km 84.9 to 88.2	3.3	2892
	3CU	Km 100.5 to 108.5	7.5	6207
Downstream of Moberly River	5CL	Km 49.5 to 51.0	1.5	1755
	5CU	Km 64.9 to 68.5	3.6	1430

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

1.5 SAMPLE PERIOD

Sampling occurred during 36 consecutive days between 21 August and 25 September 2007.

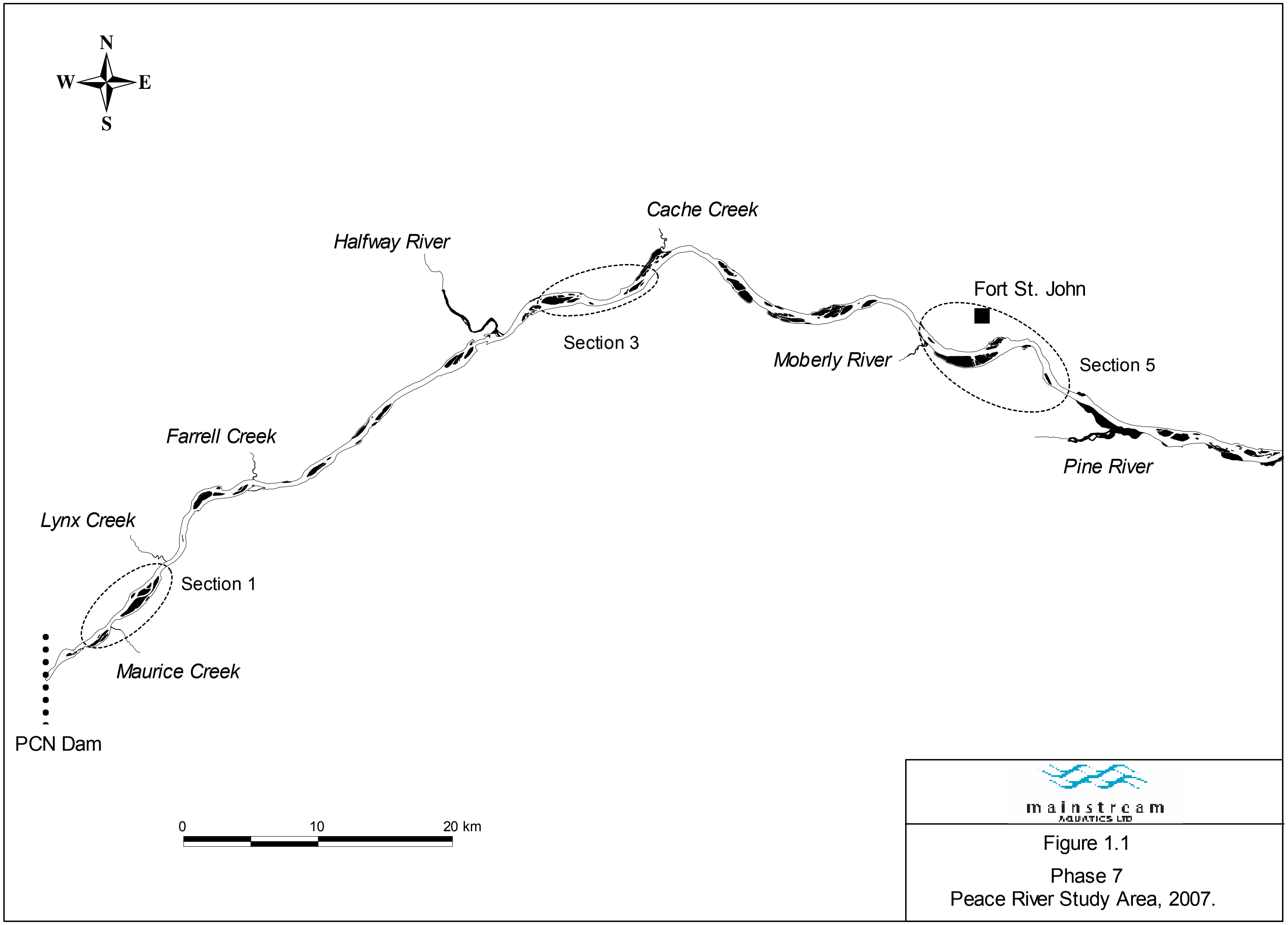


Figure 1.1 Study area of the Phase 7 Peace River Fish Community Indexing Program, 2007.

2.0 METHODS

2.1 FIELD PROGRAM

2.1.1 Approach

The field program was designed to collect data needed to monitor fish numbers (relative abundance and population estimates) and biological characteristics of target fish populations in the Peace River. Because the primary focus was to generate reliable population estimates for target fish species, the approaches used for most study components were adjusted to accommodate this requirement.

2.1.1.1 Standard Sampling

Sites

The nearshore areas (i.e., river margins) of fifteen discrete sites were sampled in each standard section using a boat electrofisher (Table 2.1; Appendix Table A2). Standard sites were distributed throughout each section and ranged in length from 445 m to 1840 m.

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 each standard section were distributed as follows: eight SFC sites and seven SFN sites.

Table 2.1 Number and length of sites sampled in standard sections during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Type	Section	Number of Sites	Length (m)		
			Average	Minimum	Maximum
Standard	1	15	827	445	1092
	3	15	1302	855	1840
	5	15	942	562	1171

Table 2.2 Habitat categories sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

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 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. The last two sessions focused on obtaining recapture data for the three target species. Mountain whitefish were not marked or processed for biological data to maximize time spent sampling during Sessions 5 and 6. 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.

Table 2.3 Distribution of sampling effort (hours sampled) in standard sections during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	Session						Total
	1	2	3	4	5	6	
1	2.0	1.9	2.0	2.1	1.8	1.9	**11.6**
3	2.8	2.8	3.3	3.1	2.9	2.9	**17.8**
5	2.1	2.2	2.4	2.0	2.0	2.0	**12.7**
Total	**6.9**	**6.9**	**7.7**	**7.2**	**6.7**	**6.8**	**42.2**

2.1.1.2 Control Sampling

Sites

Sampling occurred in control sections located immediately upstream and downstream of each standard section (Table 2.4; Appendix Table A2). Each control section contained two sites that represented either SFC or SFN habitat categories. Attempts were made to establish one SFC and one SFN site in each control section. However, the availability of suitable sites (discrete habitat types) close to standard sections and the presence of fish dictated where control sites were placed.

Table 2.4 Number, type, and length of sites sampled in control sections during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Type	Section	Number of Sites	Length (m)	
			Minimum	Maximum
Control	1CL	2	668	734
	1CU	2	483	594
	3CL	2	723	1180
	3CU	2	682	1684
	5CL	2	510	920
	5CU	2	875	880

Effort

Each permanent control site was sampled twice: once at the beginning (Session 1) and end (Session 6) of the field program. There were two reasons for this schedule. Firstly, to examine whether fish marked in the standard sections moved upstream or downstream after release (within and between years). Secondly, to collect biological data from control fish (i.e., untagged individuals assumed not to be affected by sampling in the standard sections) for comparison to treatment fish collected in the standard sections.

Table 2.5 Distribution of sampling effort (hours sampled) in control sections during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	Session		Total
	1	6	
1CL	0.2	0.2	**0.4**
1CU	0.1	0.1	**0.2**
3CL	0.3	0.3	**0.6**
3CU	0.2	0.2	**0.4**
5CL	0.3	0.2	**0.5**
5CU	0.2	0.2	**0.4**
Total	**1.3**	**1.2**	**2.5**

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 used during Phase 7 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 m) 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.

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.

Upon completion of an electrofishing section, captured fish were enumerated, processed, and released. To avoid recapture of previously collected fish, processed fish were released several hundred metres upstream in the same section.

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 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. Structures were placed in labeled envelopes and air-dried before storage.

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. It should be noted that PIT tags used prior to 2006 were of the FECAVA type (125 kHz), which have a 10 digit alpha-numeric code. The Power Tracker VIII could read both tag types. Fish collected from control sections were not marked with PIT tags.

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. Size 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. All nontarget species were counted and released.

2.1.5 Measured Parameters

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

- Date and time
- Effort (seconds/meters)
- Sample method settings
- Water conductivity (microseimens)
- Water temperature (^{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).

2.1.6 Measurement of Water Levels

The 8007WDP water depth logger manufactured by Unidata, was used to monitor water levels (and temperature) in Section 1 and Section 5. The instrument consists of a 4 cm diameter, 60 cm long submersible stainless steel tube containing a pressure sensitive transducer, thermistor, power supply, and data logger. The instrument cable contains a hollow polyethylene tube to provide an atmospheric pressure reference for the transducer and a communication line mounted within a urethane jacket protected with stainless wire mesh. The polyethylene tube is vented through a silica gel desiccant to minimize the potential for condensation. The data logger can store 52,000 entries. Each instrument was pre-programmed to measure water depths and water temperature every minute and record the average value every fifteen minutes. This sampling procedure increases the signal to noise ratio and the accuracy of the recorded data.

Both instruments were tested prior to being shipped to the field. The lower 50 m of polyethylene tube on each unit was protected using a metal flex conduit tube.

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). 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 processed mountain whitefish required use of a random subsample of ageing structures. A random number generator was used to select ageing structures from approximately 10% of nonfloy-tagged mountain whitefish captured for the first time in 2007 (previously PIT-tagged and unmarked fish) in each section using SPSS© software. Floy-tagged fish were not included due to strong, negative tag effects (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).

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 Analytical Approach

Parameters used as monitoring tools included biological characteristics, relative abundance, and population estimates. Methods are described below. Unless otherwise stated, statistical analyses followed procedures described in Sokal and Rohlf (1981).

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 required for parametric statistical analyses.
4. Univariate statistical analyses included t-test for two independent samples, Analyses of Variance (ANOVA), and Analysis of Covariance (ANCOVA).
5. Post-hoc means tests included Tukey's B (homogeneous sample variance) and Dunnett's T3 (heterogeneous sample variance).
6. 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, 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).

Fish age was an integral part of the biological characteristics analyses. Age data of unmarked and fish marked during previous investigations were available for use. Age distribution and annual mortality were described using unmarked and marked fish captured for the first time in 2007. Length-at-age, growth rate, and body condition were described using age data collected during the present study and age data collected during previous investigations. This latter approach was used to increase sample sizes in order to improve the power of statistical tests. Age data from Floy-tagged mountain whitefish and Arctic grayling were excluded from all analyses due to negative tag effects (Mainstream and Gazey 2007).

<u>Body Condition</u>

The relationship between weight and length of fish was used as a measure of fish health. Fulton's Condition Index (*k*) was used for this purpose. To minimize potential problems associated with correlations between fish length and body condition (Cone 1989), samples were stratified by age for comparisons.

<u>Length-at-Age and Growth Rate</u>

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 bull trout in some sections due to the absence of smaller fish. For these cases, a best-fit regression model was applied. A linear regression best described the age-length relationship 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_∞.

<u>Mortality</u>

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 sections and years, data were combined for catch curve analyses of Arctic grayling and bull trout. This 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.

2.2.5 Index of Recruitment

An index of recruitment for each target species in each section was calculated by dividing the number of younger fish (defined as < 250 mm fork length) and the number of older fish (≥ 250 mm) by the total number of fish recorded in the section. A fork length of 250 mm was used as the threshold between small and large fish because it corresponded to the predicted length of sexual maturity for Arctic grayling (Age 2) and mountain whitefish (Age 3). For bull trout 250 mm fork length corresponded to length at Age 2 or Age 3. Use of 250 mm also allowed inclusion of observed Arctic grayling and bull trout in the analyses.

To facilitate comparisons between years, the index was weighted by the relative contribution of fish (in terms of total number recorded) for a particular species and section over the period of record. For sections 1 and 3 this was 2002 to 2007; for Section 5 this was 2004, 2005, and 2007. The approach facilitated evaluation of annual recruitment within each section because sampling effort (number of sites and sessions) was constant among years. The approach does not allow comparisons between sections.

2.2.6 Sampling Effects

The growth rate of Floy and PIT tagged mountain whitefish was examined through the parameterization of von Bertalanffy growth models based on the growth increment exhibited by marked and recaptured fish during the associated time-at-large. The model can be derived from the differential form of the von Bertalanffy model described by Taylor (1963),

(1) $$\frac{dL}{dt} = KL_{\infty} - K \cdot t$$

where K is the growth coefficient, L_∞ is the asymptotic length coefficient and t is time. The integration of Equation (1) with initial conditions that length (L) equals 0 when age $t = t_0$ yields the usual formulation of the model suitable for length-at-age data:

(2) $$L = L_\infty\left[1 - \exp\{-K(t - t_0)\}\right]$$

Similarly, the integration of Equation (1) with initial conditions that length at release (L_0) equals length at recapture (L_r) when time-at-large is zero ($\Delta t = 0$) yields a formulation suitable to mark and recapture data:

(3) $$L_r = L_\infty - (L_\infty - L_0)\cdot\exp\{-K\cdot\Delta t\}$$

Estimates of the parameters of K and L_∞ were made through nonlinear least squares regression of Equation (3). Statistical comparisons of the Floy and PIT mark-recapture sets were then made using the anabolic constant (Product (K, L_∞) following Gallucci and Quinn (1979).

Estimates of growth of Floy and PIT tagged fish were compared to estimates of growth of the aged sample of mountain whitefish collected from standard sections.

2.2.7 Population Estimates

A mark-recapture program was conducted on mountain whitefish, Arctic grayling, and bull trout over the period August 22 to September 24, 2007 (duration of 34 days). Three sections were sampled (Figure 1.1) by six sequential sessions (Table 2.6).

Table 2.6 Sampling dates by zone and session and the study days used for the Jolly Seber model during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Session	Section		
	One	Three	Five
Actual Sampling Dates			
1	22, 23 Aug	29, 30 Aug	25, 26 Aug
2	28, 31 Aug	1, 2 Sep	3, 4 Sep
3	5, 6 Sep	7, 8 Sep	9, 10 Sep
4	11, 12 Sep	13, 14 Sep	15, 16 Sep
5	17 Sep	18 Sep	19-Sep
6	20 Sep	22 Sep	24 Sep
Mid or Study Day			
1	1.0	8.0	4.0
2	8.0	11.0	13.0
3	15.0	17.0	19.0
4	21.0	23.0	25.0
5	26.5	27.5	28.5
6	29.5	31.5	33.5

During the first five sessions marks were applied, but during the final session emphasis was placed on searching for the presence of a mark on fish encountered. 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 (section 2.2.7.3) could be applied because of sparse data.

2.2.7.1 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 vulnerability may be different because of possible differences in catchability, number of available marks for recapture or the population size.

We investigated the importance of these factors by first examining the capture behavior of the marked fish. Floy tags have been applied from 2002 to 2004 and PIT tags have been applied over the 2004 to 2007 period. For marks applied prior to 2007, the fish had to be caught again in 2007 and the tag recorded to qualify as a mark release. The recapture rate in 2007 by tag type (Floy and PIT) and initial year of release were compared (G-test, Sokal and Rohlf, 1981), 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 Phase 7 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). Possible tag effects on growth and condition were also investigated as described above (see section 2.2.3).

The movement of fish between sections in 2007 and at-large for over a year (marked in 2002 to 2006 and recaptured in 2007) was assessed through weighting the recaptures by sampling intensity. Within each section are 15 sampling 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. In order to further examine fish movement, two control sections were added to each standard section (one upstream and the other downstream) where sampled fish were examined for the presence of a mark (i.e., no new marks were applied at the control sections).

2.2.7.2 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 estimating total survival, the time of sampling was assumed to be the mid-point of the actual sampling dates (Table 2.6). Each section was modeled independently with fish recaptured in a different section treated as removals. For all sections (1, 3, and 5), the model selection was for a closed population (nochange in population size over the period of the study). Similarly, the large number of recaptures also allowed an empirical evaluation of homogeneous and heterogeneous capture probabilities by employing MARK (closed population capture-recapture models) software (White 2006) to calculate delta Akaike's information criteria, adjusted to account for the number of parameters, and the associated model likelihood for each of the sections.

A Jolly-Seber open population model (allows for recruitment into the population and survival other than 1.0), using the POPAN-5 software, was applied to each section as well to provide more diagnostics for model selection. As recommended by Seber (1982), survival estimates were unconstrained (i.e., can exceed 1.0) such that changes in capture probability (catchability) over the study period are not obscured by constraining survival.

2.2.7.3 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 to the data, allow for stratified capture probabilities and cope with sparse recaptures characteristic of Arctic grayling and bull trout. The major assumptions required for the Bayesian model are as follows:

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 or first observed in 2007 from a previous study 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 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:

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

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

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 removal 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 22 August 2007, 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%. Other parameter values 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. For mountain whitefish, 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 population estimates were only available for Sections 3 and 5 and the posterior distributions were very skewed which precluded the application of the central limit theorem. Instead, the compound posterior distribution for the sum of Sections 3 and 5 for Arctic grayling and bull trout were calculated following Gazey and Staley (1986).

2.2.8 Catchability

One of the key quantities of interest is the catchability coefficient, or catchability. If catchability is constant across years and river sections then indices of abundance such as catch rate (No. fish per unit effort) are comparable.

An estimate for catchability for the *i*'th section was calculated as:

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

where E_i is effort and N_i is the population estimate for section *i.* Given the mark recapture and effort data, the variance of catchability 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 was also examined using the empirical relationship between catch rate (No. fish per km) and the fish population estimate as follows. Firstly, a weighted estimate of the mean catch rate was calculated for each section using procedures described in Mainstream and Gazey (2004). Sampling protocols required stratification of section data by habitat category (SFC and SFN) as a way to improve precision. The mean catch rate (across all sample sessions) in each habitat category (and associated variation) was weighted by the total length of that habitat category sampled within the section. The two values were summed to generate a weighted estimate of catch rate. Secondly, 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).

2.2.9 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 2007 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 marks applied or fish examined is small in relation to the population size, a sampling factor of 2 nearly doubles the marks applied and examined, 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.

2.2.10 Data Management System and Update Database

Microsoft® Access 2000 was used to enter, check, and store the raw fish and habitat data collected during Phase 7. This information was used to update the Peace River Fish Community Indexing Program database.

3.0 RESULTS AND DISCUSSION

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, sampling effects, population estimates, and catchability. Raw data are provided in Appendices B, C, D, and E.

3.1 SAMPLING CONDITIONS

Sampling conditions examined included discharge, water temperature, and water clarity.

3.1.1 Discharge

In 2007, there was no large change in mean daily discharge or the hourly pattern of discharge. At the start of the field program (22 August) mean daily discharge from the PCN Dam was approximately 1013 cms (Figure 3.1). In general, discharge increased gradually during the entire field program, which ended on 25 September; mean daily discharge on this date was 1156 cms. Within this general trend, hourly discharge fluctuated widely during each 24 h period on most sample days (Figure 3.2). This discharge pattern differed from that of previous studies. In 2006, discharge tended to be lower and more stable (Mainstream and Gazey 2007).

Similarly, there were no large changes in Peace River discharge caused by inputs from the Halfway River and other tributaries. Field observations indicated that flows of these tributaries were moderate at the start of the field program and slowly decreased during the session.

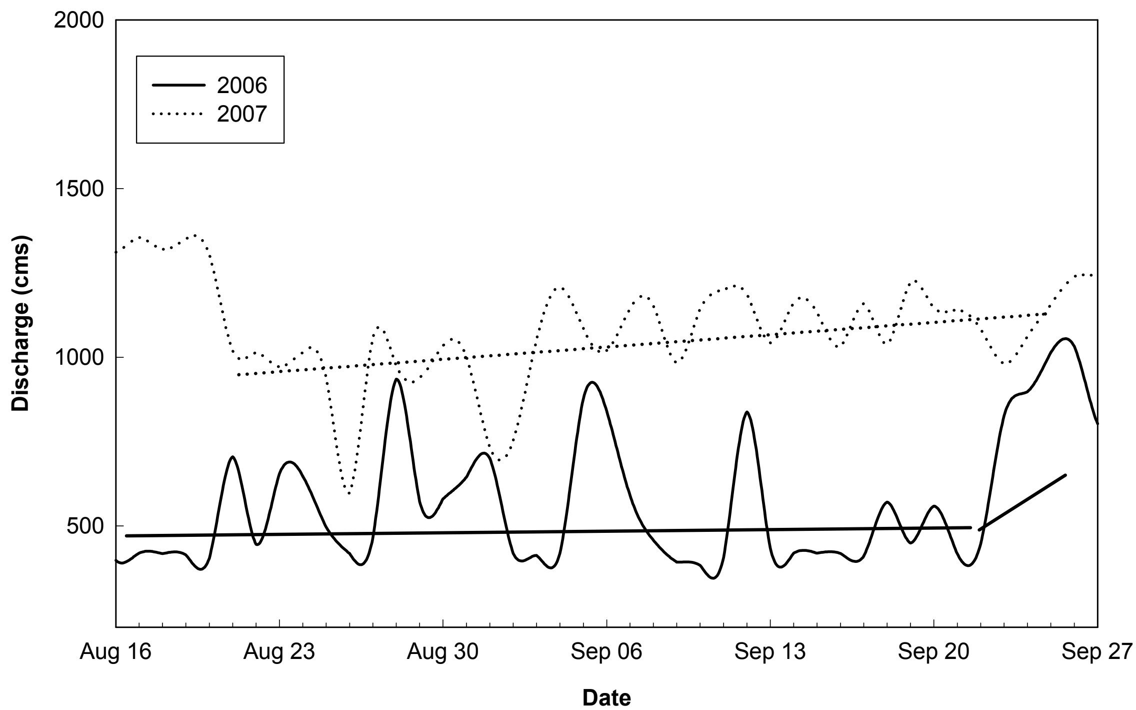


Figure 3.1 Comparisons of Peace River mean daily discharge during field sessions of the Peace River Fish Community Indexing Program, 2006 and 2007.

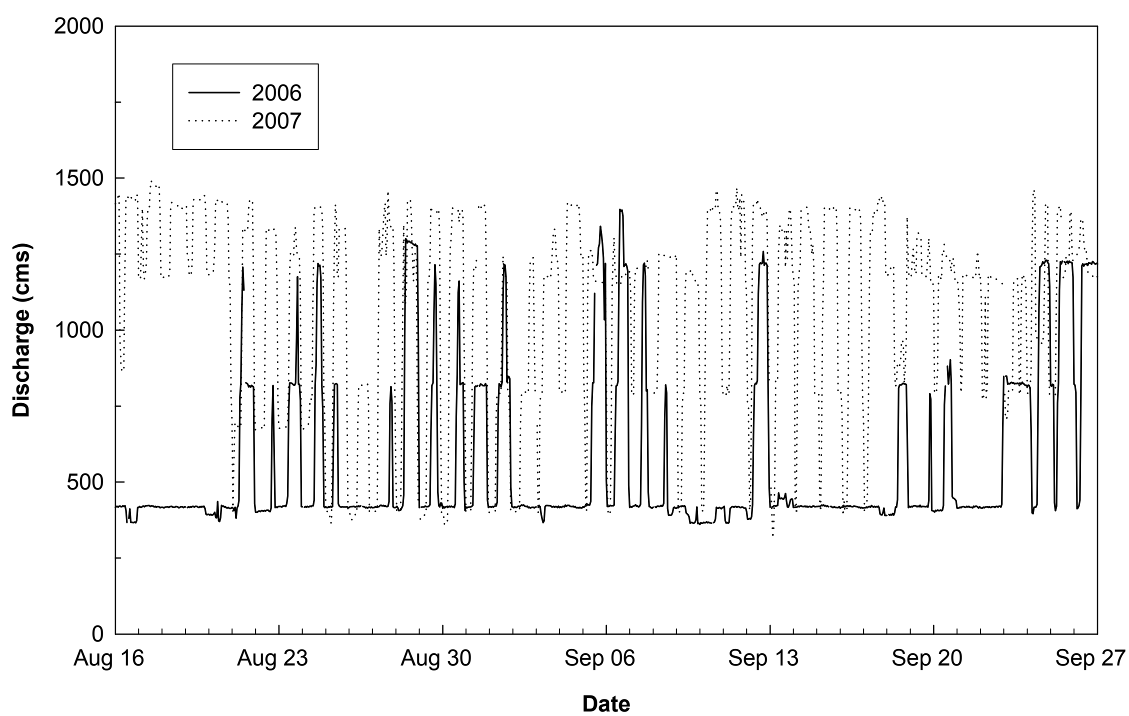


Figure 3.2 Comparisons of Peace River hourly discharge during field sessions of the Peace River Fish Community Indexing Program, 2006 and 2007.

3.1.2 Water Clarity

Mean water clarity in the Peace River changed over time and space the during the field program (Table 3.1, Figure 3.3). Water clarity values were generally close to or above 200 cm in Section 1. At the start of the program water clarity was low in Sections 3 and 5 (daily mean < 60 cm). Measured values in both sections progressively increased during the remainder of the program until mean daily values were approximately 150 cm. Work by P&E (2002) indicated that water clarity of 50 cm was the threshold at which there was a negative effect on capture efficiency. As such, capture efficiency may have been negatively impacted by low water clarity in Sections 3 and 5 at the beginning of the field program.

Table 3.1 Water clarity (cm) during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	Mean (±SE)	Range
1	196.8 ± 2.7	135 - 210
3	109.1 ± 6.6	20 - 210
5	109.2 ± 4.6	30 - 180

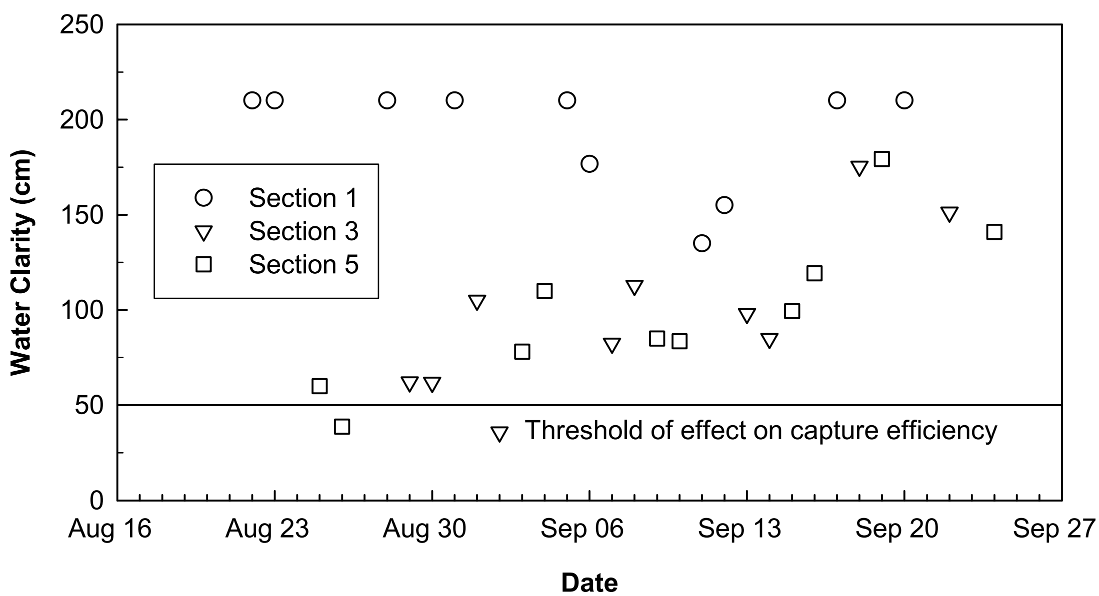


Figure 3.3 Mean daily water clarity in Sections 1, 3, and 5 during Phase 7 of the Fish Community Indexing Program, 2007.

3.1.3 Water Temperature

Mean daily water temperatures ranged from 9.0°C to 12.9°C in Section 1 and 10.1°C to 12.7°C in Section 5 during the 2007 field program (Figure 3.4). Temperatures were slightly higher in Section 1 compared to Section 5 at the start of the program, but this pattern was reversed after September 5. These temperatures were well above the threshold for initiation of mountain whitefish spawning.

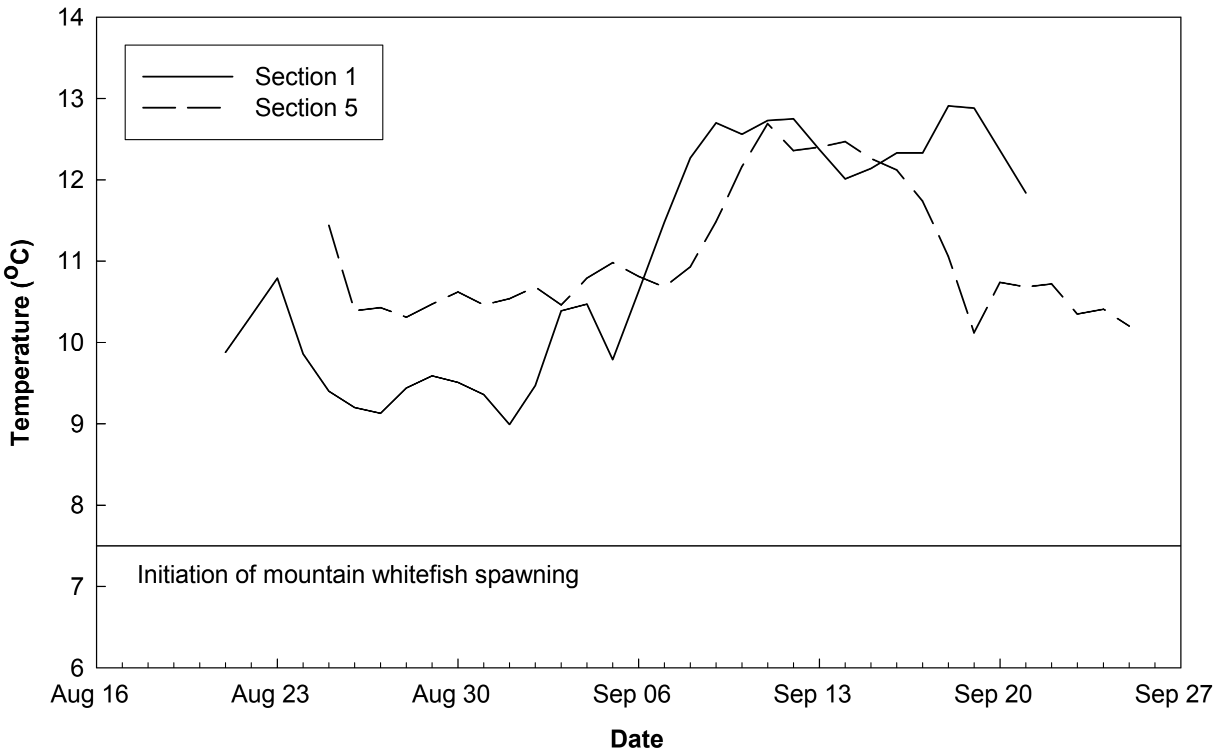


Figure 3.4 Mean daily water temperatures in Sections 1 and 5 during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

3.2 GENERAL CHARACTERISTICS OF THE FISH COMMUNITY

In total, 12,882 fish representing 15 species were recorded in 2007 (Table 3.2). The species included 11 sportfish, 3 suckers, and 1 cyprinid. Mountain whitefish were very numerous and dominated the sample (11,200 fish; 87.0%). The two other target species were not abundant; in total 365 Arctic grayling (2.8%) and 166 bull trout were recorded (1.3%). After mountain whitefish, longnose sucker was the most prominent species (679 fish; 5.3%). The results were similar to findings of previous studies where mountain whitefish was the dominant species followed by much lower numbers of all other species and longnose sucker was the second most numerous species recorded.

Table 3.2 Number and percent composition of fish species recorded during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Family	Common Name	Scientific Name	Number	Percent
Salmonidae	Arctic grayling	*Thymallus arcticus*	365	2.8
	Bull trout	*Salvelinus confluentus*	166	1.3
	Kokanee	*Oncorhynchus nerka*	154	1.2
	Lake trout	*Salvelinus namaycush*	3	0.0
	Lake whitefish	*Coregonus clupeaformis*	4	0.0
	Mountain whitefish	*Prosopium williamsoni*	11,200	87.0
	Rainbow trout	*Oncorhynchus mykiss*	102	0.8
Gadidae	Burbot	*Lota lota*	4	0.0
Esocidae	Northern pike	*Esox lucius*	7	0.1
Percidae	Walleye	*Sander vitreus*	17	0.1
	Yellow perch	*Perca flavescens*	1	0.0
Catostomidae	Largescale sucker	*Catostomus macrocheilus*	146	1.1
	Longnose sucker	*Catostomus catostomus*	679	5.3
	White sucker	*Catostomus commersoni*	10	0.1
Cyprinidae	Northern pikeminnow	*Ptychocheilus oregonensis*	24	0.2
Total			**12,882**	**100.0**

The majority of species were recorded in all three sections (Table 3.3). Exceptions included lake trout, lake whitefish, burbot, northern pike, walleye, and yellow perch, which occurred in only one or two sections. These findings were generally similar to those recorded during previous studies.

Table 3.3 Spatial distribution of fish species recorded during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Name	Section		
	1	3	5
Arctic grayling	●	●	●
Bull trout	●	●	●
Kokanee	●	●	●
Lake trout		●	
Lake whitefish	●	●	
Mountain whitefish	●	●	●
Rainbow trout	●	●	●
Burbot		●	●
Northern pike			●
Walleye		●	●
Yellow perch			●
Largescale sucker	●	●	●
Longnose sucker	●	●	●
White sucker	●	●	●
Northern pikeminnow	●	●	●

3.3 BIOLOGICAL CHARACTERISTICS

Biological characteristics examined for target species populations included length and age distributions, growth rate, length-at-age, anabolic constant, body condition, and mortality rate. Summaries are presented for each section. When appropriate, section and annual differences are examined.

3.3.1 Arctic grayling

In total, 365 Arctic grayling were sampled for biological characteristics: 10 in Section 1 and 142 in Section 3, and 213 in Section 5. The low numbers of sampled fish limited the assessment of biological characteristics in Section 1. Fork lengths of sampled populations ranged from 96 mm to 446 mm and represented fish Age 0 to Age 5. Age 0 fish were recorded only in Section 5 (*n* = 2).

Arctic grayling displayed spatial differences in length and age (Figure 3.5). The sample was dominated by Age 1 fish (48% of the sample) in Section 3. Ages 2 to 4 accounted for most of the sample in Section 5 (23% to 31%).

The von Bertalanffy growth curves indicated similar growth of Arctic grayling (Figure 3.5 and Table 3.4). Mean length of Age 1 fish in Section 3 was significantly smaller than the mean length of Age 1 fish in Section 5 (P = 0.000; t-test for independent samples; unequal variances). There were no significant differences in growth rates (ANCOVA homogeneity of slopes, P = 0.239) or adjusted mean lengths of fish from Age 2 to Age 4 between Sections 3 and 5 (ANCOVA, P = 0.812). The results indicated that growth of sampled Arctic grayling from Ages 2 to 4 in Sections 3 and 5 were similar.

Table 3.4 Mean length-at-age of Arctic grayling sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Age	Section 1		Section 3		Section 5	
	n	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**
0	-		-		2	97.5 ± 1.5
1	2	189.5 ± 5.5	66	180.0 ± 1.5	35	201.5 ± 3.9
2	2	303.0 ± 8.0	32	282.6 ± 4.3	50	289.9 ± 3.1
3	2	285.5 ± 31.5	15	346.0 ± 4.9	60	333.7 ± 3.3
4	2	366.5 ± 7.5	21	365.5 ± 7.4	45	369.9 ± 3.6
5	2	398.5 ± 5.5	4	391.0 ± 4.6	2	388.5 ± 7.5

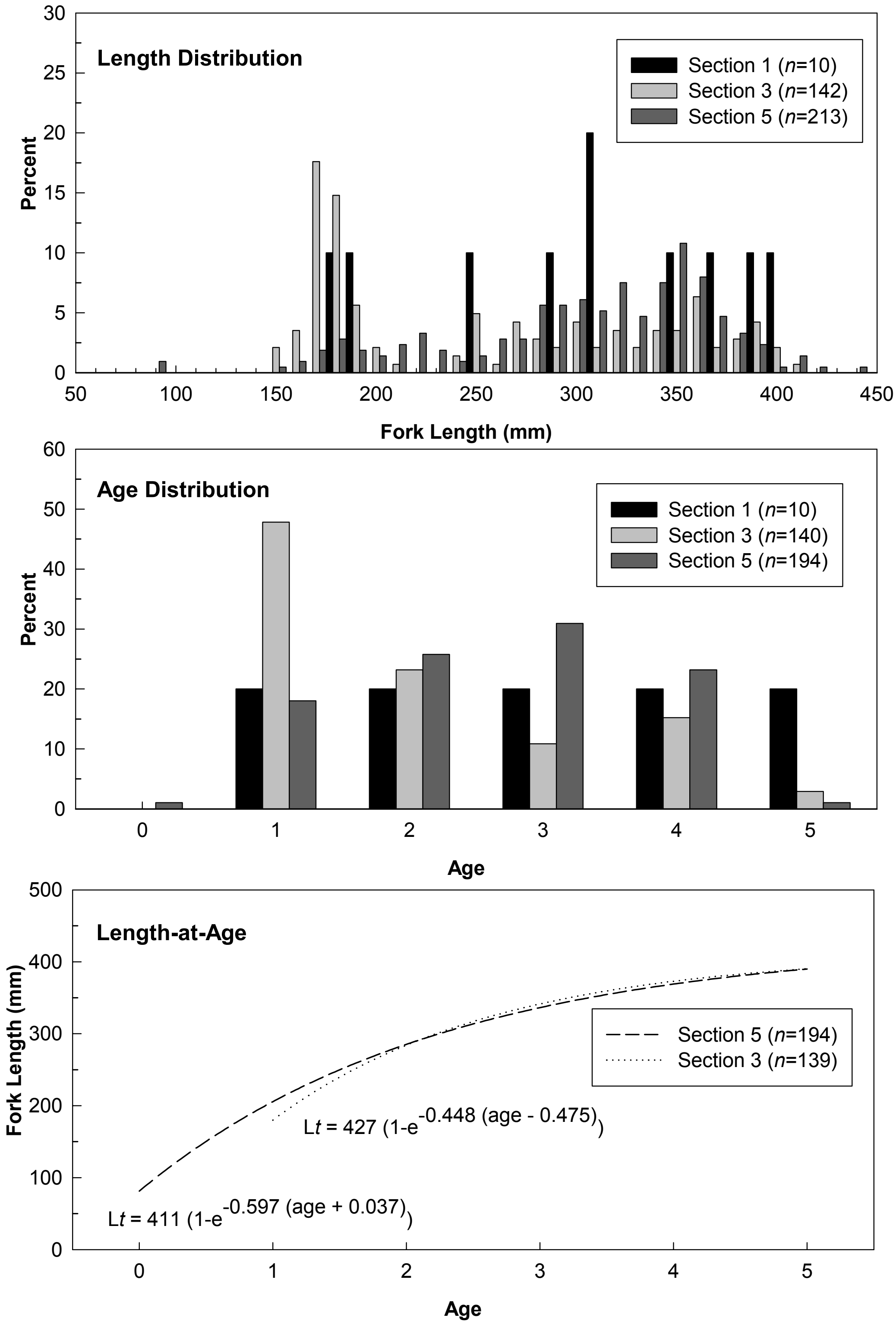


Figure 3.5 Length and age distributions and length-at-age relationships for Arctic grayling sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007 (length-at-age relationship described using von Bertalanffy growth model).

Body condition-at-age of Arctic grayling was similar among Sections 3 and 5 (Table 3.5). A visual inspection of the data indicated that Arctic grayling body condition in Section 1 was consistently higher than body condition of fish in the other two sections. Small samples sizes prevented a statistical evaluation of this apparent difference.

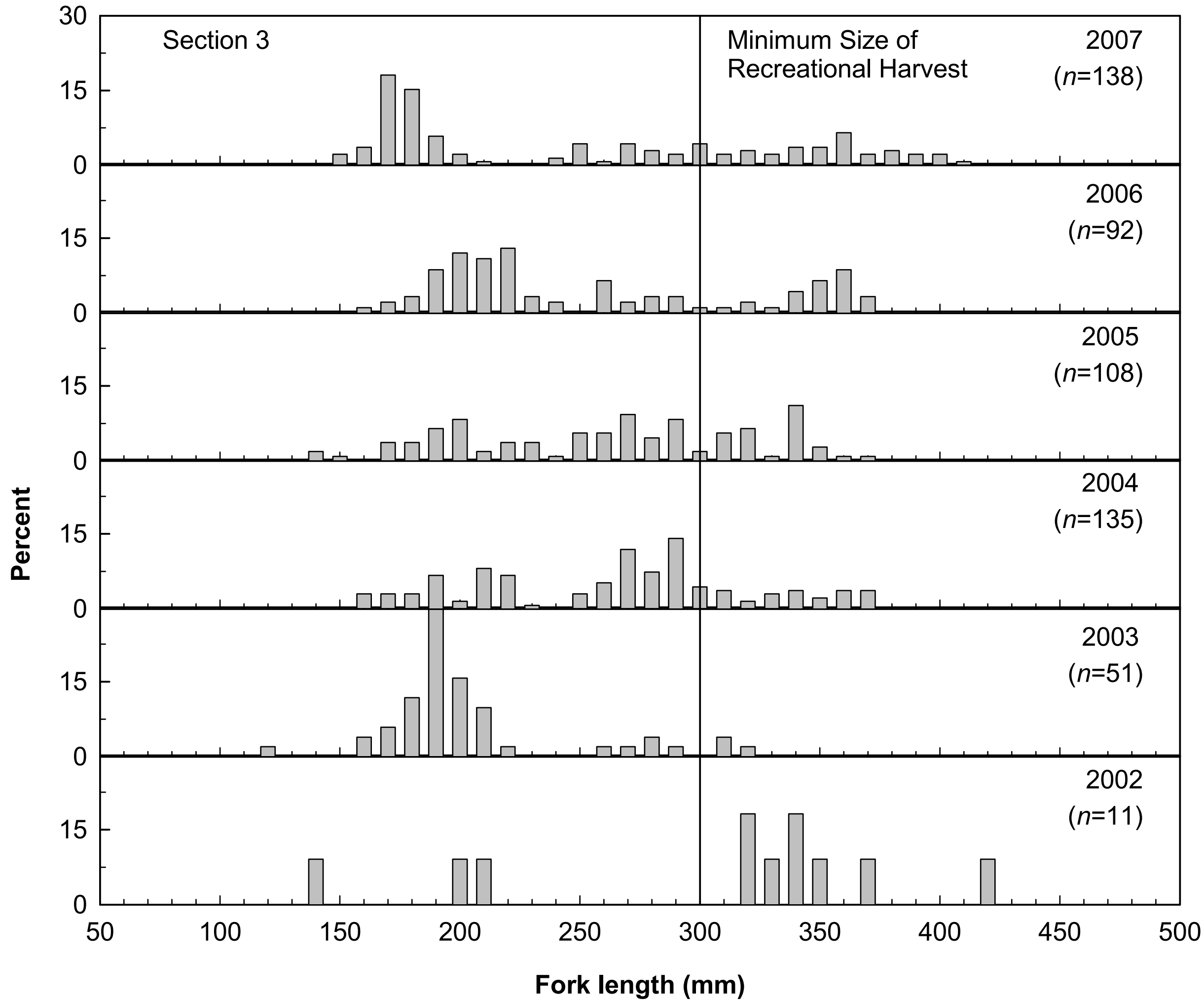
Table 3.5 Mean body condition (*K*) of Arctic grayling sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Age	Section 1		Section 3		Section 5	
	n	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)
0	-		-		2	1.18 ± 0.05
1	2	1.36 ± 0.09	66	1.25 ± 0.01	35	1.29 ± 0.02
2	2	1.50 ± 0.14	32	1.30 ± 0.02	50	1.30 ± 0.01
3	2	1.45 ± 0.16	15	1.35 ± 0.02	59	1.31 ± 0.02
4	2	1.48 ± 0.14	21	1.33 ± 0.04	45	1.30 ± 0.02
5	2	1.33 ± 0.13	4	1.30 ± 0.05	2	1.16

Comparisons of annual length (Figure 3.6) and age (Figure 3.7) distributions indicated differences between years. During the initial years of the program (2002 to 2005) smaller (≤ 300 mm fork length), younger (≤ Age 2) fish dominated the samples. In 2006, larger, older fish (≥ Age 3) became more prominent in Section 3 (Section 5 was not sampled). This pattern continued in 2007 with larger, older fish being very prominent in both Sections 3 and 5.

A possible explanation for this apparent change included annual differences in recruitment. In Section 5, the large percentage of Age 1 fish in 2004 would have contributed to the Age 4 cohort recorded in 2007. In Section 3, however, recruitment of Age 1 fish in 2003 did not result in greater numbers of older fish in 2005, nor was there a strong Age 1 cohort in 2005 that could explain the preponderance of older fish during the present study.

Annual difference in recreational angling harvest may provide an alternate explanation for the 2007 results. Recreational angling harvest (regulations specify a minimum harvest size of 300 mm) has been presented as a potential explanation for the scarcity of larger, older fish in sample populations (Mainstream and Gazey 2004 and 2005). Low water clarity in the Peace River from May to early August 2007 caused poor conditions for angling, which resulted in low success by some anglers (anecdotal communications with local anglers).



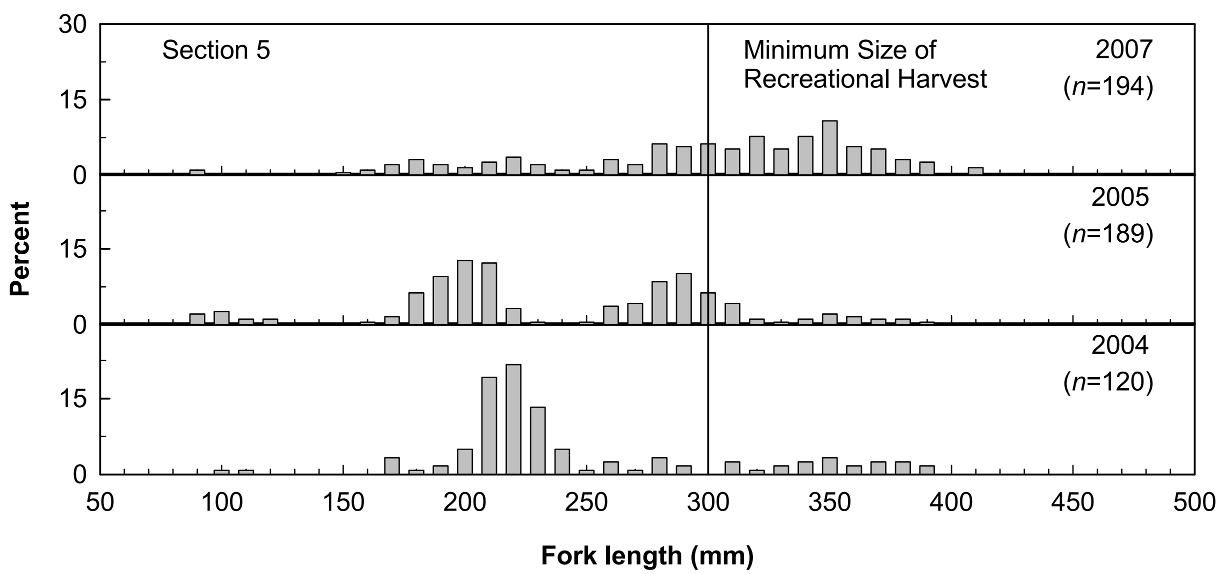


Figure 3.6 Yearly comparisons of length distributions of Arctic grayling during the Peace River Fish Community Indexing Program, 2002 to 2007.

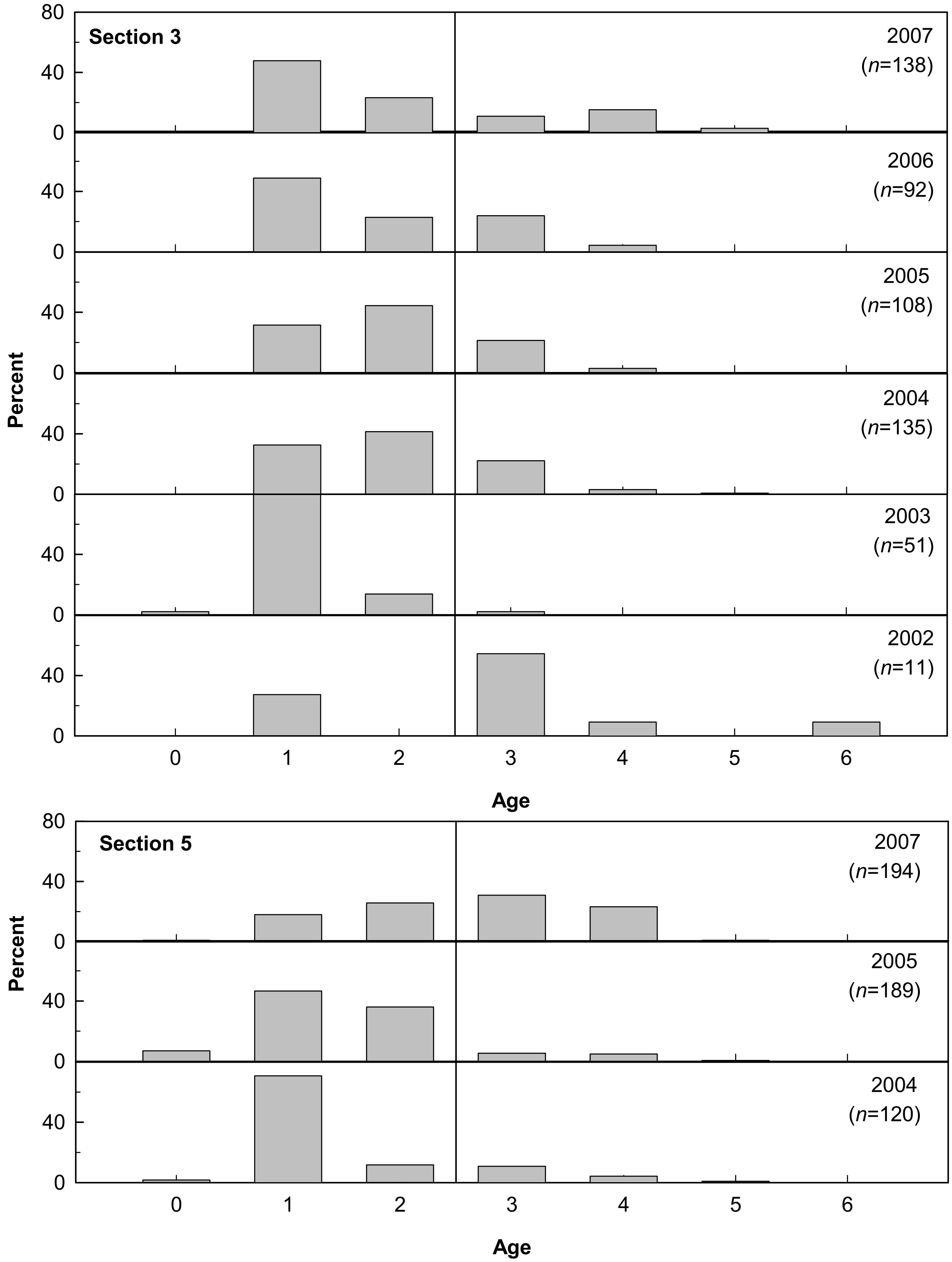


Figure 3.7 Yearly comparisons of age distributions of Arctic grayling during the Peace River Fish Community Indexing Program, 2002 to 2007.

Inspection of the catch curve for Arctic grayling (all years and sections combined) indicates that the fish become fully vulnerable to the capture gear at Age 1 (Figure 3.8). The apparent annual mortality was 59% (95% confidence interval 18% to 79%).

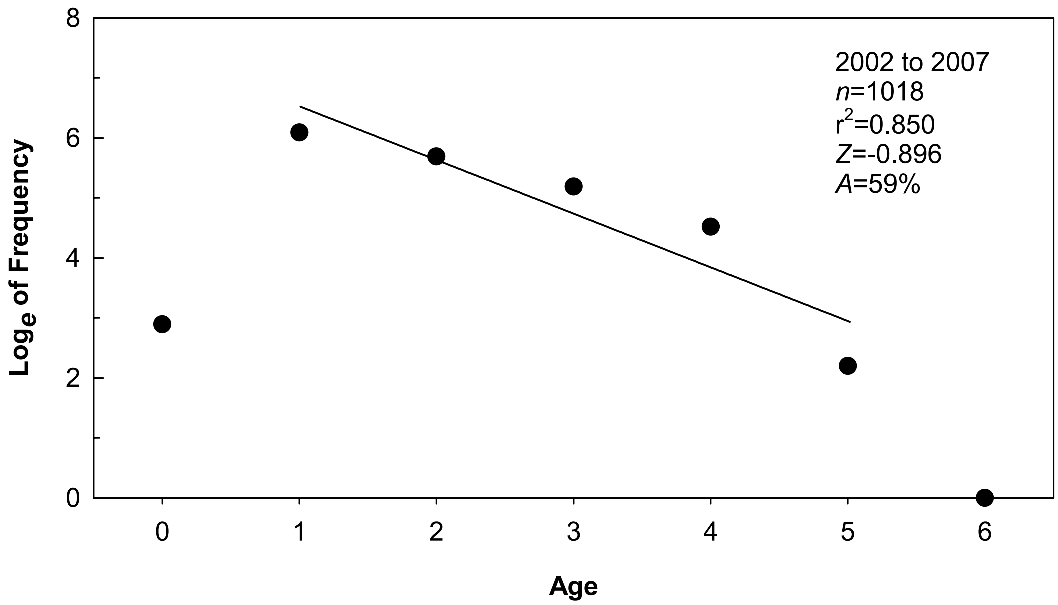


Figure 3.8 Catch curve of Arctic grayling based on assumed stable age composition during the Peace River Fish Community Indexing Program, 2002 to 2007.

The significant difference in mean length of Age 1 between Sections 3 and 5 recorded in 2007 was consistent with previous investigations: Section 5 fish are consistently larger than Section 3 fish at Age 1 (Figure 3.9). Comparisons of mean fork length and associated 95% confidence intervals also indicated significant differences between years. Lengths of Age 1 fish in 2004 and 2006 were significantly larger than lengths of Age 1 fish in 2003, 2005, and 2007. It is interesting to note that Peace River discharges during the field program were lower in 2004 and 2006 compared to discharges in 2003, 2005, and 2007.

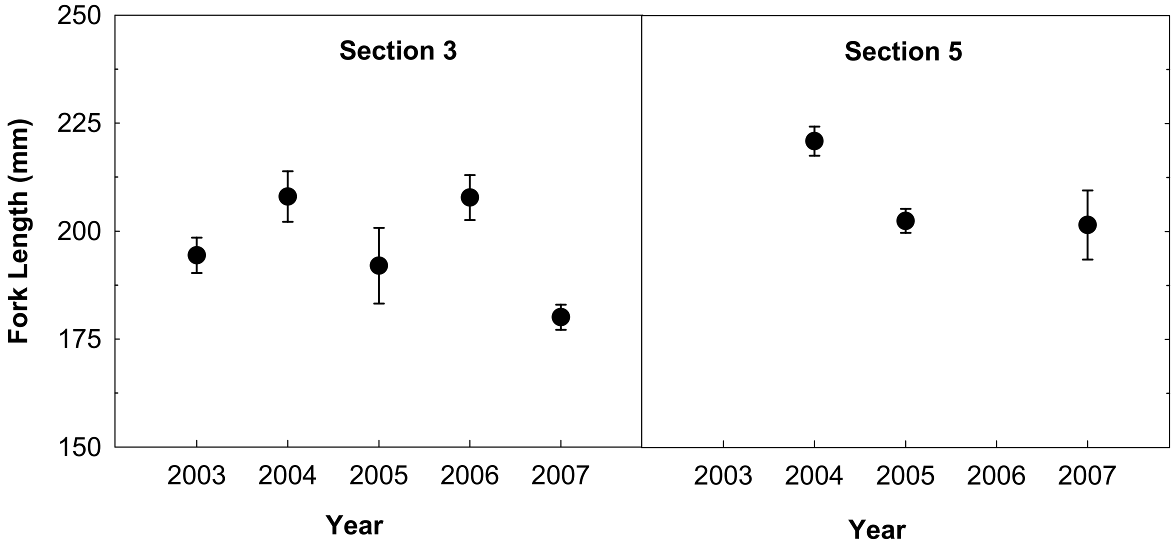


Figure 3.9 Comparisons of mean fork length of Age 1 Arctic grayling in Sections 3 and 5 during the Peace River Fish Community Indexing Program, 2003 to 2007 (vertical bars represent 95% confidence intervals).

Growth curves of Arctic grayling recorded during selected sample years are presented in Figure 3.10 (Section 3 data for 2002, 2003, and 2006 omitted due to lack of data or non-convergence using the von Bertalanffy growth model; analyses restricted to Ages 1 to 4).

Anabolic constants were used to assess whether there were annual differences in growth of sampled Arctic grayling. Comparisons of anabolic constant estimates and associated 95% confidence intervals indicated no statistical differences between years in Section 3 and Section 5 (Figure 3.11).

Estimates of Arctic grayling body condition (*K*) from 2003 to 2007 are presented in Figure 3.12 (heterogeneous slopes for the age-condition relationship precluded use of ANCOVA). The body condition of younger Arctic grayling (Age 1 and Age 2) differed between years in Sections 3 and 5, but there were no consistent temporal patterns.

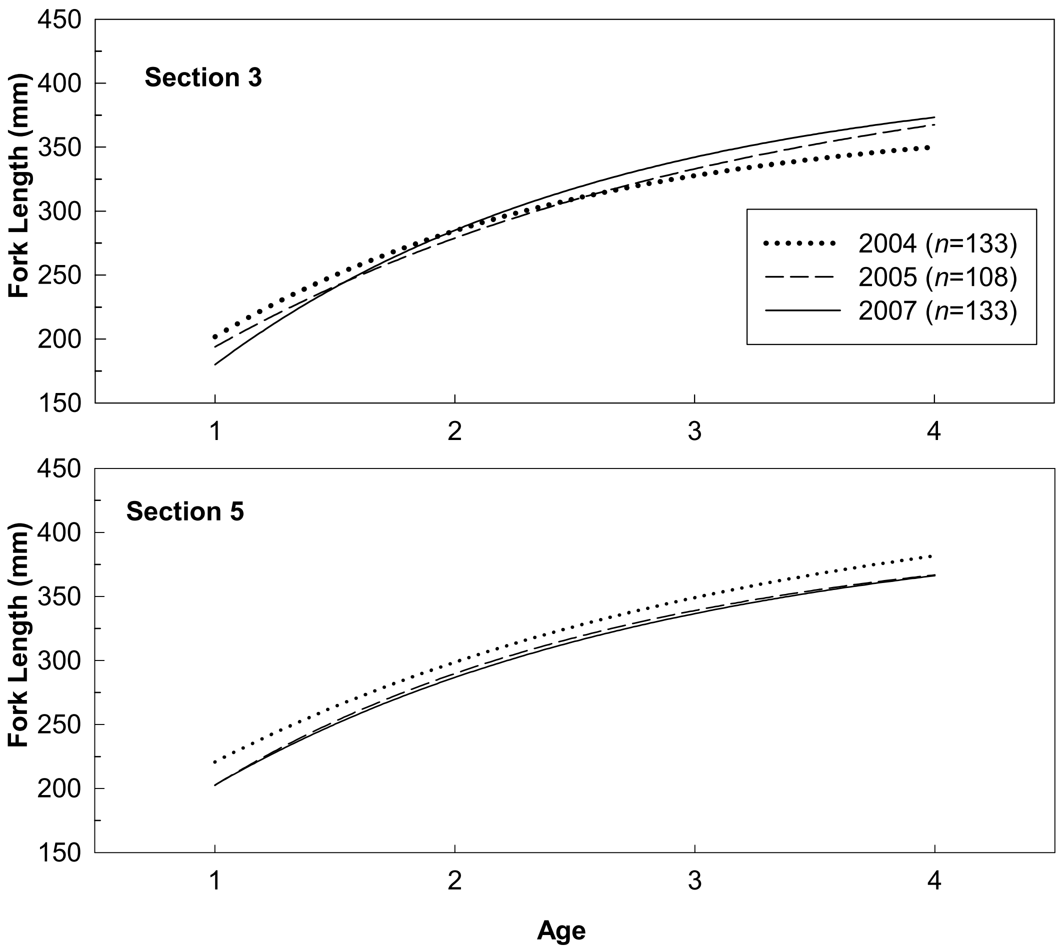


Figure 3.10 Comparisons of Arctic grayling growth curves (Age 1 to Age 4) in Sections 3 and 5 during the Peace River Fish Community Indexing Program, 2004, 2005, and 2007.

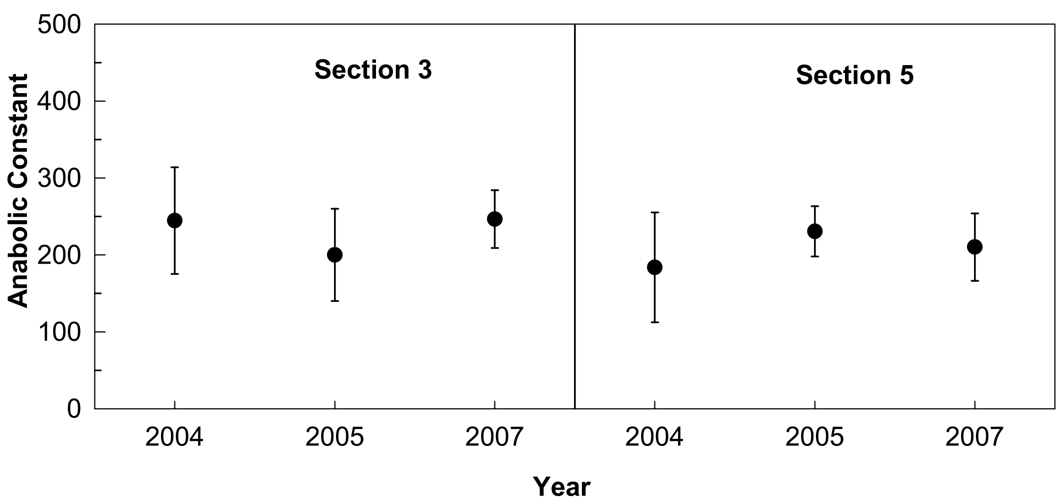


Figure 3.11 Anabolic constant estimates for Arctic grayling in Sections 3 and 5 during the Peace River Fish Community Indexing Program, 2004, 2005, and 2007 (vertical bars represent 95% confidence intervals).

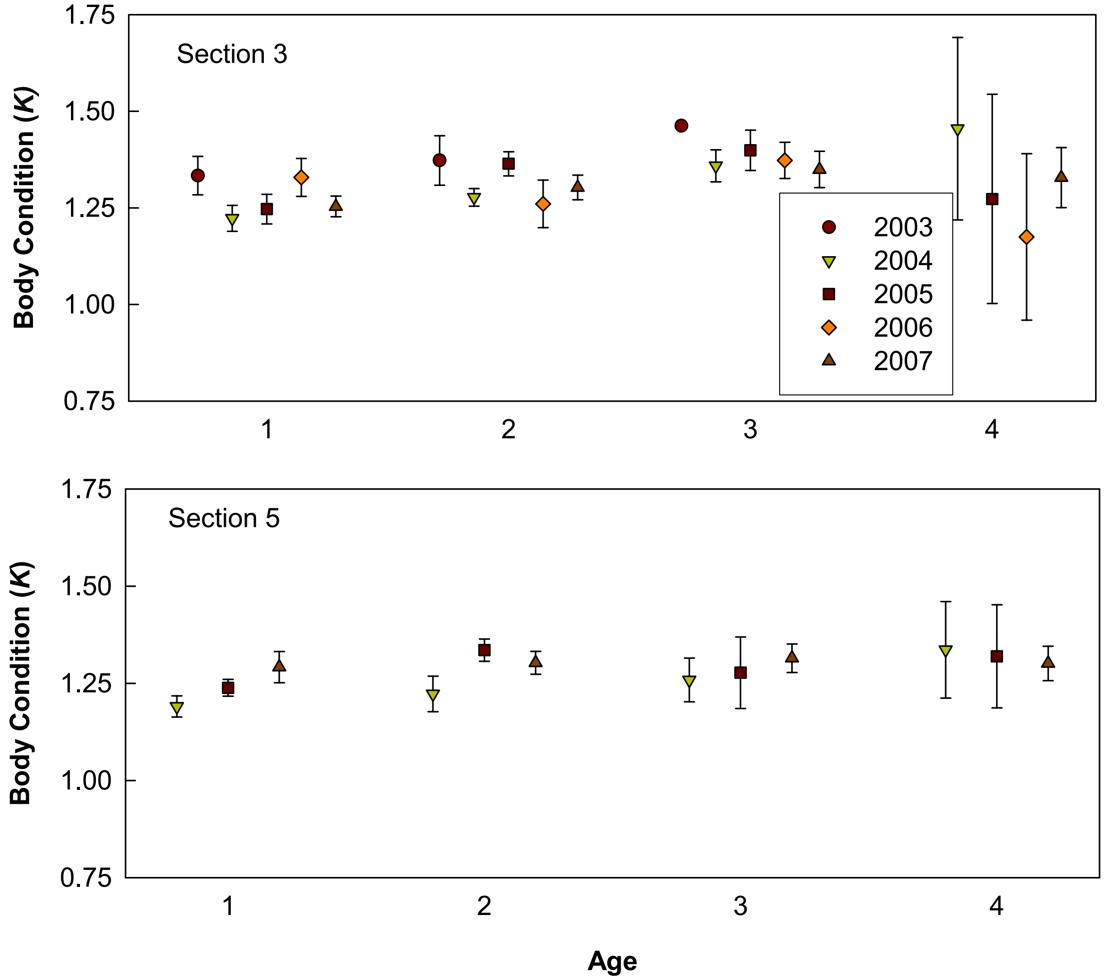


Figure 3.12 Comparisons of mean body condition (*K*) of Arctic grayling in Sections 3 and 5 during the Peace River Fish Community Indexing Program, 2003 to 2007 (vertical bars represent 95% confidence intervals).

3.3.2 Bull trout

In total, 118 bull trout were sampled for biological characteristics; 34 from Section 1, 73 from Section 3, and 59 from Section 5. Fork lengths ranged from 164 mm to 865 mm with ages ranging from Age 1 to 10.

Length and age distributions of bull trout were generally similar among sections (Figure 3.13). Younger fish (Ages 2 to 5) dominated in all sections (> 80% of each sample). The median lengths of fish were 361 mm in Section 1, 340 mm in Section 3, and 364 mm in Section 5. Age 3 fish was the most prominent group in each section (38% to 42% of the sample) and a single Age 1 fish was encountered during the study; the fish was recorded in Section 3. Bull trout older than Age 6 were not well represented. This latter finding may have been an artifact of tributary use by spawning adults at the time of the study.

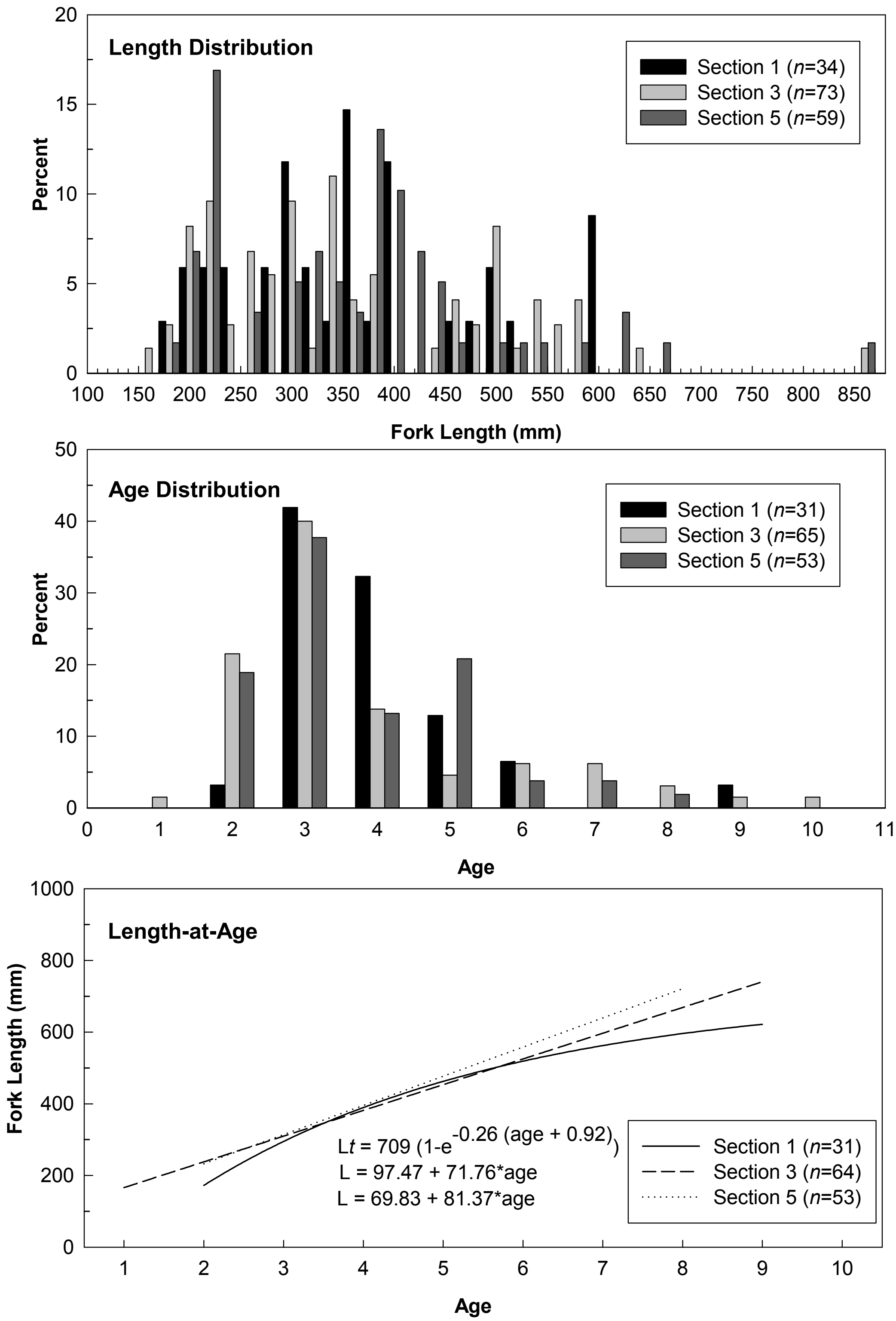


Figure 3.13 Length and age distributions and length-at-age relationships of bull trout sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

The von Bertalanffy growth equation was applied to bull trout sampled in Section 1; non-convergence of growth curves caused by small sample sizes and the absence of older fish required use of linear regression to describe bull trout growth in Sections 3 and 5 (Figure 3.13). The slopes of these lines provide an approximate description of growth of sampled fish.

Strong spatial differences in sample populations were not apparent from mean length-at-age and mean body condition-at-age (Table 3.6 and Table 3.7, respectively). Significant differences were recorded only for the body condition of Age 3 fish.

Table 3.6 Mean length-at-age of bull trout sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Age	Section 1		Section 3		Section 5	
	n	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**
1	-		1	164.0	-	
2	1	196.0	14	217.9 ± 3.4	10	220.0 ± 3.9
3	13	290.0 ± 14.6	26	317.8 ± 10.9	20	331.3 ± 16.5
4	10	396.7 ± 22.6	9	391.0 ± 22.3	7	375.1 ± 18.1
5	4	446.8 ± 29.6	3	518.7 ± 34.3	11	473.5 ± 31.7
6	2	543.0 ± 57.0	4	524.5 ± 12.7	2	495.0 ± 26.0
7	-		4	559.8 ± 9.8	2	610.5 ± 21.5
8	-		2	577.5 ± 2.5	1	860.0
9	1	610.0	1	865.0	-	
10	-		1	511.0	-	

Table 3.7 Mean body condition (*K*) of bull trout sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Age	Section 1		Section 3		Section 5	
	n	**Mean Body Condition (± SE)**	***n***	**Mean Body Condition (± SE)**	***n***	**Mean Body Condition (± SE)**
1	-		1	1.09	-	
2	1	0.93	14	1.00 ± 0.02	10	1.06 ± 0.04
3	13	1.10 ± 0.03 (A)[a]	26	1.06 ± 0.01 (AB)	20	1.01 ± 0.02 (B)
4	10	1.15 ± 0.04	9	1.04 ± 0.03	7	1.91 ± 0.85
5	4	1.37 ± 0.18	3	1.19 ± 0.13	11	1.13 ± 0.06
6	2	1.09 ± 0.02	4	1.25 ± 0.13	2	0.91 ± 0.04
7	-		4	1.08 ± 0.08	2	1.17 ± 0.41
8	-		2	1.21 ± 0.08	1	1.05
9	1	1.19	1	1.07	-	
10	-		1	1.04	-	

[a] Based on post-hoc means test; different letter denotes statistical difference at $P \leq 0.05$.

In general length and age distributions remained stable across years (Figure 3.14 and Figure 3.15, respectively). In all sections in most years the age distributions were dominated by subadults (Age 2 to Age 5). The absence of older fish during most years likely was caused by use of spawning tributaries by the adult cohort during the study period and did not reflect the actual age structure of the Peace River population. Age 1 fish were poorly represented in 2007 and in most other years (except 2005). This may reflect use of tributary systems for early rearing by this population (McPhail 2007) or low capture efficiency of these smaller fish by boat electrofishing. Highest recruitment of Age 1 and Age 2 fish occured in 2005, 2006, and 2007 in most sections.

Inspection of the catch curve for bull trout (all years and sections combined) indicates that the fish become fully vulnerable at Age 3 (Figure 3.16). The apparent annual mortality was 41% (95% confidence interval 32% to 50%). Information from other unexploited bull trout populations, suggest that annual mortality of approximating 20% to 30% may be most representative of the actual mortality of the Peace River bull trout population (Post *et al.* 2003). To confirm this hypothesis, sampling would need to occur when all age cohorts of the population are located in the study area.

Annual growth rates of sampled bull trout are presented in Figure 3.17. To improve the potential contrast between years, data for all sections have been combined and the linear component (Age 2 and Age 7) was examined. Growth rates declined from 2002 to 2004 then increased to 2006, before declining again in 2007. Despite this apparent trend there was no significant difference among years (95% confidence intervals).

The wide variance around each age class and small sample sizes precluded an assessment in annual differences in length-at-age or body condition.

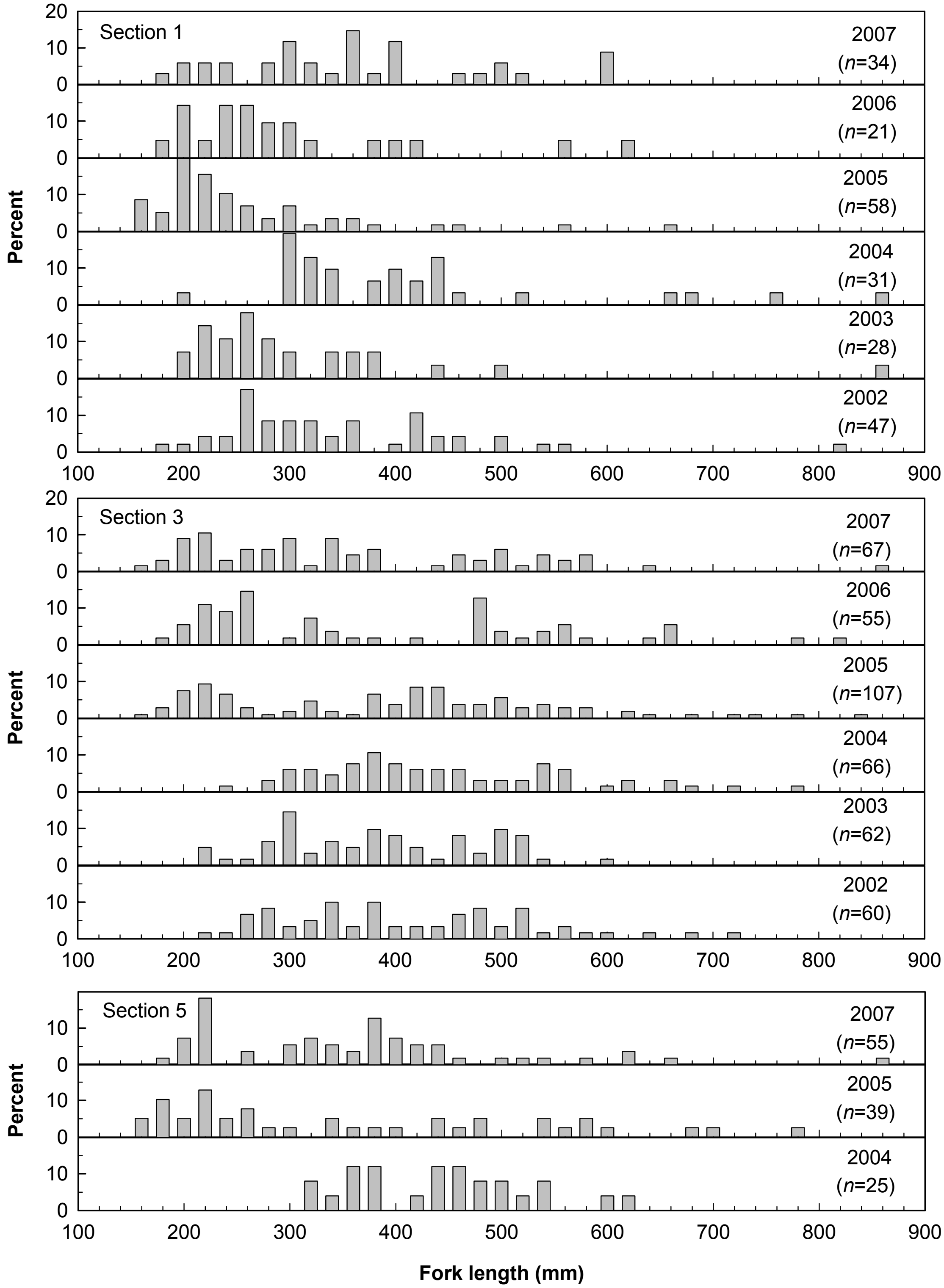


Figure 3.14 Yearly comparisons of length distributions of bull trout sampled during the Peace River Fish Community Indexing Program, 2002 to 2007.

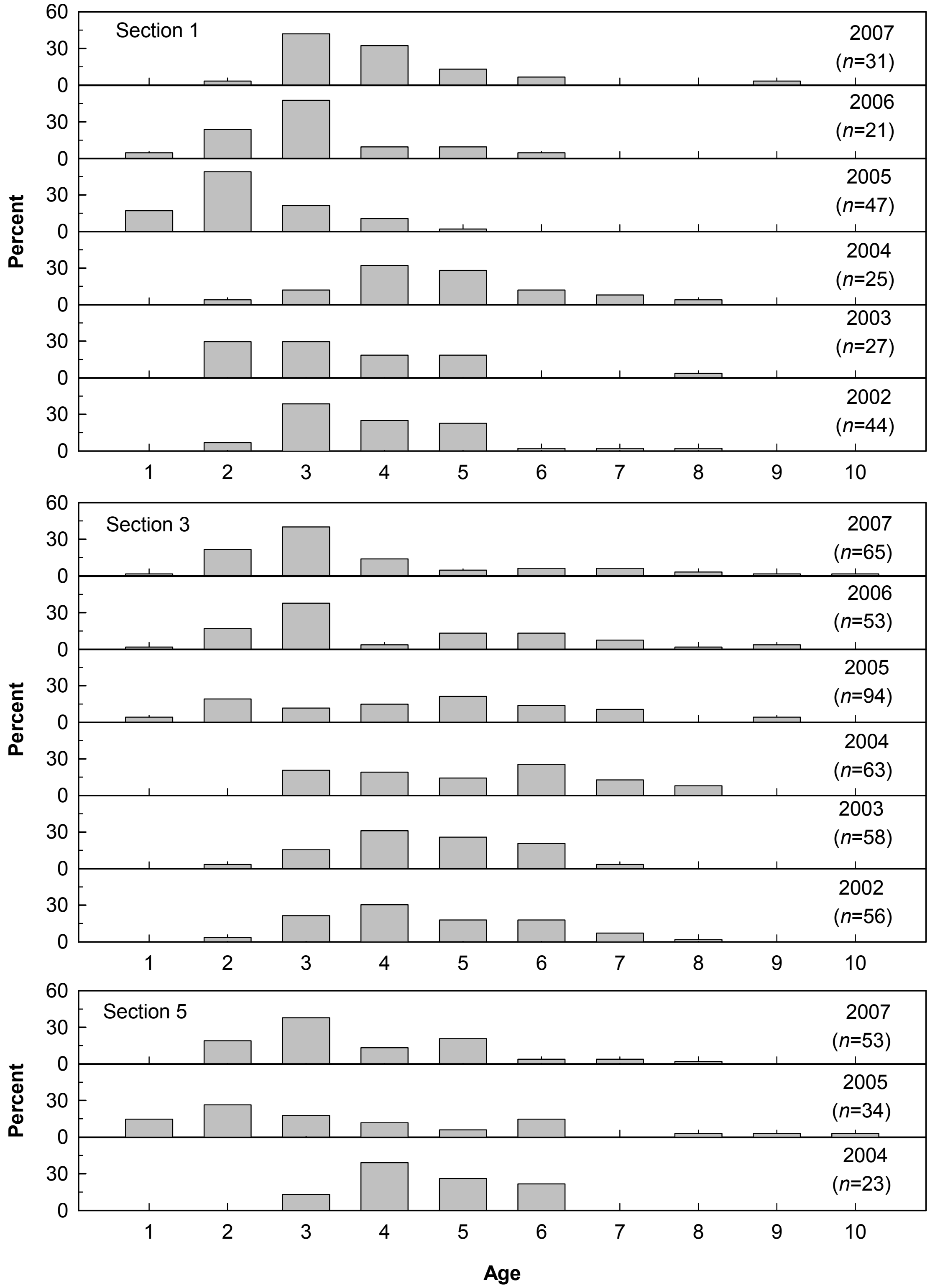


Figure 3.15 Yearly comparisons of age distributions of bull trout sampled during the Peace River Fish Community Indexing Program, 2002 to 2007.

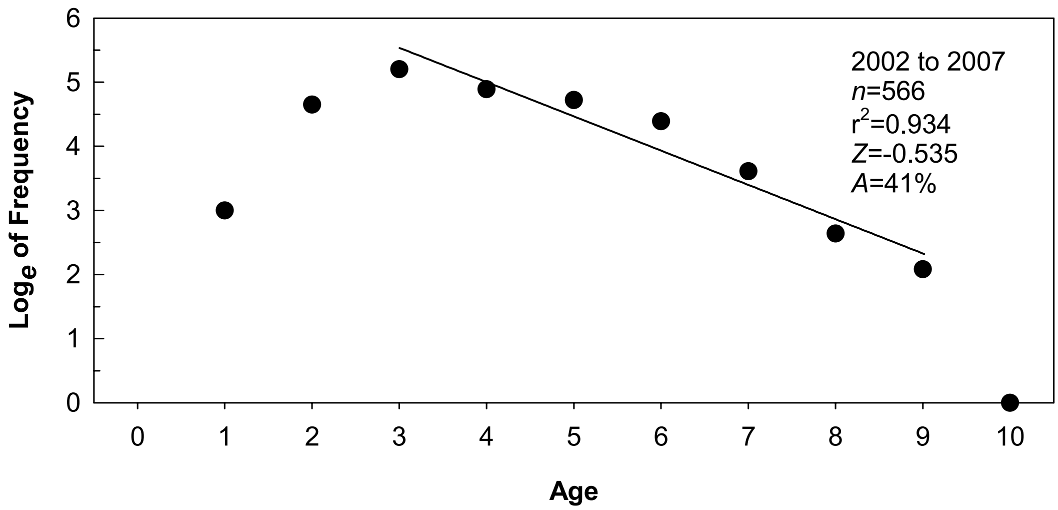


Figure 3.16 Catch curve of bull trout based on assumed stable age composition during the Peace River Fish Community Indexing Program, 2002 to 2007.

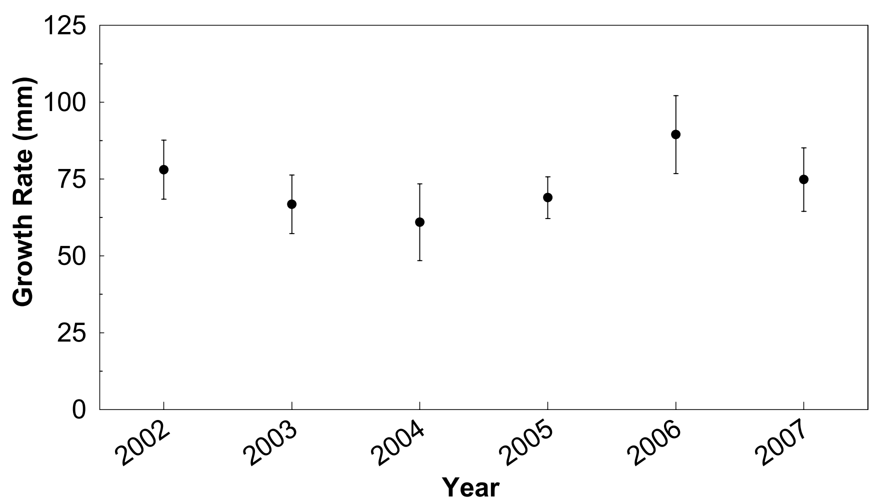


Figure 3.17 Comparisons of growth rates of bull trout sampled during the Peace River Fish Community Indexing Program, 2002 to 2007 (analyses based on mean length-at-age; restricted to Age 2 to Age 7 fish; data from all sections were combined).

3.3.3 Mountain whitefish

In total, 8094 mountain whitefish fish were measured; 2449 from Section 1, 3428 from Section 3, and 2217 from Section 5. Fork lengths ranged from 74 mm to 520 mm with ages ranging from Age 0 to Age 13. Only two Age 0 fish were recorded; both from Section 5.

In total, 816 aged mountain whitefish were available for analyses (12.5% of the sample). These included a random sample of 720 fish from the present study and 96 fish that were marked and aged during previous studies.

A comparison of length and age distributions of mountain whitefish indicated that there were spatial differences in sampled populations (Figure 3.18). The Section 1 sample exhibited a truncated length distribution with one primary (300 mm) and one secondary (230 mm) modal peak. This pattern was caused by the dominance of Age 4 to Age 6 fish, which accounted for 54% of the sample. Younger fish (Age 0 and Age 1) were largely absent as were fish older than Age 7.

In contrast, samples from Section 3 and 5 exhibited broad multi-modal length distributions. Modal peaks occurred at approximately 150 mm, 210 mm, 240 mm, and 320 mm. These corresponded to Ages 1, 2, 3, and 5, respectively. Ages 1 to 8 were well represented.

The length-at-age results suggested spatial differences in growth (Table 3.8, Figure 3.18). The mean length of Age 1 fish decreased from upstream to downstream (173 mm in Section 1; 156 mm in Section 3; 146 mm in Section 5). Results were ambiguous for Ages 2 and 3. However, mean length of Age 4 and older fish tended to increase from upstream to downstream. Differences were statistically significant for Ages 4 to 10.

Table 3.8 Mean length-at-age of mountain whitefish sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Age	Section 1		Section 3		Section 5	
	n	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**	***n***	**Mean Fork Length (± SE)**
0	-		-		1	74.0
1	7	173.3 ± 3.7 (C)[a]	44	155.9 ± 1.7 (B)	33	145.6 ± 1.7 (A)
2	30	217.5 ± 2.0 (AB)	39	212.1 ± 1.5 (A)	22	221.7 ± 4.5 (B)
3	28	248.6 ± 2.5	37	247.5 ± 2.3	38	254.8 ± 2.3
4	39	278.6 ± 1.8 (A)	56	277.9 ± 1.7 (A)	20	285.9 ± 3.2 (B)
5	44	300.8 ± 2.8 (A)	57	301.7 ± 2.4 (A)	32	313.4 ± 3.7 (B)
6	62	313.3 ± 2.0 (A)	40	326.8 ± 4.0 (B)	16	345.8 ± 6.2 (C)
7	32	324.3 ± 2.3 (A)	25	346.5 ± 5.2 (B)	22	349.5 ± 5.9 (B)
8	8	345.1 ± 9.7 (A)	18	361.2 ± 7.3 (AB)	17	380.5 ± 5.4 (B)
9	4	353.0 ± 15.0 (A)	6	368.5 ± 14.4 (AB)	15	395.9 ± 6.6 (B)
10	2	351.5 ± 11.5 (A)	5	418.8 ± 7.1 (B)	4	413.8 ± 8.7 (B)
11	1	413.0	3	432.0 ± 6.4	3	436.7 ± 8.4
12	-		-		4	453.3 ± 10.1
13	1	356.0	-		1	433.0

[a] Based on post-hoc means test; different letter denotes statistical difference at $P \leq 0.05$.

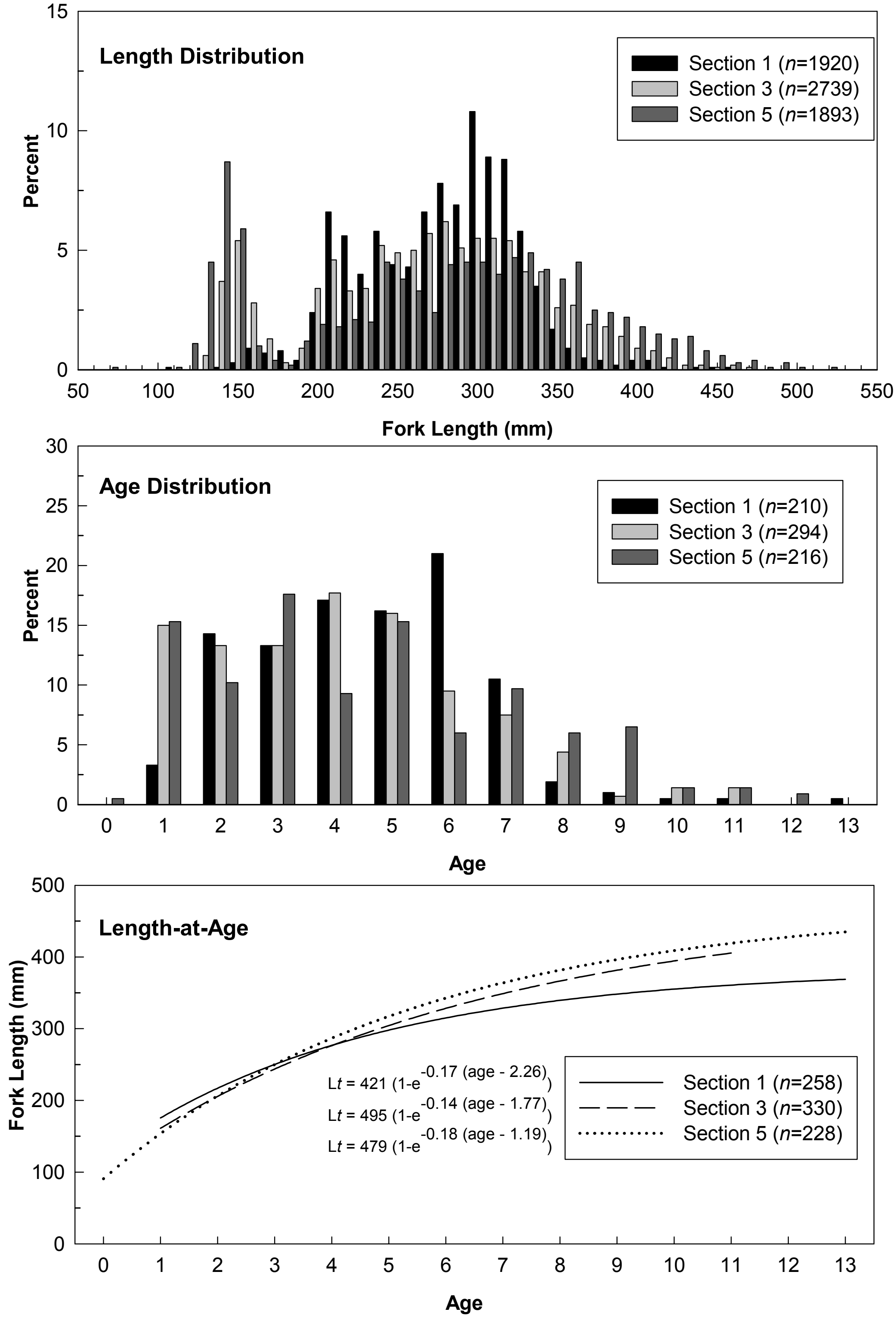


Figure 3.18 Length and age distributions and length-at-age relationships for mountain whitefish sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007 (Length distributions and age distributions represent data for non-recaptured fish in 2007; length-at-age relationships represent data for fish aged during present and previous studies).

Evaluation of linear segments of the growth curves (Age 2 to Age 4 [younger fish] and Age 5 to 8 [older fish]) illustrated spatial differences in growth characteristics of the sampled populations (Figure 3.19). Younger fish exhibited similar growth. ANCOVA identified no significant differences in growth rate (P = 0.385) or adjusted mean lengths (P = 0.172). Growth rates of older mountain whitefish differed. The growth rate of fish in Section 1 (13.7 mm) was lower than the growth rates of fish in Section 3 (21.9 mm) and Section 5 (20.8 mm). Differences between Sections 1 and 5 were marginally not significant; while differences between Sections 1 and 3 were significant (based on 95% confidence intervals around growth rate estimates). Following removal of Section 1 fish ANCOVA identified no significant differences in growth rate of older fish between Sections 3 and 5 (P = 0.692). Adjusted mean length of Section 5 fish was significantly larger than the adjusted mean length of Section 3 fish (P = 0.001).

These results support the growth pattern illustrated by the von Bertalanffy growth models presented in Figure 3.18.

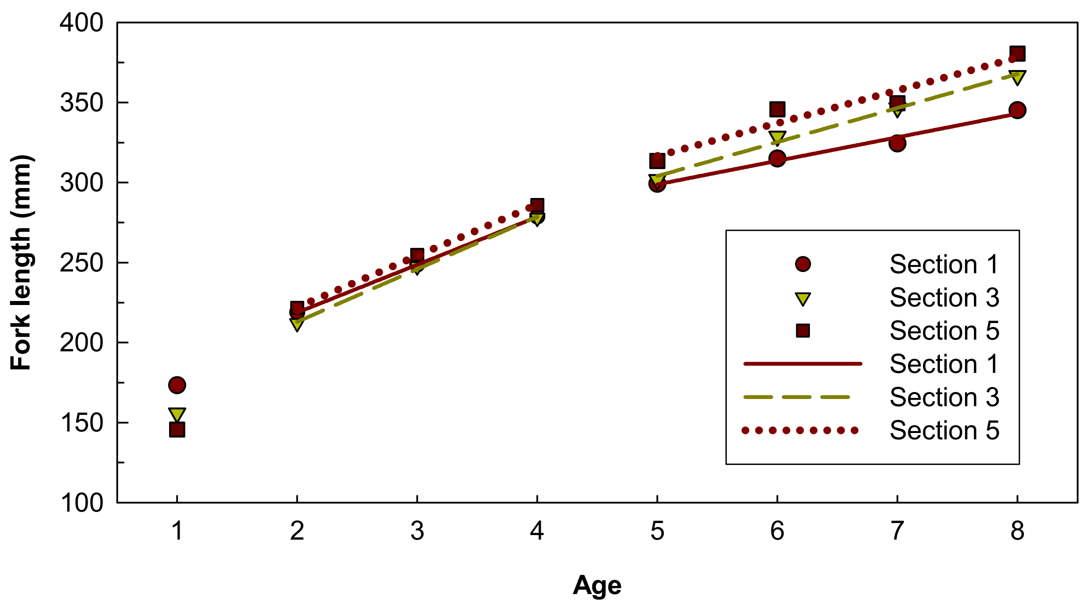


Figure 3.19 Comparisons of mean length-at-age and linear segments of growth curves of sampled mountain whitefish in Sections 1, 3, and 5 during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Mountain whitefish body condition differed by section in 2007 (Table 3.9). The condition estimates for Age 1 to Age 4 fish were higher in Section 1 compared to Sections 3 and 5. Differences were significant for Age 2 and Age 3 fish. The opposite was the case for Age 5 to Age 9 fish. Section 5 fish tended to have higher body condition than fish in Sections 1 and 3.

Table 3.9 Mean body condition (*K*) of mountain whitefish sampled during Phase 7 of the Peace River Fish Community Indexing Program, 2007

Age	Section 1		Section 3		Section 5	
	n	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)	*n*	Mean Body Condition (± SE)
0	-		-		-	
1	7	1.15 ± 0.04	44	1.09 ± 0.01	33	1.06 ± 0.02
2	30	1.22 ± 0.02 (B)	39	1.12 ± 0.02 (A)	21	1.15 ± 0.04 (AB)
3	27	1.22 ± 0.02 (B)	37	1.13 ± 0.02 (A)	38	1.11 ± 0.01 (A)
4	35	1.22 ± 0.02	54	1.17 ± 0.01	20	1.15 ± 0.02
5	39	1.18 ± 0.02	57	1.17 ± 0.01	31	1.23 ± 0.04
6	54	1.17 ± 0.01 (B)	40	1.11 ± 0.02 (A)	14	1.20 ± 0.02 (B)
7	30	1.14 ± 0.02 (AB)	22	1.12 ± 0.02 (A)	22	1.20 ± 0.02 (B)
8	8	1.07 ± 0.04	16	1.08 ± 0.05	17	1.13 ± 0.02
9	3	1.09 ± 0.08	5	1.13 ± 0.04	15	1.15 ± 0.03
10	2	1.11 ± 0.04	5	1.01 ± 0.05	4	1.04 ± 0.04
11	1	1.02	3	1.13 ± 0.05	3	1.25 ± 0.04
12	-		-		2	0.81 ± 0.32
13	1	1.29	-		-	

[a] Based on post-hoc means test; different letter denotes statistical difference at $P \leq 0.05$.

A plot of mean body condition-at-age revealed patterns based on age and location (Figure 3.20). Younger fish (Ages 1 to 4) exhibited an increase in body condition with age. ANCOVA identified no significant differences between slopes ($P = 0.470$), and as expected from the individual comparisons, the body condition of Section 1 fish was significantly higher than the body condition of fish in Sections 3 and 5 (Post-hoc means test on adjusted means; $P \leq 0.05$).

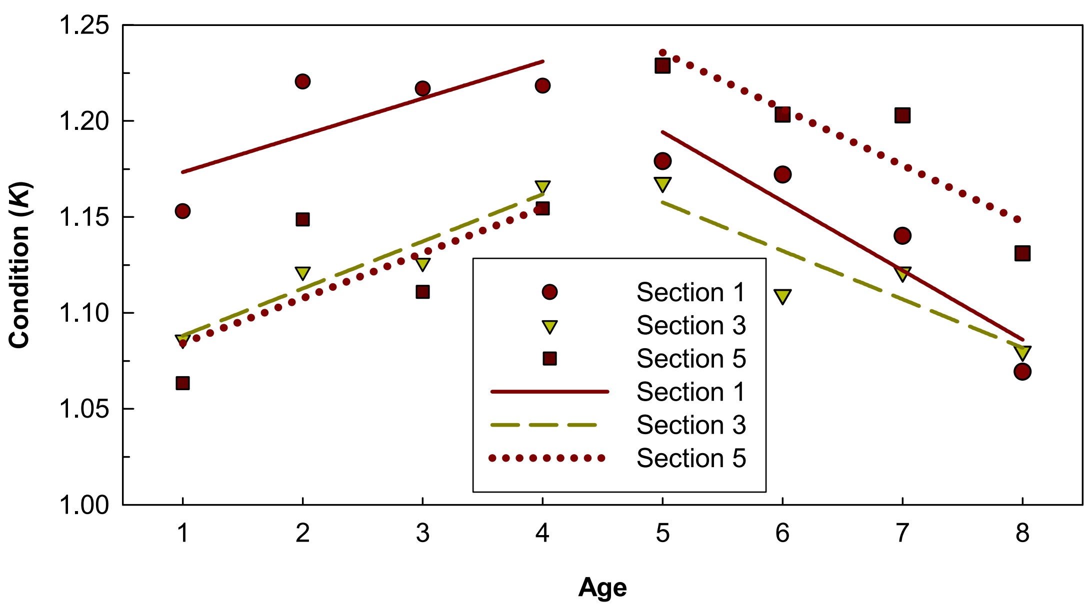


Figure 3.20 Comparisons of mean body condition (*K*) of sampled mountain whitefish in Sections 1, 3, and 5 during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Body condition of older fish (Ages 5 to 8) exhibited a decrease in body condition with age. ANCOVA identified no significant differences between slopes in this group (P = 1.00), and as expected from the individual comparisons, the body condition of Section 5 fish was significantly higher than the body condition of fish in Sections 1 and 3 (post-hoc means test on adjusted means; $P \leq 0.05$).

The reasons for spatial patterns of mountain whitefish length-at-age and body condition are not known. Potential reasons include spatial differences in water temperature and/or reproductive strategy. Water temperature may influence the timing of gonad development of sexually mature fish (spatial differences in water temperature described in Section 3.1.3). Mountain whitefish in Section 1 may represent a component of the study area population that invests a larger proportion of annual reserve to reproduction rather than growth. This latter hypothesis may help explain the unique age distribution and length-at-age characteristics of mountain whitefish in Section 1.

Age and length distributions within each section generally remained stable between 2002 and 2007 (Figure 3.21 and 3.22). 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. Length and age distributions of mountain whitefish in Section 3 and Section 5 showed strong representation of younger fish (Age 1 and Age 2) and the presence of older fish (≥ Age 7) in all years.

The “catch curve” of mountain whitefish in each section (data for individual years combined) indicated that fish were fully recruited to the sample gear at Age 5 (Figure 3.23). The apparent annual mortality was highest in Section 1 (62%), intermediate in Section 3 (46%), and lowest in Section 5 (39%).

Annual differences in mountain whitefish growth in each section were evaluated using growth rate, length-at-age data, anabolic constant, and body condition. Growth rates of younger (Age 2 to Age 4) mountain whitefish differed between years (Figure 3.24). Growth rates of fish in Sections 1 and 3 declined between 2002 and 2004, increased slightly in 2005, but then declined until 2007. In Section 5, which is represented by a discontinuous data set (2004, 2005, and 2007), no clear trend was apparent. Comparisons of the 95% confidence intervals demonstrated significant differences between certain years in each section. Unlike younger fish, there were no annual differences in growth rates of older fish (Age 5 to Age 7).

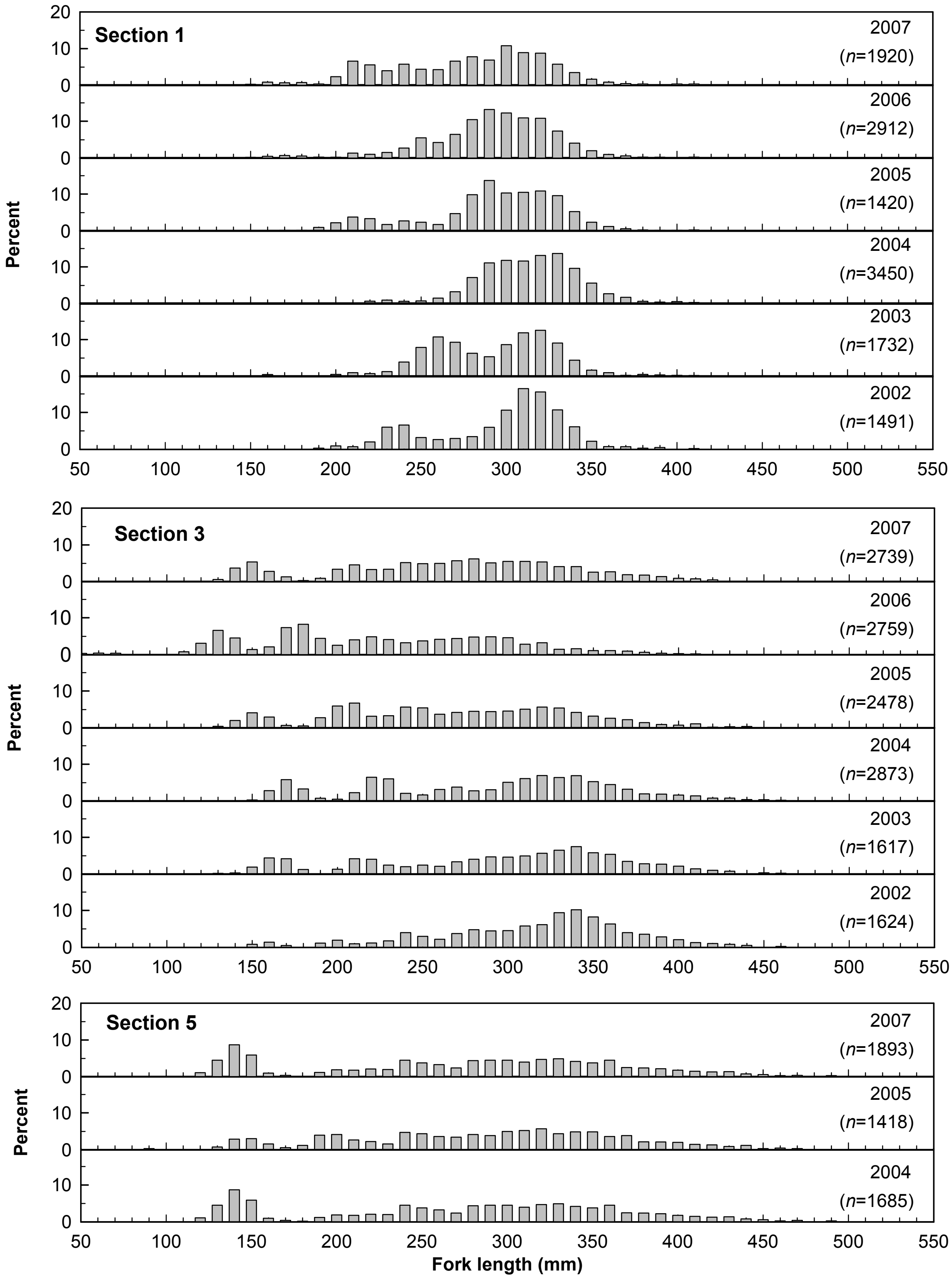


Figure 3.21 Yearly comparisons of length distributions of mountain whitefish sampled during the Peace River Fish Community Indexing Program, 2002 to 2007.

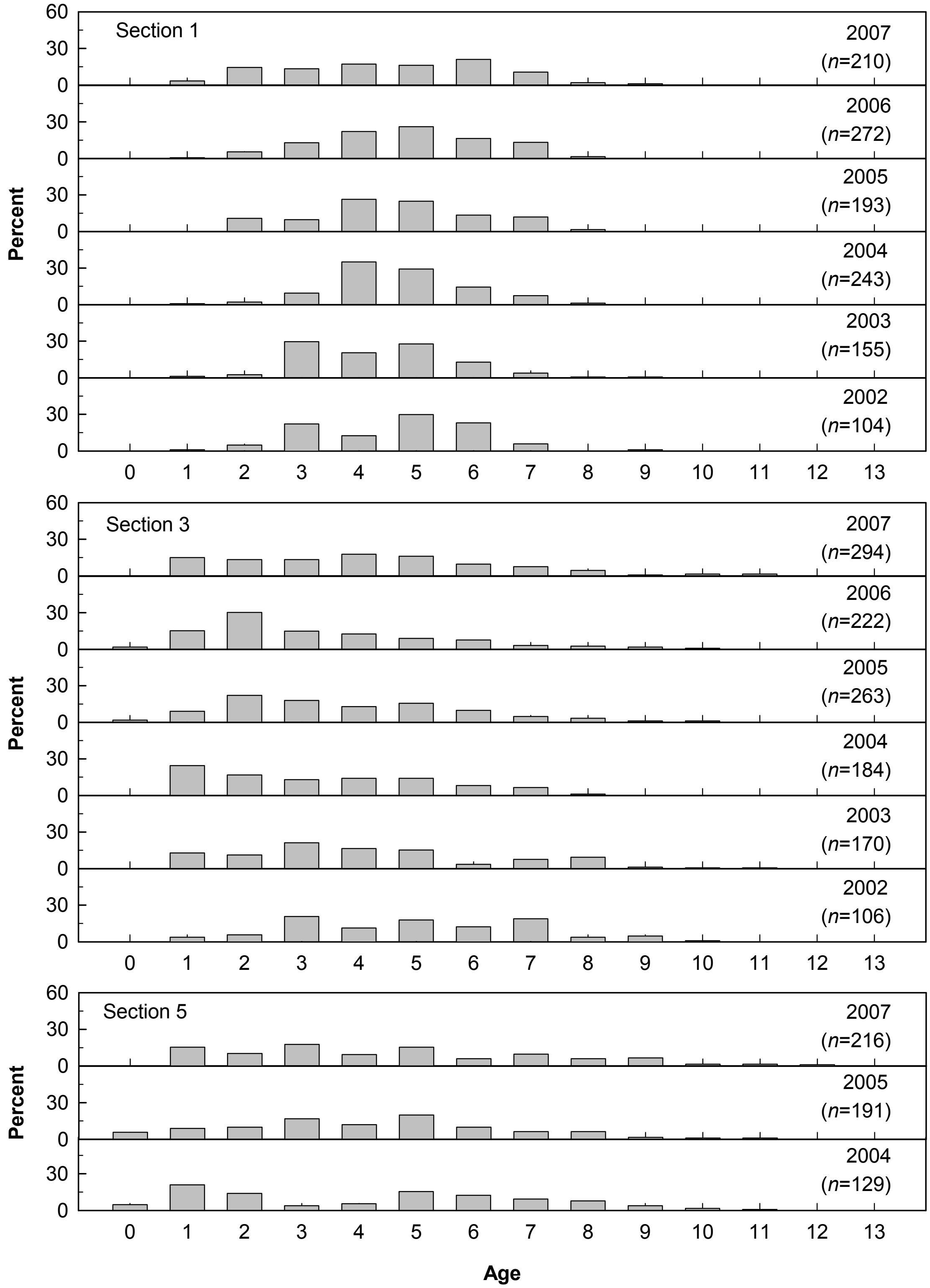


Figure 3.22 Yearly comparisons of age distributions of mountain whitefish sampled during the Peace River Fish Community Indexing Program, 2002 to 2007.

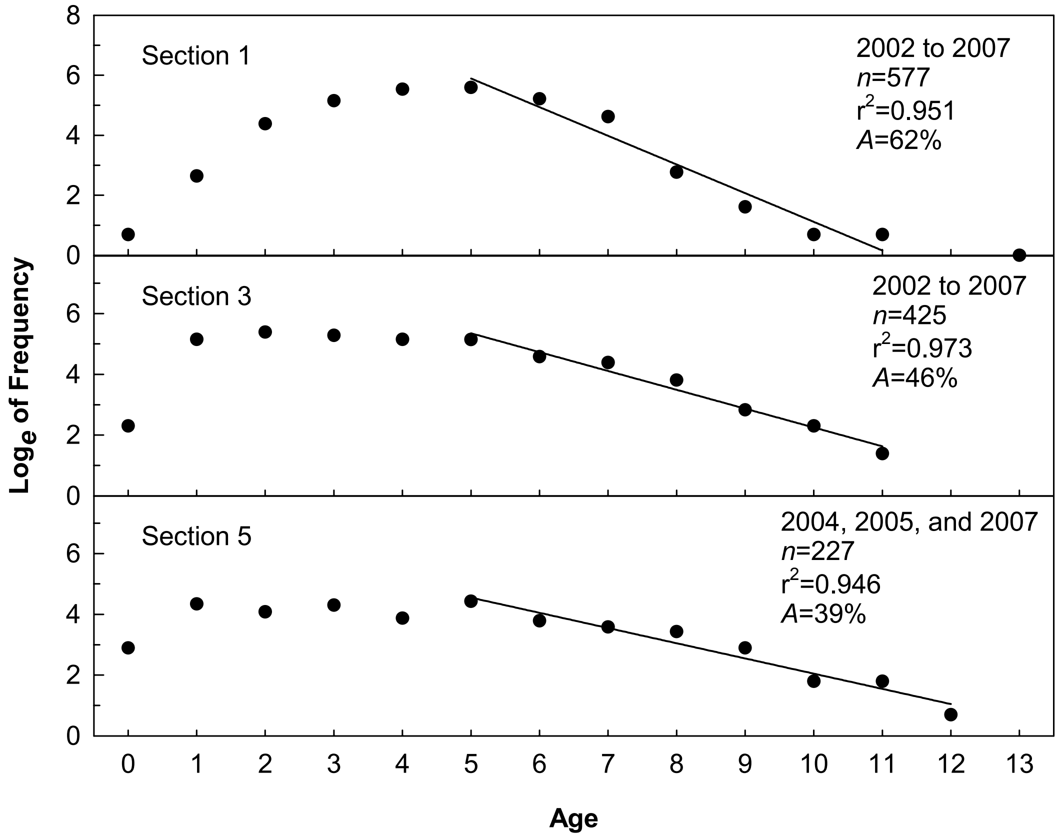


Figure 3.23 Catch curve annual mortality of mountain whitefish in Sections 1, 3, and 5 during the Peace River Fish Community Indexing Program, 2002 to 2007 (data for all years combined).

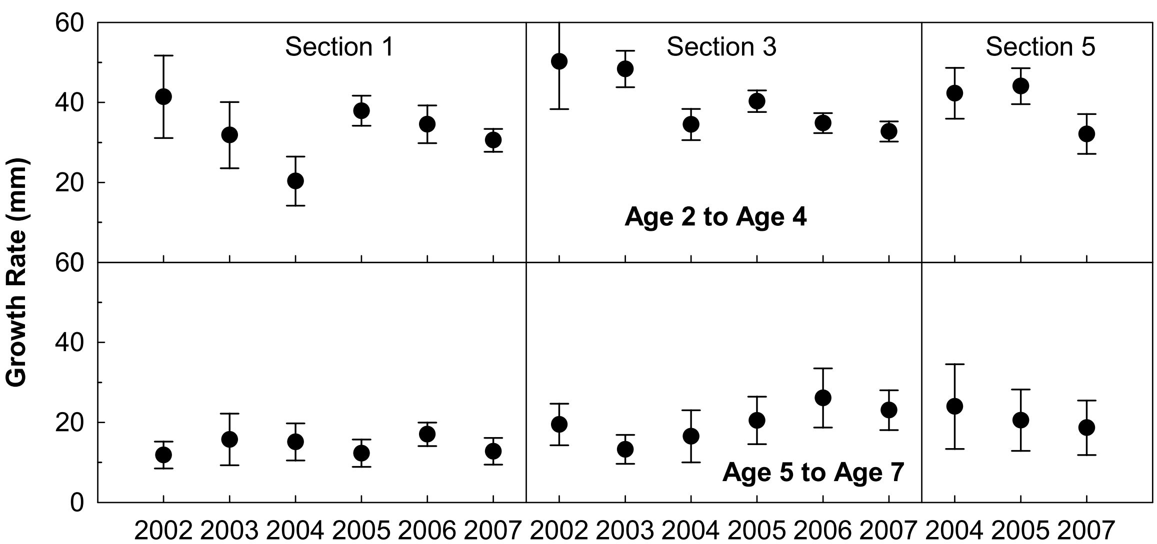


Figure 3.24 Growth rates of younger (Ages 2 to 4) and older (Ages 5 to 7) mountain whitefish in Sections 1, 3, and 5 during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent 95% confidence intervals).

Comparisons of annual mean length-at-age of mountain whitefish suggest year effects and temporal trends for some age classes (Figure 3.25). No distinct patterns were apparent in Age 1 and Age 2 fish, although mean length-at-age was generally highest in 2004. Beginning with Age 3 fish, there was a general downward trend in mean length-at-age starting in 2003, which was clearly demonstrated in Section 1 and Section 3. The 95% confidence intervals around the estimates indicate significant differences between some years. The adjusted mean length-at-age for Age 5 to Age 7 fish demonstrated a similar negative trend in mountain whitefish length-at-age (heterogeneous growth rates [ANCOVA, $P = 0.0565$] precluding use of adjusted means for the younger age group [Age 1 to Age 4]). The absolute decrease in length-at-age ranged for approximately 5 mm for younger fish to 20 mm for older fish.

Annual anabolic constant (product L_{∞}, K) estimates of mountain whitefish during each year of study are presented for Sections 1, 3, and 5 (Figure 3.26). The results suggest a decline in growth between 2002 and 2004 and then generally stable growth from 2005 to 2007. The results for Section 1 are confounded by wide 95% confidence intervals (caused by the absence of older fish in the sample).

Statistical evaluation of body condition (K) using age as a covariate established that slopes of the relationship between body condition and age were not significantly different among age groups (Ages 2 to 4; Ages 5 to 7) and sections (1, 3, and 5) ($P \geq 0.115$). Comparisons of adjusted mean body condition and associated 95% confidence intervals are presented in Figure 3.27. Yearly differences were evident for both age groups. In Section 1, body condition increased from 2002 to 2004, declined in 2005, and increased to 2007. In Section 3, mountain whitefish body condition increased from 2002 to 2004, and then remained stable. No changes were recorded in Section 5.

Annual comparisons of mountain whitefish biological characteristics indicated a downward trend in growth rate of younger fish (Ages 2 to 4) and length-at-age of most age classes suggesting a decline in mountain whitefish population health. In contrast, age distributions of sample populations remained generally stable, as did estimates of growth (anabolic constant); body condition appeared to increase or remained stable.

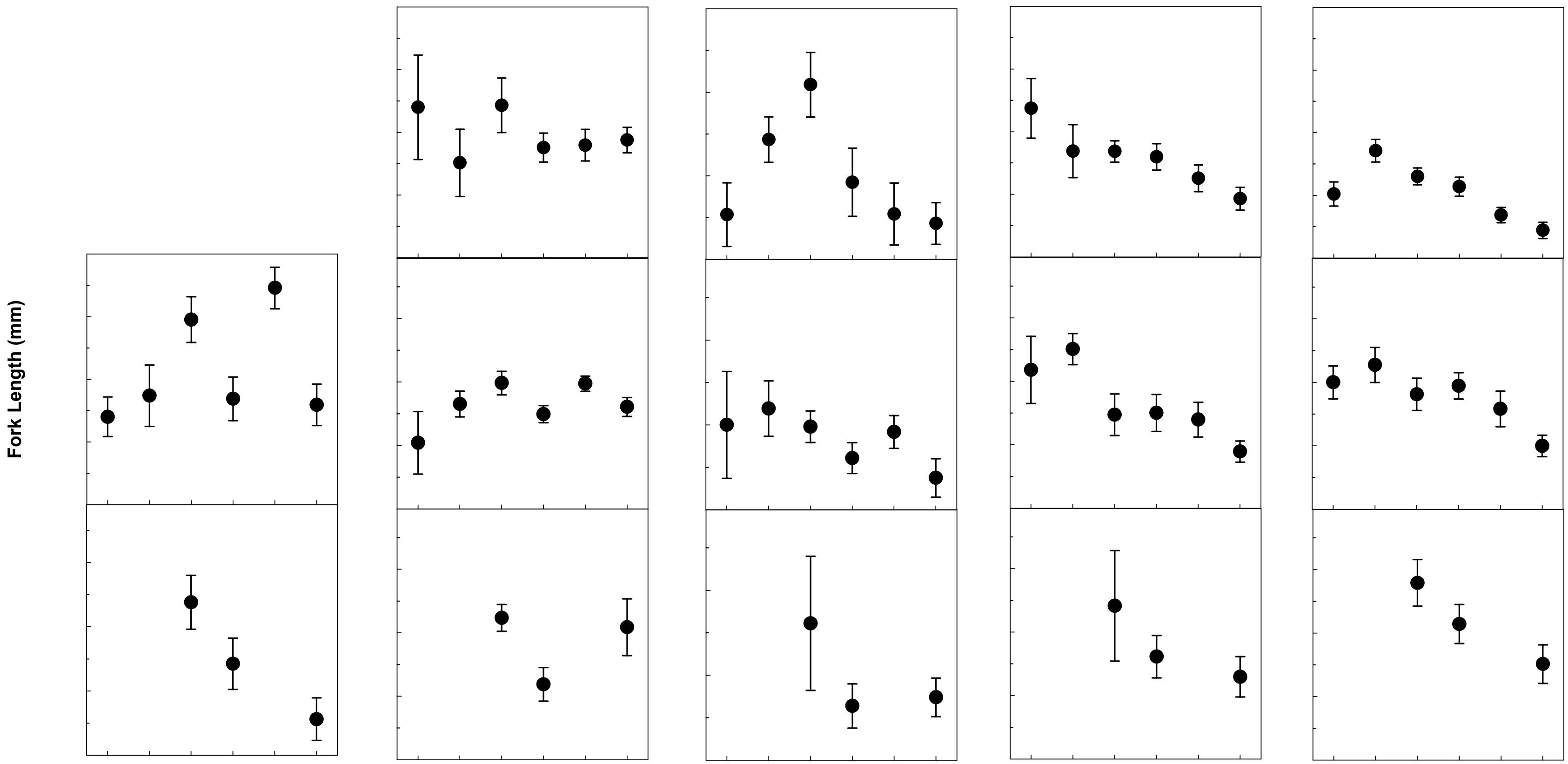


Figure 3.25 Mean length-at-age (Ages 1 to 4) and adjusted mean length-at-age (Ages 5 to 7) of mountain whitefish in Sections 1, 3, and 5 during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent 95% confidence intervals).

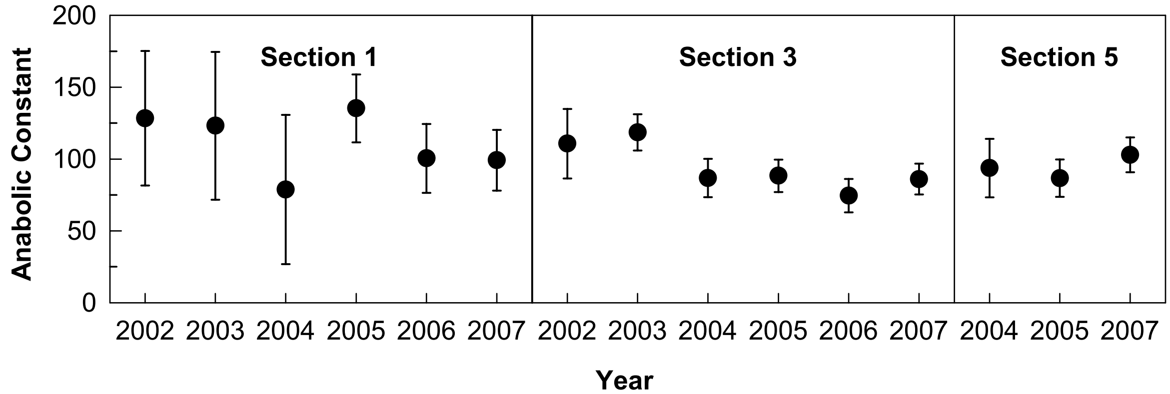


Figure 3.26 Anabolic constant (Product L_∞, K) estimates of mountain whitefish in Sections 1, 3, and 5 during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent 95% confidence intervals).

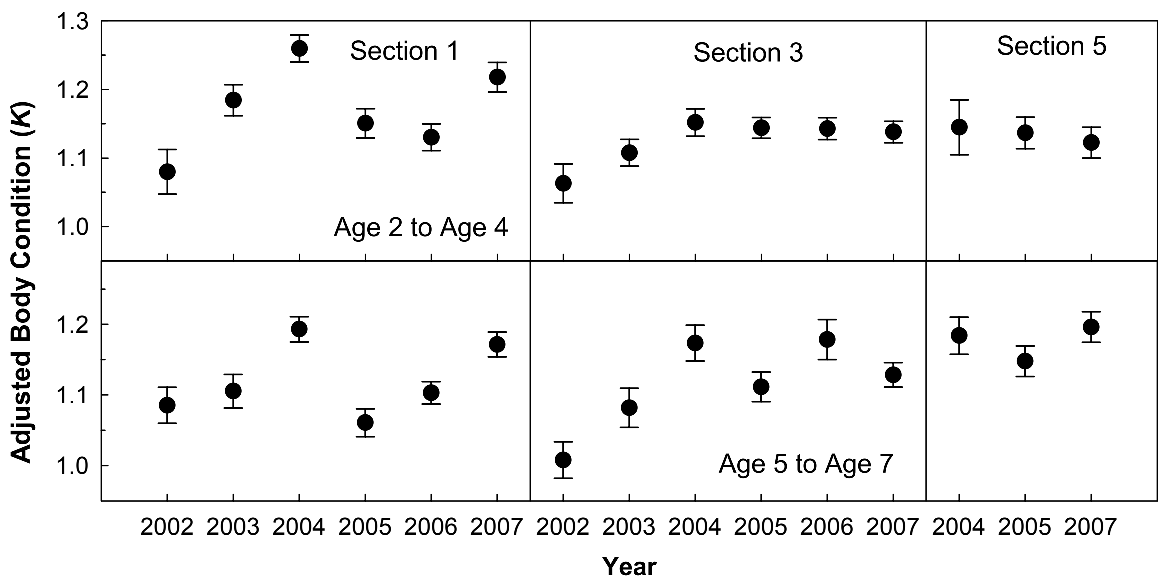


Figure 3.27 Adjusted mean body condition (K) for younger (Ages 2 to 4) and older (Ages 5 to 7) mountain whitefish in Sections 1, 3, and 5 during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent 95% confidence intervals).

Potential causes of the apparent trends in mountain whitefish biological characteristics include changes in environmental conditions and population density. For example, 2004 was a year with very low flow and the highest recorded fish densities. Other causes include sampling effects related to the program. Floy tags caused reduced growth and body condition of mountain whitefish (Mainstream and Gazey 2007). Although the use of Floy tags was stopped in 2005, fish marked with Floy tags still occur in the study area (fish with tags and fish that have lost tags); therefore, adverse Floy tag effects will continue until these fish leave the population. Sampling protocols (fish capture, marking, and processing) are other sampling effects that could cause the downward trends recorded in some of the parameters.

3.4 CATCH RATE

3.4.1 General

Previous studies established that catch rates of target fish species were influenced by habitat and river section. The 2007 results supported these findings. Mean catch rates differed between species, section, and habitat (Table 3.10 and Figure 3.28). Catch rates for Arctic grayling and bull trout were low in all sections. Values ranged from 0.21 to 4.72 fish/km and 0.61 to 1.07 fish/km, respectively. Mountain whitefish catch rates were much higher; mean values exceeded 34 fish/km.

Table 3.10 Mean catch rates of the three target species stratified by section and habitat during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Species	Section	SFC Habitat[a]		SFN Habitat[a]		P-value[b]
		n	Mean (± SE)	*n*	Mean (± SE)	
Arctic grayling	1	48	0.34± 0.11 (A)	42	0.21± 0.09 (A)	0.350
	3	48	2.87 ± 0.48 (B)	42	1.26 ± 0.33 (B)	0.000
	5	48	4.72 ± 0.72 (C)	42	4.55 ± 0.87 (C)	0.430
P-value[c]		0.000		0.000		
Bull trout	1	48	0.78 ± 0.16	42	0.61 ± 0.19 (A)	0.252
	3	48	1.01 ± 0.14	42	0.89 ± 0.16 (AB)	0.334
	5	48	1.07 ± 0.15	42	1.02 ± 0.16 (B)	0.739
P-value		0.133		0.049		
Mountain whitefish	1	48	37.51 ± 2.18	39	53.47 ± 5.11	0.128
	3	48	37.71 ± 2.27	42	42.03 ± 2.92	0.267
	5	48	33.94 ± 2.41	42	45.77 ± 2.98	0.003
P-value		0.124		0.641		

[a] See Table 2.2 for definitions of habitat type.
[b] Based on Independent samples t-test using log-transformed data.
[c] Based on Oneway Analysis of variance using log-transformed data. Different letters designate significantly different ($P \leq 0.05$) values using post hoc means test.

Mean catch rates differed between sections. Arctic grayling were scarce in Section 1 (≤ 0.34 fish/km), moderately abundant in Section 3 (≥ 1.26 fish/km), and most abundant in Section 5 (≥ 4.55 fish/km). Bull trout were slightly less abundant in Section 1 compared to Sections 3 and 5. Mean catch rates were approximately 0.75 fish/km. Arctic grayling and bull trout catch rates in each section were higher in SFC habitats than in SFN habitats. Catch rates of mountain whitefish showed no consistent spatial pattern. In SFC habitat, mean catch rates in all three sections were approximately 35 fish/km. Mean catch rates in SFN habitat were higher in Section 1 (54 fish/km) compared to Sections 3 and 5 (approximately 44 fish/km). The section and habitat differences generally were not significant (Table 3.10).

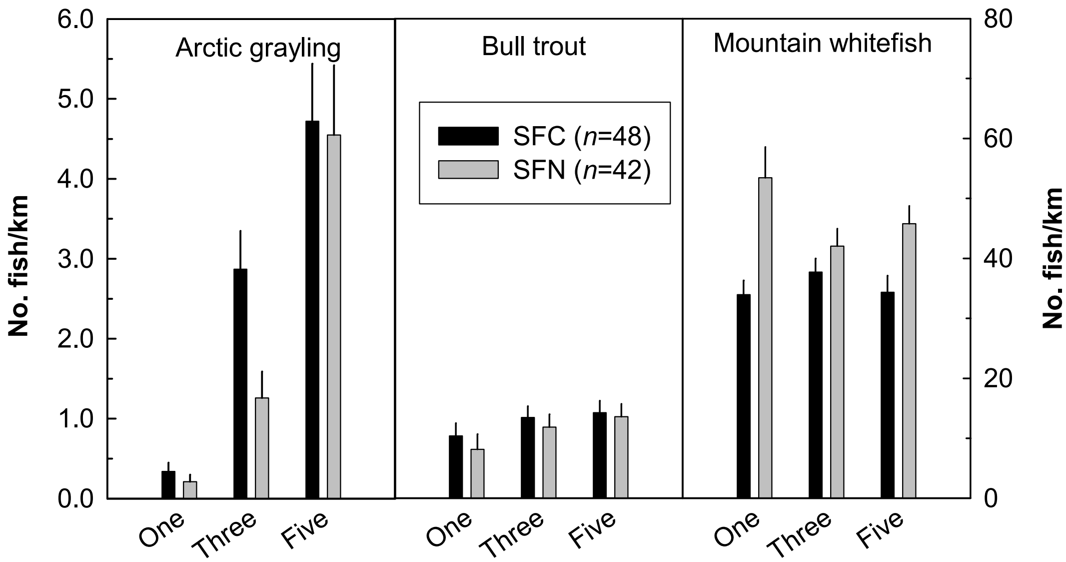


Figure 3.28 Mean catch rate of three target species stratified by section and habitat type during Phase 7 of the Peace River Fish Community Indexing Program, 2007 (vertical bars represent standard error; Y-axis scale for Arctic grayling and bull trout is 0 to 6 fish/km; see Table 2.2 for definitions of habitat type).

3.4.2 Confounding Variables

The field program was structured to collect information for calculation of population estimates. As such, sampling was repeated six times in each section. Previous investigations indicated that during some years catch rates changed over the duration of the field program. Potential causes of this included immigration/emigration of fish, and altered catchability caused by effects of repeated sampling, or changes in discharge and water clarity). Catch rates can be negatively correlated with discharge and water clarity (Mainstream and Gazey 2005 and 2006). In 2007, discharge was relatively constant during the field program and low water clarity was a potential issue only during the first session (see Section 3.1).

Mean catch rate can also vary by sample session for each target species (Figure 3.29). Catch rates of Arctic grayling in Sections 3 and 5 tended to be highest during earliest sessions. Bull trout catch rates exhibited no temporal trend in any of the three sections. Temporal patterns of mountain whitefish catch rates differed between sections. In Section 1 catch rates were constant. In Sections 3 and 5 catch rates declined from Sessions 1 to 3 and then gradually increased. However, the results indicated no large changes in catch rates during the field program. The higher catch rate values for Arctic grayling and mountain whitefish during Session 1 (period of low water clarity) indicated that low water clarity did not adversely affect catchability of these species. It should be noted that none of these apparent trends were statistically significant.

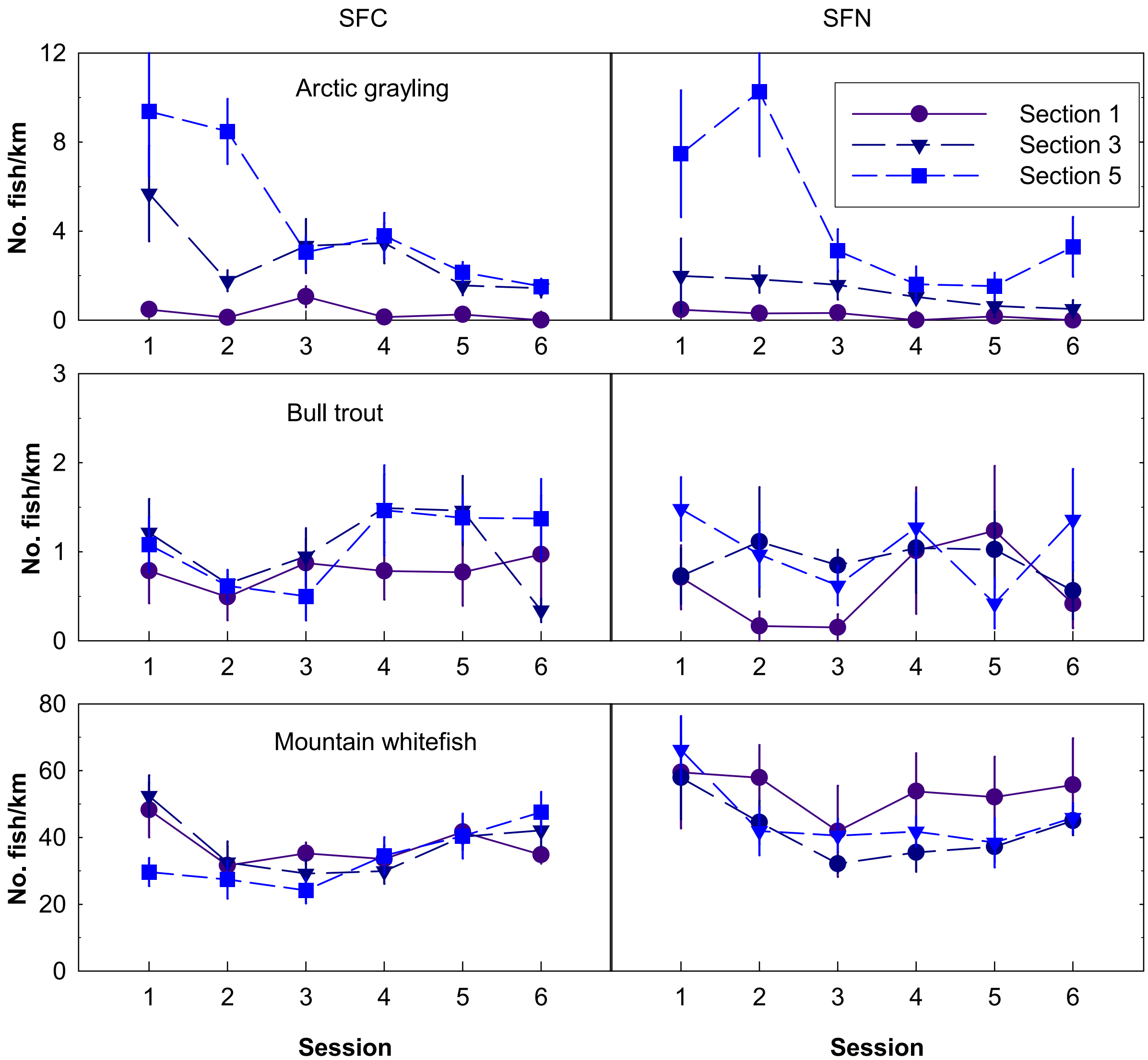


Figure 3.29 Arctic grayling, bull trout, and mountain whitefish catch rates in SFC and SFN habitats by sample session during Phase 7 of the Peace River Fish Community Indexing Program, 2007(vertical bars represent standard errors; see Table 2.2 for definitions of habitat type).

3.4.3 Annual Comparisons

Mean catch rates of target species populations changed between years (Figure 3.30). Arctic grayling catch rates in Sections 3 and 5 continued to increase since the beginning of structured sampling in 2002. For example, in SFC habitat in Section 3 Arctic grayling catch rates almost doubled between 2006 and 2007 (1.5 fish/km versus 2.9 fish/km). In Section 5, catch rates increased from 3.2 fish/km in 2005 to 4.7 fish/km in 2007.

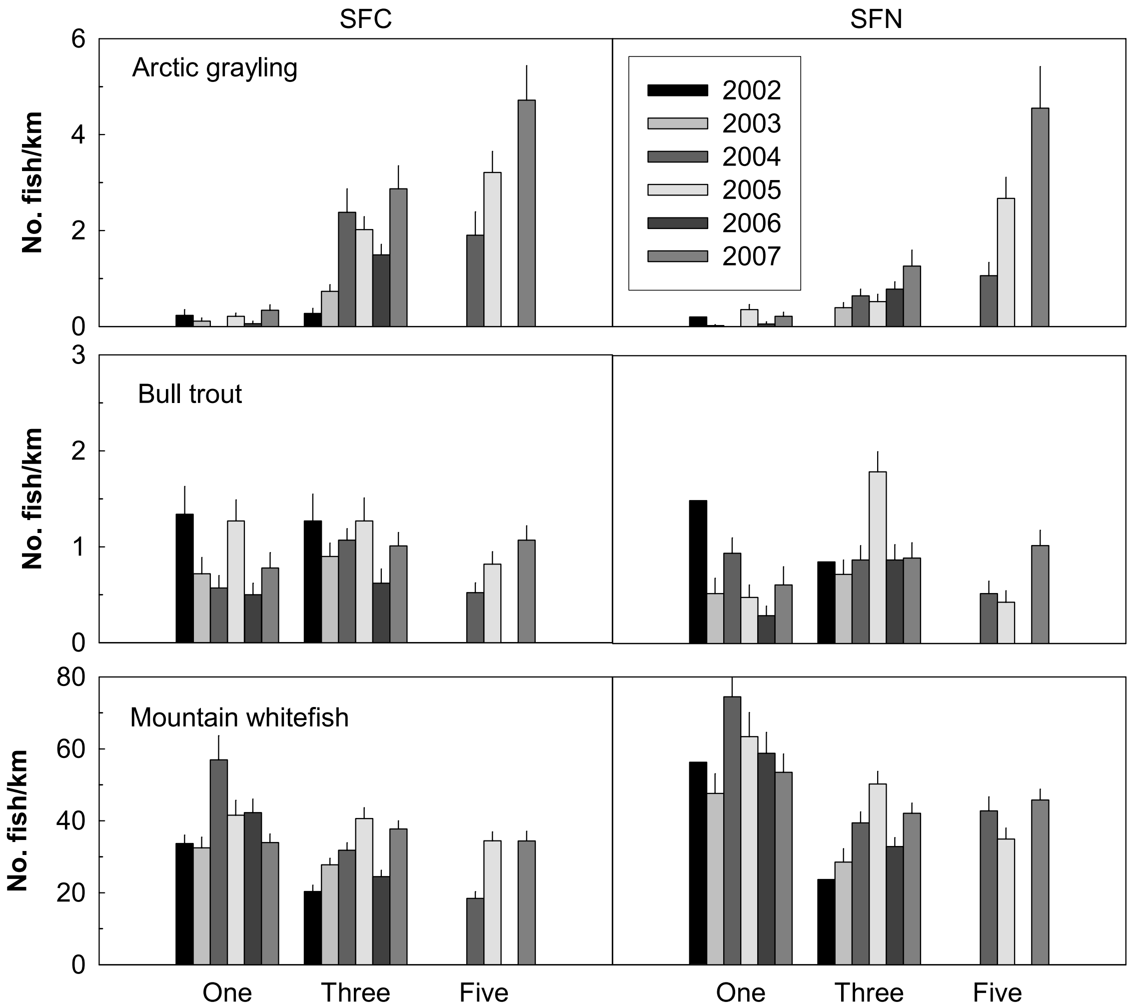


Figure 3.30 Comparisons of mean catch rates of target fish species during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent standard errors).

Bull trout catch rates remained low in 2007 (< 1.5 fish/km), which was consistent with previous studies. Catch rates increased between 2006 and 2007 in Sections 1 and 3; they also increased between 2005 and 2007 in Section 5. The magnitude of the increase varied between sections and habitat types, but was approximately 30%.

Mountain whitefish catch rates in Section 1 in 2007 represented a continuation in the decline from the high recorded in 2004. Mean catch rates during the present study were similar to mean catch rates recorded in 2002 and 2003. In Section 3, mountain whitefish catch rates in 2007 rebounded from the drop recorded in 2006. Mean catch rates during the present study were slightly below the highest value recorded in 2005. Results from Section 5 did not suggest a substantive change in mountain whitefish abundance. Mean catch rates during the present study were similar to values recorded in 2005.

3.4.4 Index of Recruitment

The relative contribution of younger and older fish provides a coarse index of recruitment across the period of record (Figure 3.31).The contribution of younger Arctic grayling (≤ Age 2) was essentially zero in Section 1. In Section 3, younger Arctic grayling were recorded during all years. Following 2002 (a year when few fish were encountered) the relative contribution of younger Arctic grayling remained constant (4% to 8%). In Section 5, the relative contribution of younger Arctic grayling decreased between 2004 and 2007 (11% versus 5%, respectively) suggesting recruitment of younger fish into this sample population was not stable. In contrast, the relative contribution of older Arctic grayling (≥ Age 3) was variable during the period of record. In Section 3, contribution varied between 4 and 21%, and in Section 5 it varied from 8% to 43%. In addition, pattern recorded for older Arctic grayling did not appear to be related to the relative contribution of the younger group during the preceding years.

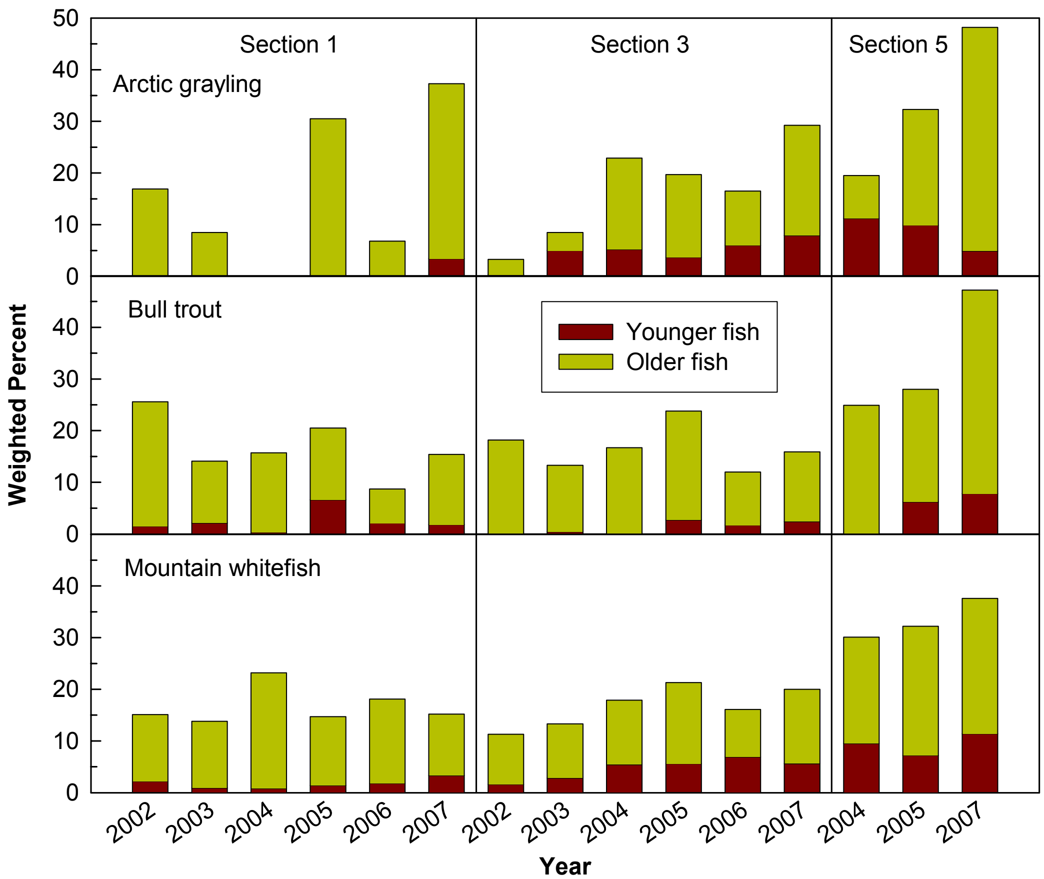


Figure 3.31 Relative contribution of younger and older fish of target species in Sections 1, 3, and 5 across the period of record during the Peace River Fish Community Indexing Program, 2002 to 2007 (see Section 2.2.4 for definition of age groups).

Younger bull trout (≤ Age 2) were recorded in each section during most years, but recruitment was low and variable in each section. After 2004 values tended to be higher (2% to 8%). The relative contribution of older fish (≥ Age 3) also varied between years within each section (7% to 24% in Section 1; 10% to 21% in Section 3; 22% to 39% in Section 5).

Trends in the relative contribution of younger mountain whitefish (≤ Age 3) differed between sections over the period of record. Values in Section 1 ranged from 0.8% to 3.3%, but tended to increase after the low of 0.8% recorded in 2004. In Section 3 values ranged from 2% to 7%, but were generally stable between 2004 and 2007 5.4% to 6.9%). Values recorded in Section 5 ranged from 7% to 11%. With the exception of 2004, the relative contribution of older mountain whitefish (≥ Age 4) was generally stable in Section 1 (13% to 16%). Results for Sections 3 and 5 also indicated stable contributions of older mountain whitefish into sampled populations (10% to 16% in Section 3; 21% to 26% in Section 5).

3.5 SAMPLING EFFECTS

The intensity of sampling during the Peace River Fish Indexing Program has the potential to adversely affect fish growth and body condition. Adverse effects could be caused by fish capture by boat electrofisher, marking fish with tags, and/or processing fish for biological information. Phase 3 studies suggested that project activities adversely affected mountain whitefish (i.e., reduced growth and body condition). The use of Floy T-bar anchor tags rather than boat electrofisher capture was identified as the likely causal mechanism; therefore, a recommendation was made to use PIT tags in place of Floy tags.

Phase 4 studies examined growth differences between Floy marked and unmarked fish and concluded that Floy tagged fish grew at a significantly lower rate than unmarked fish. Phase 5 compared the growth of Floy tagged, PIT tagged, and unmarked mountain whitefish and found that Floy tagged fish grew at a significantly lower rate than both PIT tagged and unmarked mountain whitefish. PIT tagged and unmarked fish grew at similar rates. Phase 6 continued the evaluation of sampling effects on mountain whitefish. Similar to previous investigations, there were negative Floy tag effects on growth and body condition. Also, there was no difference in growth and body condition of PIT tag and unmarked study fish. This provided evidence that PIT tags were a suitable alternative to use of Floy tags.

Phase 7 continued its evaluation by examining tag effects on incremental growth of mountain whitefish. For the incremental growth of marked fish, all available data were used over the period 2001 to 2007 to increase contrast and the sample size to deal with large variation. Since a three-dimensional plot of the scatter (Equation 3, Section 2.2.5) would be difficult to interpret, Figure 3.32 provides the predicted versus observed relative growth (as a fraction of the maximum possible length given length-at-release and time-at-large) based on mark-recapture incremental growth. Note that all measurement error is included in the observed relative growth.

Growth curves derived from the incremental growth of Floy and PIT marked fish up to 10 years of age to illustrate the divergence in predicted lengths (Figure 3.33). Estimates of the non-linear von Bertalanffy parameters (Equation 3) for the length increment data are listed in Table 3.11.

Comparison between growth curves are complicated by the large negative correlation between the asymptotic length ($L\infty$) and the growth coefficient (K). Following Gallucci and Quinn (1979) the products $\omega = L\infty K$, termed the anabolic constant, were calculated and listed in Table 3.11 and plotted in Figure 3.34. Age-length derived intervals for unmarked fish using biological data presented in Section 3.3.3 are included for comparison.

With respect to the Figures 3.32 to 3.34 and Table 3.11 the following should be noted:

1. The anabolic constants derived from incremental growth of Floy and PIT marked mountain whitefish were significantly different (the 95% confidence regions do not overlap) for the 2005, 2006, and 2007 studies.
2. The interval derived from incremental growth of PIT marked fish is not significantly different (overlap) from the age-length derived intervals for unmarked fish for 2005 and 2006; but it is significantly different (no overlap) from the age-length derived intervals for unmarked fish in 2007.
3. The anabolic constants of Floy and PIT marked mountain whitefish decrease over the three studies indicating lower growth rates.
4. The confidence intervals for PIT marked fish are also tighter over the three studies because of more recaptured fish and longer times at large.

The apparent decline in growth of Floy and PIT marked mountain whitefish and significantly lower growth of PIT marked fish compared to unmarked fish in 2007 may be an artifact of sample methods. The marked cohort is composed of fish that have the potential to age over time (2001 to 2007); therefore, the growth of this cohort is expected to decline as tagged fish get older. The unmarked cohort of mountain whitefish included younger fish (Age 0 to Age 3) as well as older fish (Age 4 to Age 12). As such, the growth rate of this group would be biased upward. An alternate explanation may be that the growth of PIT marked fish has been negatively affected over time.

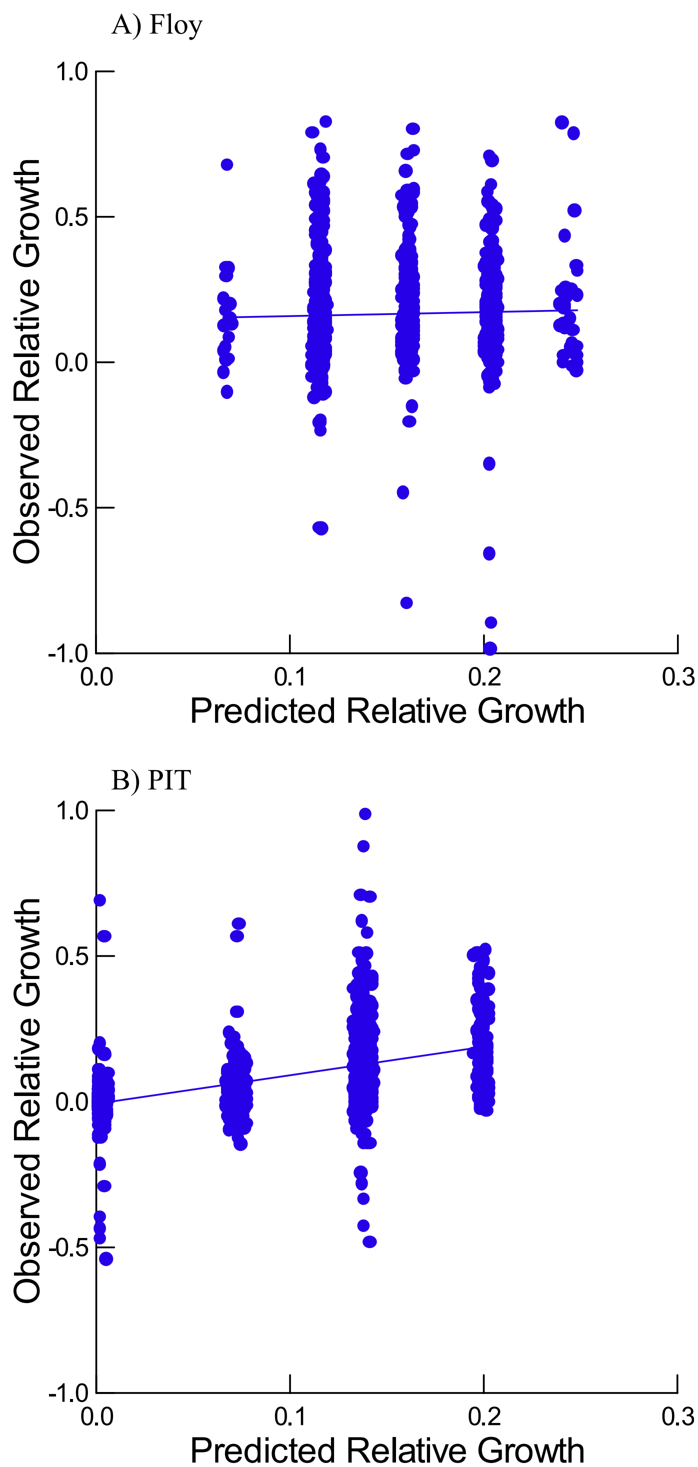


Figure 3.32 Predicted versus observed relative growth as a fraction of the maximum possible given length-at-release and time-at-large) for Floy tags (A) and PIT tags (B) based on mark-recapture incremental growth of mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007. Predicted = 1-exp(-KΔt) and observed = (Lr-L0)/(L∞-L0). All measurement error is included in the observed relative growth.

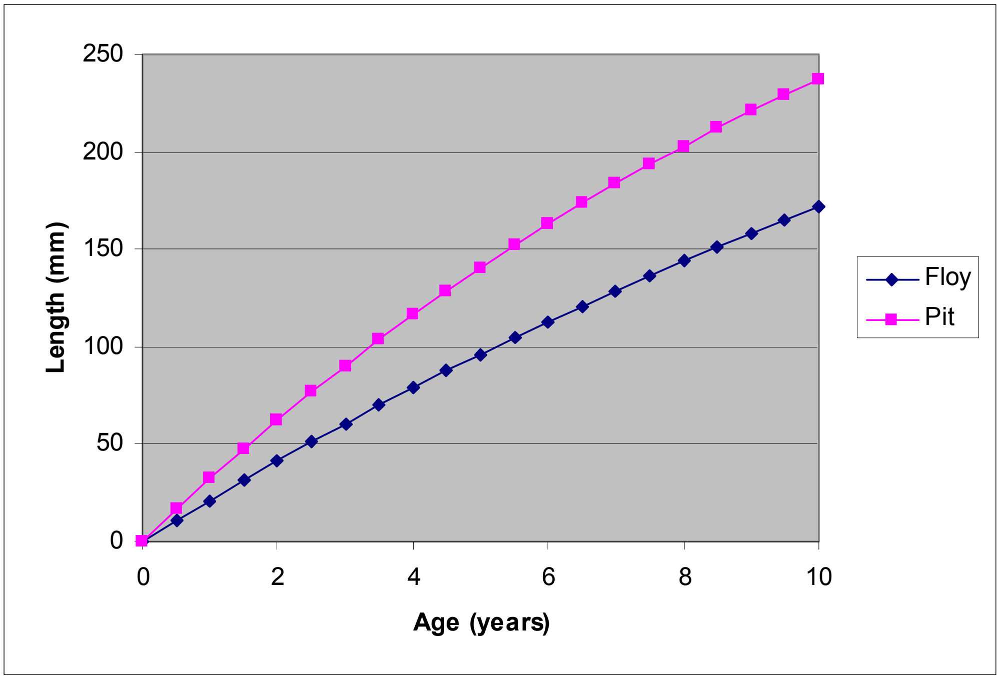


Figure 3.33 Predicted growth of mountain whitefish using a von Bertalanffy growth model with parameters based on length-at-age of Floy and PIT marked fish and the incremental growth obtained from length at release and recapture of tagged fish during the Peace River Fish Community Indexing Program (all available data were used from the period 2001 to 2007).

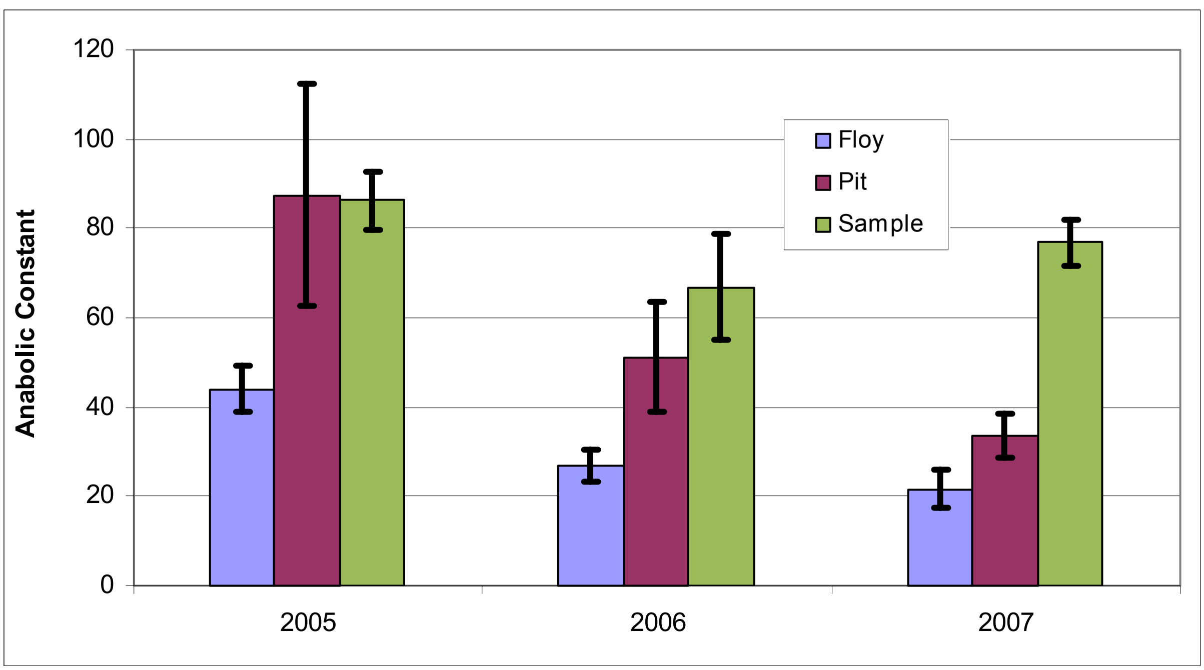


Figure 3.34 Anabolic constant ($\omega = L_{\infty}k$) with the associated 95% confidence intervals determined from incremental growth (PIT and Floy marked) for mountain whitefish marked in 2005 and recaptured in 2007 and age for unmarked mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program.

Table 3.11 Parameter estimates using nonlinear regression on von Bertalanffy growth models for mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Parameter	Estimate	Asymptotic SE	Correlation L_∞
Length Increment of Floy Marked Fish (*n* = 965)			
K	0.0479	0.0063	-0.949
L∞	452.1	16.5	
Product(K,L∞)	21.66	2.12	
Length Increment of PIT Marked Fish (*n* = 1348)			
K			-0.954
	0.0738	0.0073	
L∞	455.1	13.2	
Product(K,L∞)	33.60	2.41	
Age-at-Length of Unmarked Fish (*n* = 720)			
K	0.1670	0.0090	-0.975
L∞	460.1	10.0	
Product(K,L∞)	76.85	2.53	

3.6 POPULATION ESTIMATES

3.6.1 Mountain whitefish

3.6.1.1 Factors that Impact Population Estimates

A comparison of mountain whitefish recapture rate by tag type is plotted in Figure 3.35. A comparison of the recovery rates by the year of tag application and section is recorded in Table 3.12. The rates of recapture by year of release were significantly different for all Sections ($P < 0.05$). Consistent with earlier studies, fish marked prior to 2006 were more susceptible to capture in 2007.

Figure 3.36 plots the proportion of available marked fish recaptured two and three times by sampling session. If fish were not influenced by electrofishing (more or less prone to subsequent recapture) then the lines in Figure 3.36 should coincide and be horizontal. The confidence bounds on the recapture proportions, assuming a binomial distribution, overlap all other points.

Histograms of the mountain whitefish lengths at release and recapture are plotted in Figures 3.37 and 3.38, respectively. Inspection of the figures reveals that smaller fish (250-275 mm) were not recaptured with the same frequency. A comparison of the lengths (accumulated into 25 mm intervals) by section is tabulated in Table 3.13. While significant differences were not observed ($P > 0.05$) in any of the sections, a slight under representation of smaller fish in the recapture record has been seen consistently in this study and in all of the previous studies.

Time at large of recaptured mountain whitefish regressed on the growth increment (length at release minus length at recapture) is plotted in Figure 3.39. There was minor but statistically significant growth of marked fish over the 34 days of the study. Therefore, the border histogram of the growth increment provides an indication of measurement error (residual standard deviation of 3.1 mm for each measurement).

The movement of recaptured mountain whitefish between standard sections during 2007 is listed in Table 3.14 along with the estimates of the migration proportions adjusted for the number of fish examined (Equation 4). These proportions are plotted in Figure 3.40. Generally, fish did not travel beyond site of release (Figure 3.41). Positive values indicate fish were recaptured upstream of the release site and vice-versa. Note that most fish were recaptured in the same site-of-release. The movement of recaptured whitefish between sections with the marks applied in 2002 to 2006 are tabulated in Table 3.15 and plotted in Figures 3.42 to 3.46, respectively. For the 2002 to 2006 releases, a bar plot of the distance traveled within each section is displayed in Figure 3.47. Consistent with movement patterns in previous studies, mountain whitefish released in past years were remarkably senescent with the exception of the 2004 releases which demonstrated more movement between sections (Figure 3.44). The movement of fish within a section released 2002 to 2006 (Figure 3.47) were similar to the movement of the 2007 releases but with more movement in Sections 3 and 5. Most of the movement within a section can be attributed to the 2004 releases.

3.6.1.2 Empirical Model Selection

The empirical evaluation of recaptured tags assuming homogeneous or heterogeneous capture probabilities using MARK software is provided by Table 3.16. For all sections, the constant recapture model was the most likely; although, there is little to choose between models.

The data summary for the Jolly-Seber open population model and the associated estimates of abundance, survival (from any source of mortality or movement from the section) and births (immigration into the section) by river section are provided in Table 3.17. The total row for each section provides the mean estimated abundance over the sampled sessions, total survival is under the constant survival option and total births is the simple sum of estimated births by session. For all Sections, the 95% confidence interval for survival included 1.0 and for births included 0.

These results indicated a closed population with homogeneous capture probability for all sections as assumed by the Bayes model.

3.6.1.3 Bayes Sequential Model for a Closed Population

The mark-recapture data were extracted by section from the database using marks applied during 2007 (PIT tags) and marks that were observed during 2007 that were originally applied in 2001 to 2006 (Floy and PIT tags) and a minimum length of 250 mm. Table 3.18 lists mountain whitefish examined for marks and recaptures by date and section. The releases, adjusted for movement between sections (Equation 4) by section and date, are given in Table 3.19. The compilations of marks available (Equation 6), fish examined (Equation 7), and recaptures (Equation 8) assuming 0.0 removal and 0% undetected mark rate are listed in Table 3.20. The subsequent population estimates using the Bayesian closed model are given in Table 3.21. The sequential posterior probability plots by section are provided in Appendix F (Figures F1 to F3) and the final posterior distributions for the three sections are drawn in Figure 3.48.

The sequence of posterior probability plots can be used as an indicator of closure or change in the population size over the study period (Gazey and Staley 1986). Trends in the posterior plots can also be caused by trends in catchability or capture probability (changes in population size and changes in catchability over the study period are confounded). Inspection of the plot sequences in Appendix F reveals that all Sections are consistent with a convergence of the modal population size. These observations are consistent with the automated model selection (UFIT) and the Jolly-Seber recruitment and survival estimates (Table 3.17).

3.6.1.4 Comparison to Previous Studies

Bar plots of the population estimates for the 2002 to 2007 studies with sections common to 2007 are provided in Figure 3.49. The estimates identified as suspect (immigration of fish or changes in catchability over the project operating period) in previous studies are labeled in the figure. In 2004, very low water likely concentrated the fish in locations that could be sampled and elevated the population estimates.

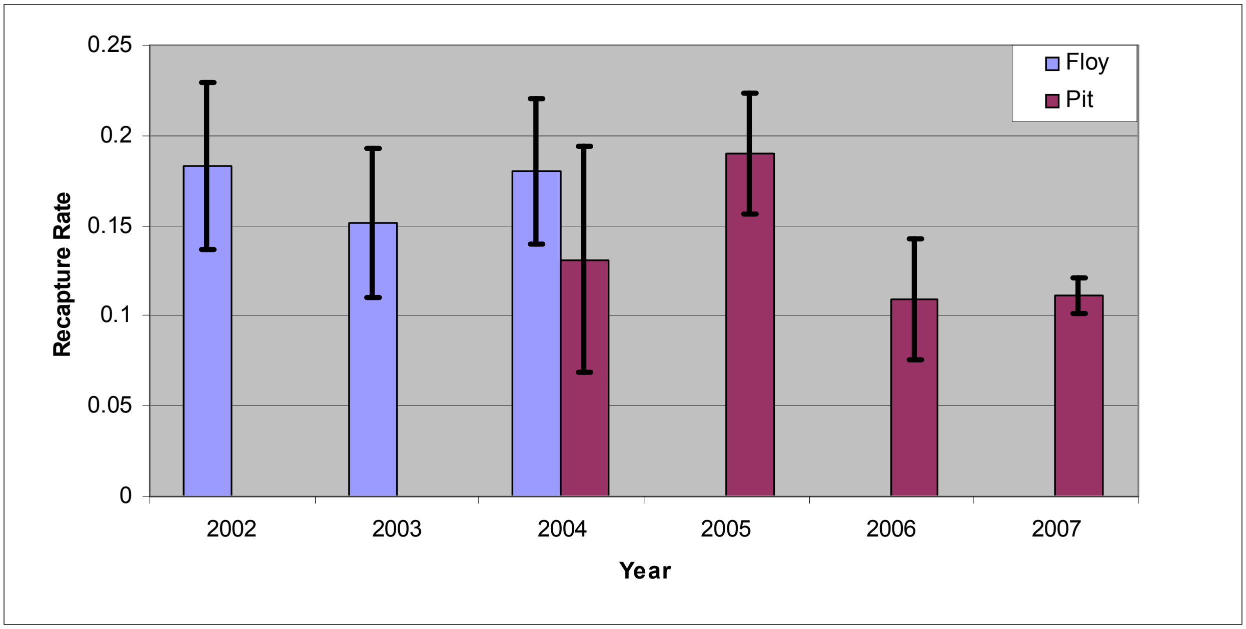


Figure 3.35 Recapture rate by tag type and year of release for mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007 (vertical bars represent 95% confidence intervals).

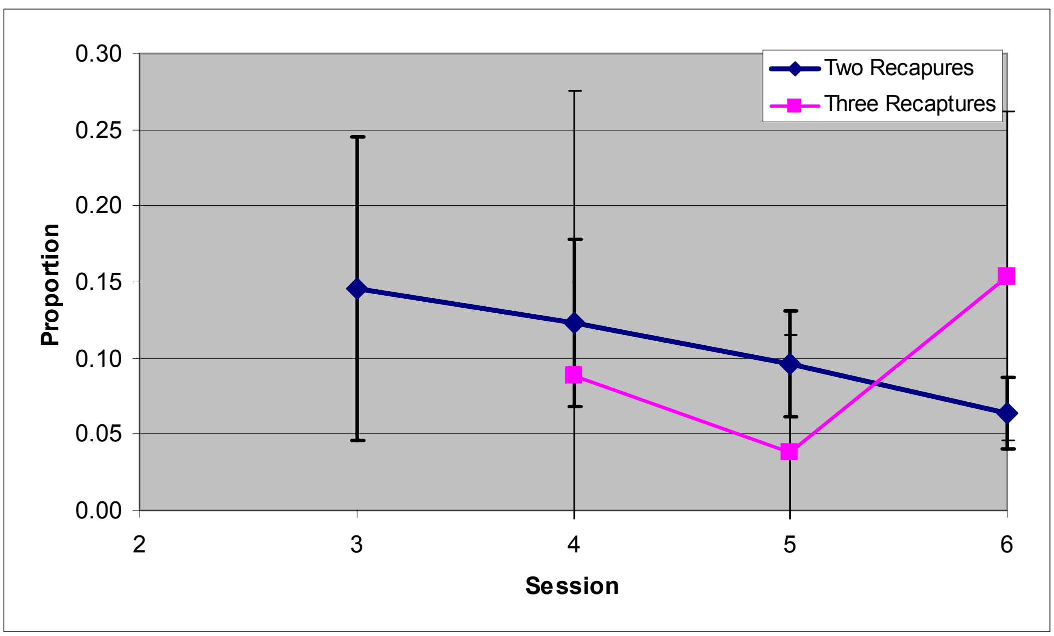


Figure 3.36 Proportion of mountain whitefish recaptured two and three times by sampling session during Phase 7 of the Peace River Fish Community Indexing Program, 2007 (vertical bars represent 95% confidence intervals assuming a multinomial distribution).

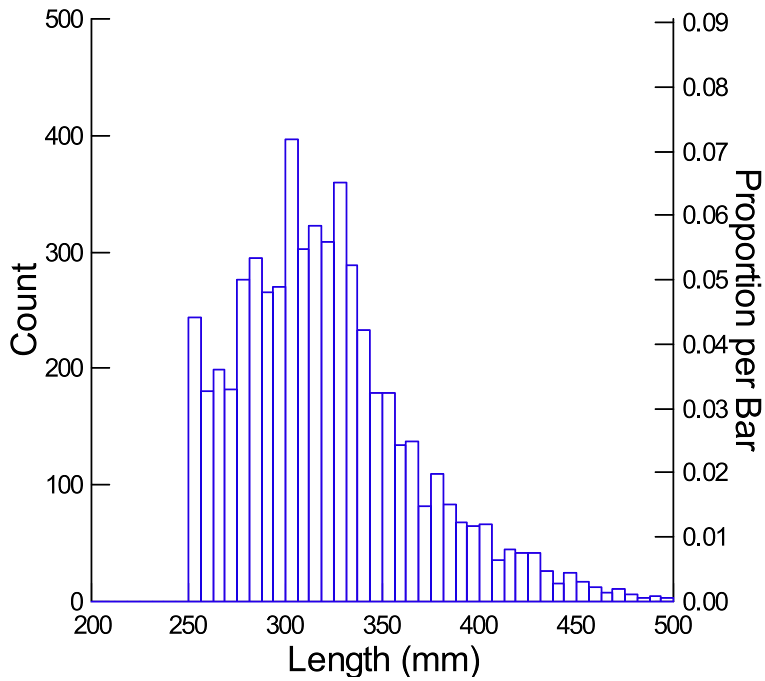


Figure 3.37 Histogram of mountain whitefish lengths at release during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

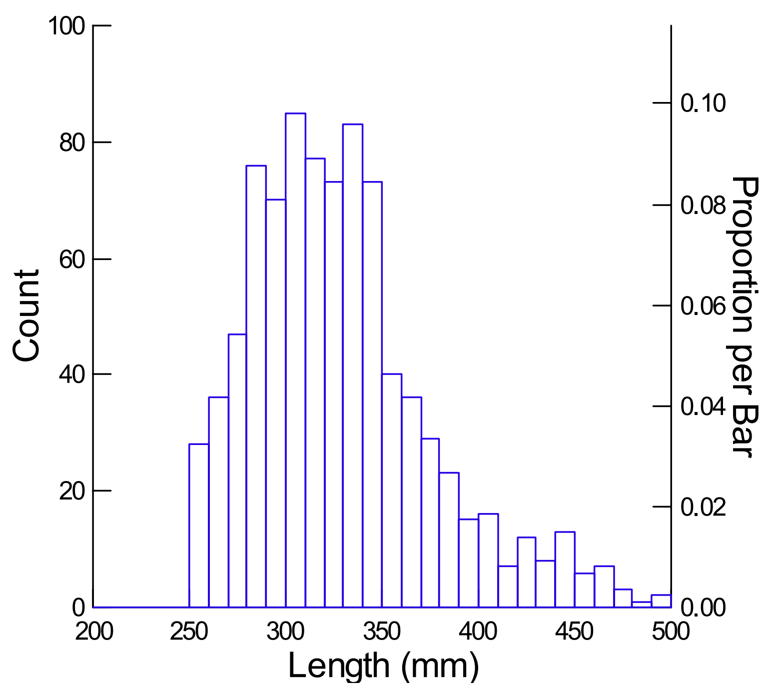


Figure 3.38 Histogram of mountain whitefish lengths at recapture during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

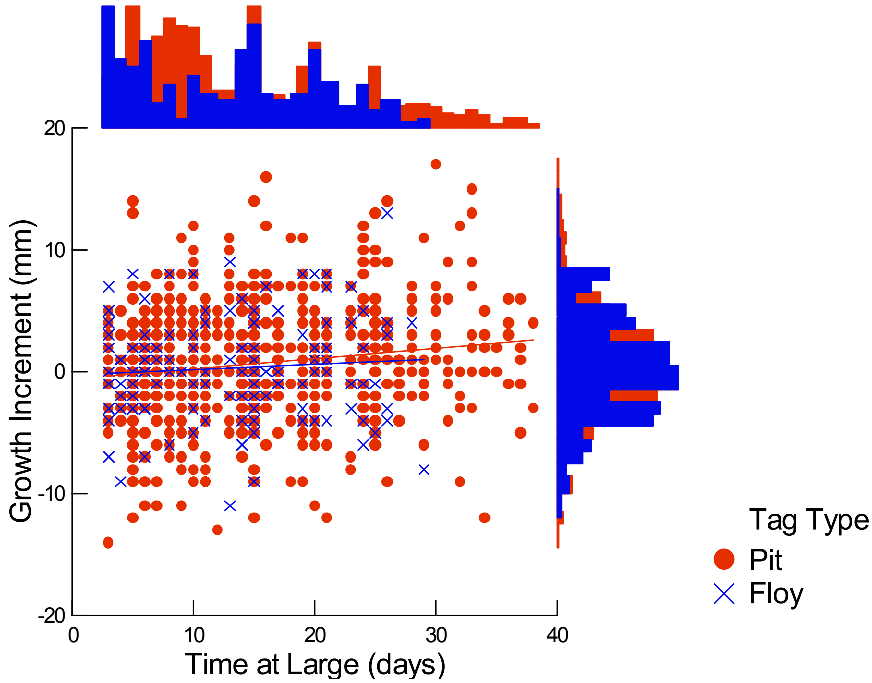


Figure 3.39 Growth over the study period of mountain whitefish with border histograms of time at large and growth increment by tag type during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

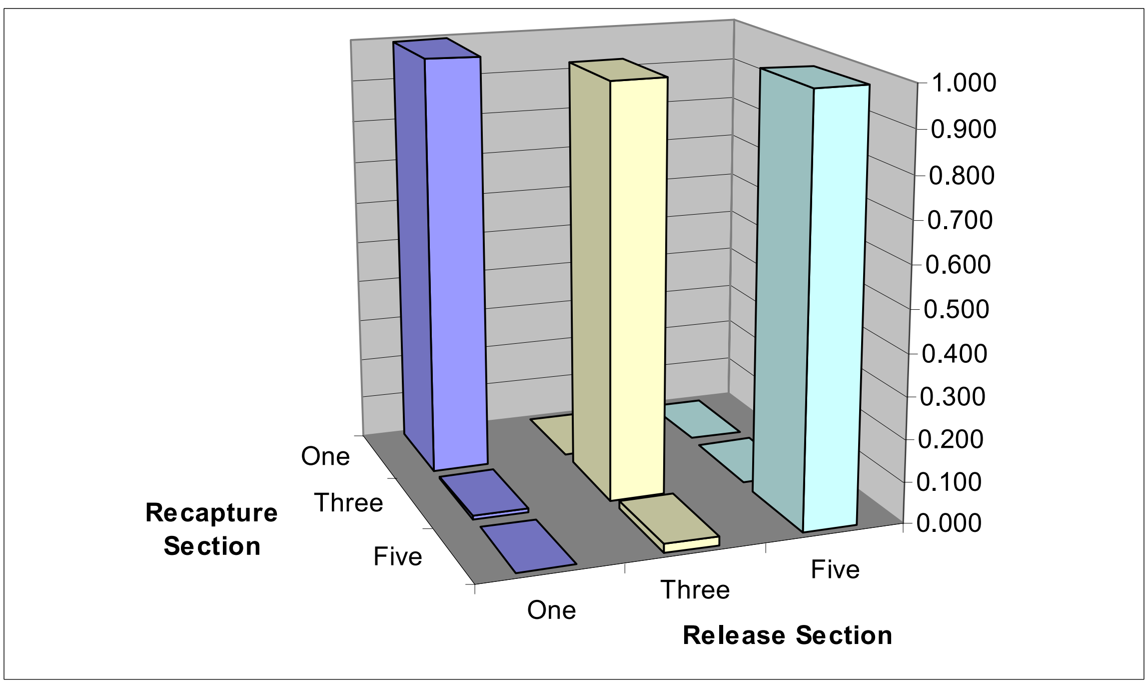


Figure 3.40 Distribution of recaptured marks released in 2007 standardized for sampling effort by section of release for mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

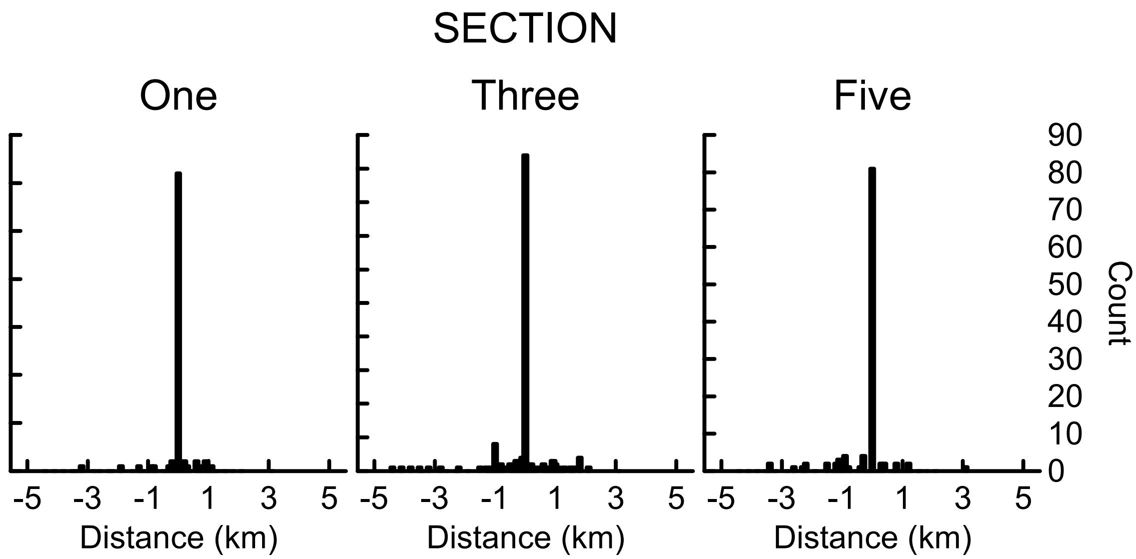


Figure 3.41 Bar plot of the travel distance of recaptured mountain whitefish released in 2007 within each of the sections sampled (positive values indicate upstream movement and *vice-versa*) during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

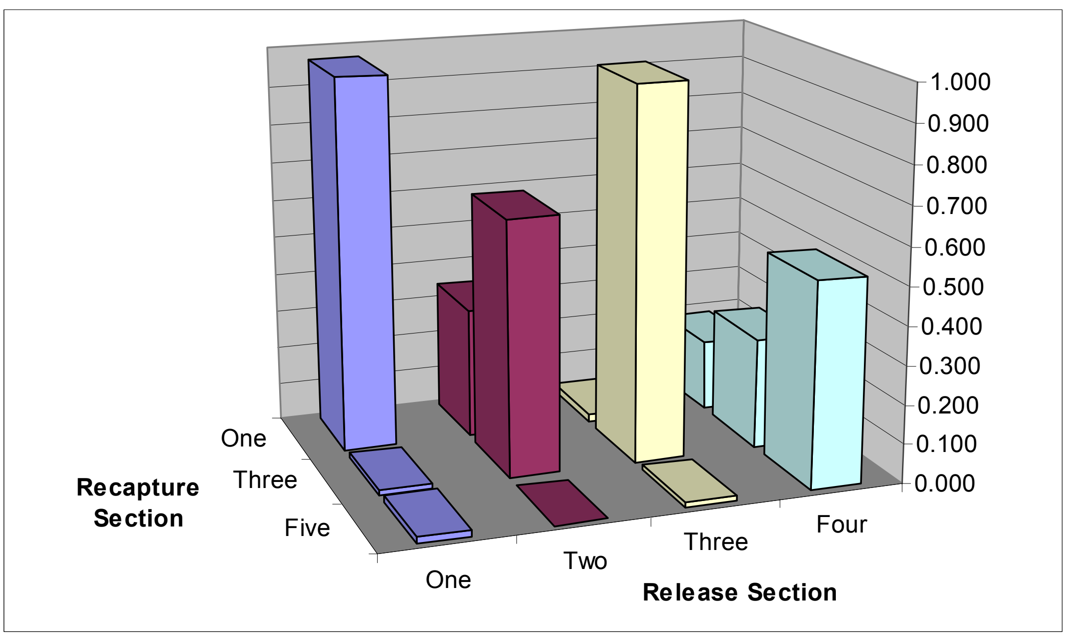


Figure 3.42 Distribution of recaptured marks in 2007 standardized for sampling effort by section of release for mountain whitefish released in 2002 during the Peace River Fish Community Indexing Program, 2002 to 2007.

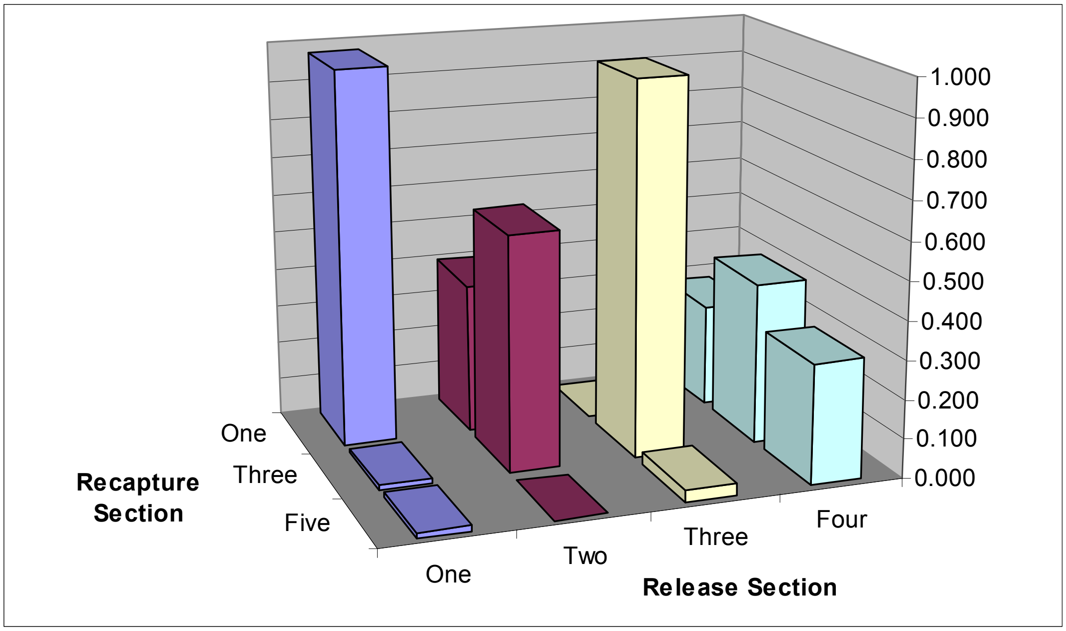


Figure 3.43 Distribution of recaptured marks in 2007 standardized for sampling effort by section of release for mountain whitefish released in 2003 during the Peace River Fish Community Indexing Program, 2002 to 2007.

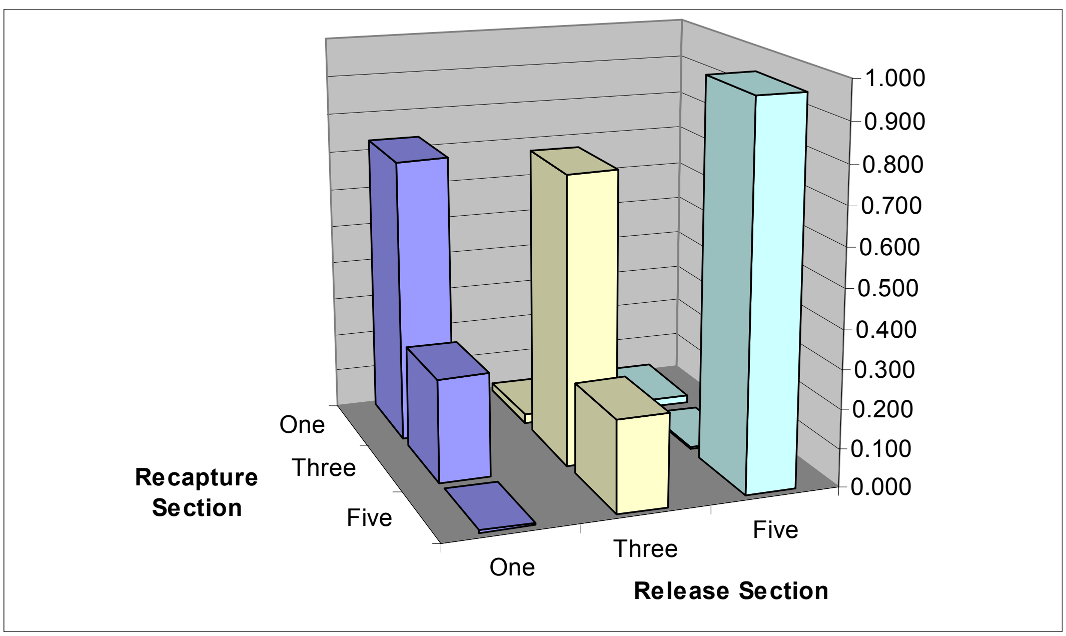


Figure 3.44 Distribution of recaptured marks in 2007 standardized for sampling effort by section of release for mountain whitefish released in 2004 during the Peace River Fish Community Indexing Program, 2002 to 2007.

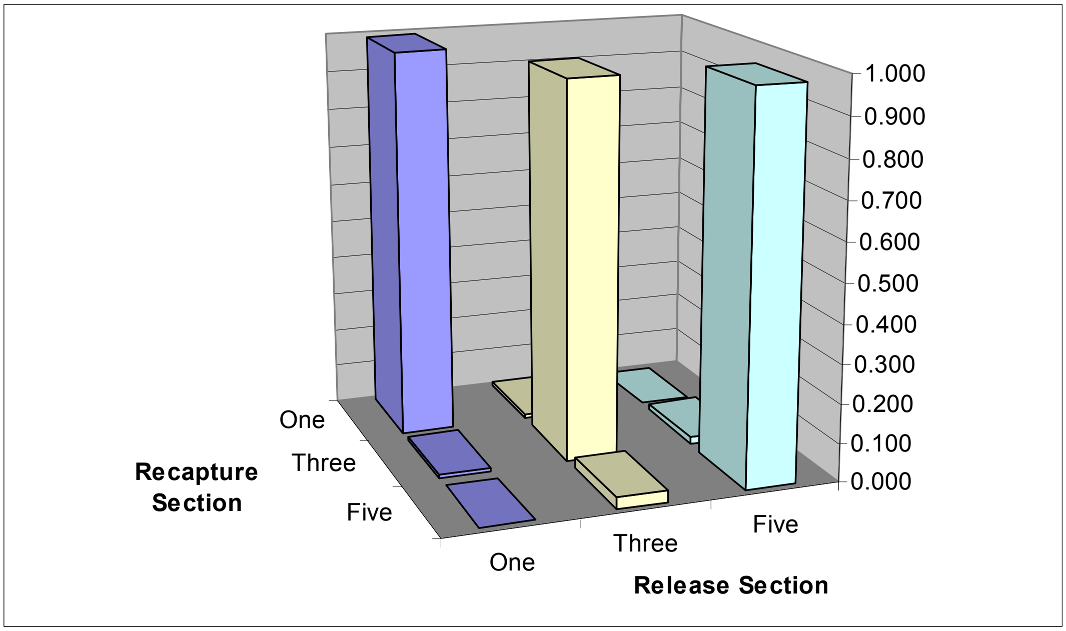


Figure 3.45 Distribution of recaptured marks in 2007 standardized for sampling effort by section of release for mountain whitefish released in 2005 during the Peace River Fish Community Indexing Program, 2002 to 2007.

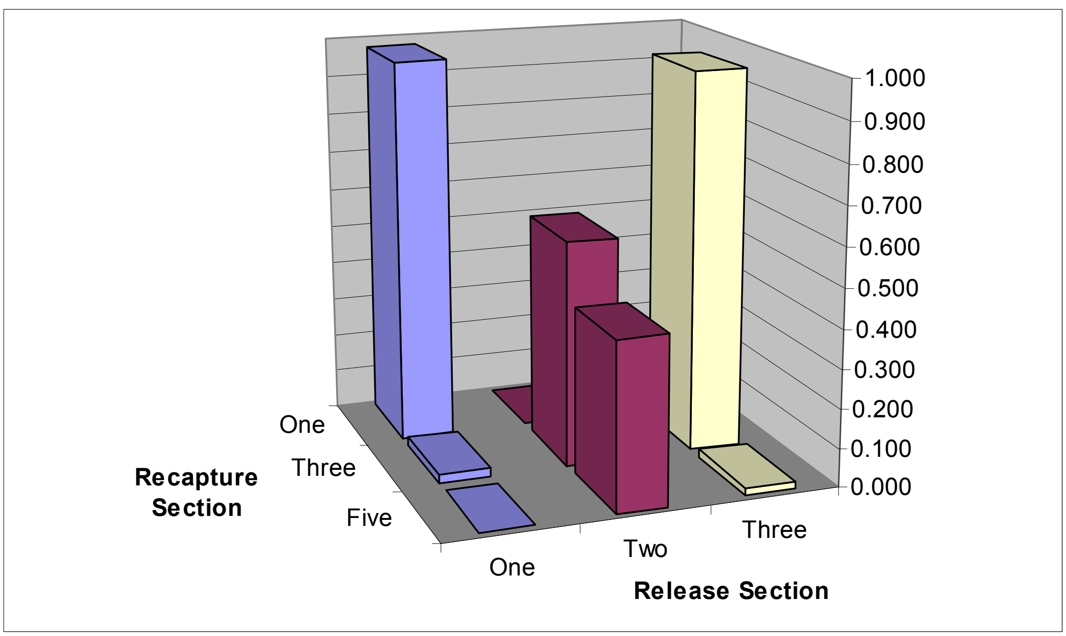


Figure 3.46 Distribution of recaptured marks in 2007 standardized for sampling effort by section of release for mountain whitefish released in 2006 during the Peace River Fish Community Indexing Program, 2002 to 2007.

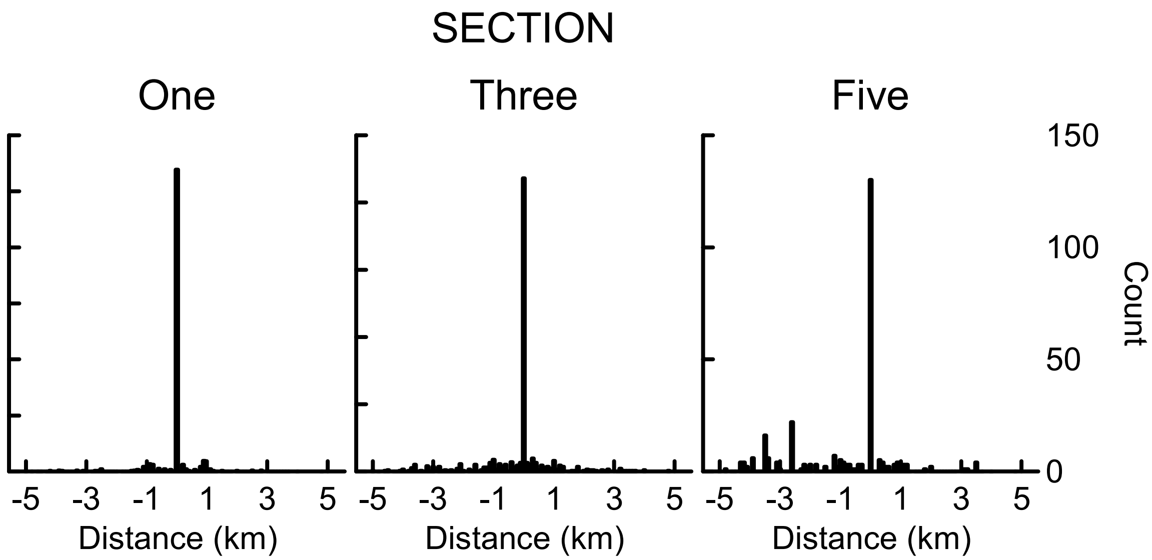


Figure 3.47 Bar plot of the travel distance of recaptured mountain whitefish released from 2002 to 2006 within each of the sections sampled (positive values indicate upstream movement and *vice-versa*) and captured in 2007 during the Peace River Fish Community Indexing Program, 2002 to 2007.

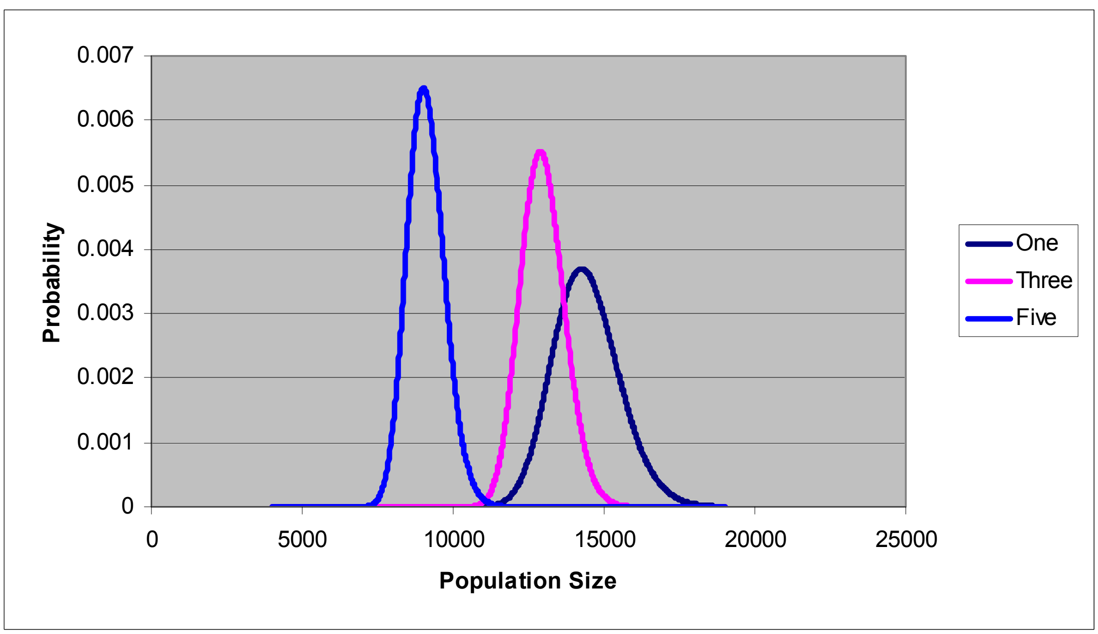


Figure 3.48 Final posterior distributions by section for mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

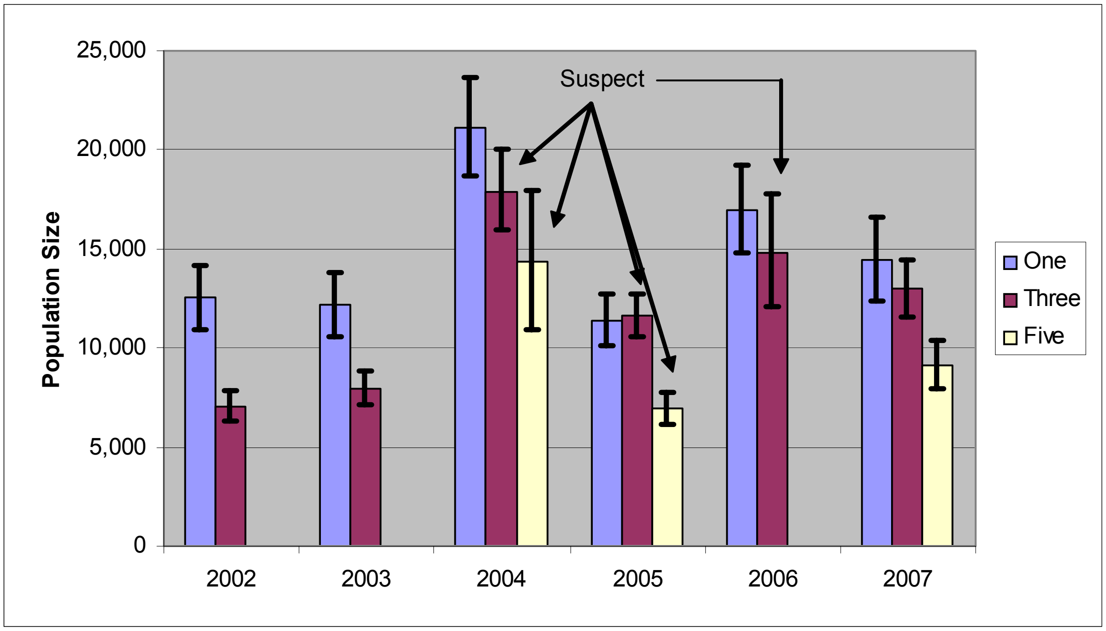


Figure 3.49 Mountain whitefish population estimates by section for 2002 to 2007 during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent 95% confidence intervals).

Table 3.12 A comparison of mountain whitefish recaptured in 2007 that were marked by section during the Peace River Fish Community Indexing Program, 2002 to 2007.

	Section			Total
	One	Three	Five	
2001 Releases				
Recaptures	2	1	1	4
Marks	9	8	5	22
Percent	22.2	12.5	20.0	18.2
Time-at-large (days)	23.0	14.0	21.0	20.3
2002 Releases				
Recaptures	15	25	1	41
Marks	108	109	7	224
Percent	13.9	22.9	14.3	18.3
Time-at-large (days)	15.1	11.5	10.0	12.8
2003 Releases				
Recaptures	17	20	1	38
Marks	128	117	6	251
Percent	13.3	17.1	16.7	15.1
Time-at-large (days)	14.4	12.6	6.0	13.2
2004 Releases				
Recaptures	14	26	26	66
Marks	114	164	115	393
Percent	12.3	15.9	22.6	16.8
Time-at-large (days)	11.5	12.7	13.6	12.8
2005 Releases				
Recaptures	14	35	36	85
Marks	92	222	146	460
Percent	15.2	15.8	24.7	18.5
Time-at-large (days)	13.5	11.5	14.6	13.1
2006 Releases				
Recaptures	20	13		33
Marks	161	137	3	301
Percent	12.4	9.5		11.0
Time-at-large (days)	13.7	14.2		13.9
2007 Releases				
Recaptures	80	161	127	368
Marks	1020	1315	987	3322
Percent	7.8	12.2	12.9	11.1
Time-at-large (days)	13.9	12.5	13.2	13.0
Independence Test				
Probability	0.031	0.016	<0.001	<0.001

Table 3.13 Comparison of mountain whitefish lengths and recapture by section during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Length Interval (mm)	Section						Total	
	One		Three		Five			
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Recaptures								
250-275	11	6.8	32	11.6	18	9.7	61	9.8
275-300	49	30.4	61	22.2	20	10.8	130	20.9
300-325	57	35.4	55	20.0	28	15.1	140	22.5
325-350	36	22.4	66	24.0	38	20.5	140	22.5
350-375	5	3.1	29	10.5	34	18.4	68	11.0
375-400	2	1.2	19	6.9	16	8.6	37	6.0
400-425	1	0.6	10	3.6	13	7.0	24	3.9
425-450			3	1.1	18	9.7	21	3.4
Total	161	100.0	275	100.0	185	100.0	621	100.0
Releases								
250-275	210	12.9	328	16.0	142	11.6	680	13.9
275-300	399	24.5	397	19.4	188	15.3	984	20.1
300-325	546	33.5	434	21.2	200	16.3	1180	24.1
325-350	360	22.1	388	19.0	223	18.2	971	19.8
350-375	77	4.7	220	10.8	194	15.8	491	10.0
375-400	17	1.0	166	8.1	128	10.4	311	6.3
400-425	15	0.9	79	3.9	85	6.9	179	3.7
425-450	4	0.2	32	1.6	67	5.5	103	2.1
Total	1628	100.0	2044	100.0	1227	100.0	4899	100.0
Like Ratio Chi-Square	4.08		4.11		4.45		7.15	
Probability	0.538		0.848		0.814		0.521	

Table 3.14 Mountain whitefish recaptures and migration proportions adjusted (inverse weight) for fish examined by section released and recaptured during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Release Section	Recapture Section			
	One	Three	Five	Total
Recaptures				
One	79			79
Three		153	2	155
Five		1	119	120
Sample	2565	3292	2218	8075
Percent Recaptured	3.08	4.68	5.46	
Proportions				
One	1.000	0.000	0.000	1.000
Three	0.000	0.981	0.019	1.000
Five	0.000	0.006	0.994	1.000

Table 3.15 Mountain whitefish recaptures and migration proportions adjusted (inverse weight) or fish examined by section released during 2002 to 2006 and recaptured in 2007 during the Peace River Fish Community Indexing Program, 2002 to 2007.

Release Section	**Recapture Section**				**Release Section**	**Recapture Section**			
	One	**Three**	**Five**	**Total**		**One**	**Three**	**Five**	**Total**
2002					**2005**				
Recaptures					*Recaptures*				
One	119	2	2	123	One	104	1	0	105
Two	2	5		7	Three	2	256	5	263
Three	2	124	1	127	Five	0	5	186	191
Four	2	4	5	11					
Sample	2565	3292	2218	8075	Sample	2565	3292	2218	8075
Recap. %	4.87	4.10	0.36		Recap. %	4.13	7.96	8.61	
Proportions					*Proportions*				
One	0.968	0.013	0.019	1.000	One	0.993	0.007	0.000	1.000
Two	0.339	0.661	0.000	1.000	Three	0.010	0.962	0.028	1.000
Three	0.020	0.968	0.012	1.000	Five	0.000	0.018	0.982	1.000
Four	0.184	0.286	0.531	1.000					
2003					**2006**				
Recaptures					*Recaptures*				
One	142	2	2	146	One	182	5		187
Two	1	2		3	Two		2	1	3
Three		131	3	134	Three	1	145	2	148
Four	2	4	2	8					
Sample	2565	3292	2218	8075	Sample	2565	3292	2218	8075
Recap. %	5.65	4.22	0.32		Recap. %	7.13	4.62	0.14	
Proportions					*Proportions*				
One	0.973	0.011	0.016	1.000	One	0.979	0.021	0.000	1.000
Two	0.391	0.609	0.000	1.000	Two	0.000	0.574	0.426	1.000
Three	0.000	0.967	0.033	1.000	Three	0.009	0.972	0.020	1.000
Four	0.269	0.419	0.311	1.000					
2004					**2007**				
Recaptures					*Recaptures*				
One	125	58	1	184	One	79			79
Three	3	136	29	168	Three		153	2	155
Five	3	1	112	116	Five		1	119	120
Sample	2565	3292	2218	8075	Sample	2565	3292	2218	8075
Recap. %	5.11	5.92	6.40		Recap. %	3.08	4.68	5.46	
Proportions					*Proportions*				
One	0.730	0.264	0.007	1.000	One	1.000	0.000	0.000	1.000
Three	0.021	0.744	0.235	1.000	Three	0.000	0.981	0.019	1.000
Five	0.023	0.006	0.972	1.000	Five	0.000	0.006	0.994	1.000

Table 3.16 Delta Akaike's information criteria adjusted to account for the number of parameters (DAICC) and model likelihood during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	Constant Recapture		Heterogeneous Recapture	
	$DAIC_C$	Likelihood	$DAIC_C$	Likelihood
One	0.000	1.000	2.001	0.368
Three	0.000	1.000	2.458	0.293
Five	0.000	1.000	1.777	0.411

Table 3.17 Jolly-Seber population estimates by river section for mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007. The total row for each section provides the mean estimated abundance over the sampled sessions, total survival is under the constant survival option and total births is the simple sum of estimated births by session.

Session	Marks	Sample	Recapture of Fish Marked at Session					Total	Abundance	Survival	Births
			1	2	3	4	5				
Section 1											
1	391										
2	318	370	15	1				16	11,370	1.030	894
3	326	360	10	7				17	12,556	0.974	1,125
4	411	467	13	12	11			36	13,320		
5	97	476	18	10	6	11		45			
6		466	9	11	8	13	7	48			
Total			65	41	25	24	7		12,415	1.007	2,019
Section 3											
1	634										
2	425	464	19					19	8077	0.991	958
3	397	461	22	21				43	8924	0.990	610
4	384	460	30	14	22			66	9377		
5	109	565	28	13	10	18		69			
6		651	27	16	17	14	7	81			
Total			126	64	49	32	7		8793	0.984	1,568
Section 5											
1	336										
2	293	323	15					15	6060	0.990	596
3	257	306	17	19				36	6566	1.056	815
4	307	368	15	16	18			49	7697		
5	44	417	14	12	11	12		49			
6		444	12	10	9	6	3	40			
Total			73	57	38	18	3		6774	1.010	1,411

Table 3.18 Sample size and recaptures of mountain whitefish by section and date during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	One		Three		Five		Total	
	Sample	Recapture	Sample	Recapture	Sample	Recapture	Sample	Recapture
22-Aug	191	0	0	0	0	0	191	0
23-Aug	235	0	0	0	0	0	235	0
24-Aug	0	0	0	0	0	0	0	0
25-Aug	0	0	0	0	249	0	249	0
26-Aug	0	0	0	0	111	0	111	0
27-Aug	0	0	0	0	0	0	0	0
28-Aug	145	7	0	0	0	0	145	7
29-Aug	0	0	314	0	0	0	314	0
30-Aug	0	0	377	0	0	0	377	0
31-Aug	225	9	0	0	0	0	225	9
01-Sep	0	0	341	16	0	0	341	16
02-Sep	0	0	123	3	0	0	123	3
03-Sep	0	0	0	0	145	7	145	7
04-Sep	0	0	0	0	178	8	178	8
05-Sep	160	4	0	0	0	0	160	4
06-Sep	200	13	0	0	0	0	200	13
07-Sep	0	0	188	24	0	0	188	24
08-Sep	0	0	273	19	0	0	273	19
09-Sep	0	0	0	0	181	27	181	27
10-Sep	0	0	0	0	125	10	125	10
11-Sep	240	24	0	0	0	0	240	24
12-Sep	227	12	0	0	0	0	227	12
13-Sep	0	0	267	37	0	0	267	37
14-Sep	0	0	193	30	0	0	193	30
15-Sep	0	0	0	0	232	30	232	30
16-Sep	0	0	0	0	136	19	136	19
17-Sep	476	45	0	0	0	0	476	45
18-Sep	0	0	565	70	0	0	565	70
19-Sep	0	0	0	0	417	50	417	50
20-Sep	466	48	0	0	0	0	466	48
21-Sep	0	0	0	0	0	0	0	0
22-Sep	0	0	651	81	0	0	651	81
23-Sep	0	0	0	0	0	0	0	0
24-Sep	0	0	0	0	444	42	444	42
Total	2565	162	3292	280	2218	193	8,075	635

Table 3.19 Mountain whitefish marks applied by section adjusted for migration during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	Section			Total
	One	Three	Five	
22-Aug	170	1	0	171
23-Aug	219	1	0	220
24-Aug	0	0	0	0
25-Aug	0	1	229	230
26-Aug	0	0	106	106
27-Aug	0	0	0	0
28-Aug	118	1	0	119
29-Aug	0	282	6	288
30-Aug	0	339	7	346
31-Aug	198	1	0	199
01-Sep	0	300	6	306
02-Sep	0	116	2	118
03-Sep	0	0	133	133
04-Sep	0	1	159	160
05-Sep	146	1	0	147
06-Sep	178	1	0	179
07-Sep	0	155	3	158
08-Sep	0	234	5	239
09-Sep	0	1	149	150
10-Sep	0	0	107	107
11-Sep	204	1	0	205
12-Sep	205	1	0	206
13-Sep	0	216	5	221
14-Sep	0	160	3	163
15-Sep	0	1	195	196
16-Sep	0	0	111	111
17-Sep	97	0	0	97
18-Sep	0	107	2	109
19-Sep	0	0	44	44
20-Sep	89	0	0	89
21-Sep	0	0	0	0
22-Sep	0	119	3	122
23-Sep	0	0	0	0
24-Sep	0	0	33	33
Total	1624	2039	1309	4972

Table 3.20 Mountain whitefish sample, cumulative marks available for recapture and recaptures by section during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date	Sample	Marks	Recaptures
Section 1			
28-Aug	145	389	7
31-Aug	225	508	9
05-Sep	160	706	4
06-Sep	200	706	13
11-Sep	240	1030	24
12-Sep	227	1030	12
17-Sep	476	1439	45
20-Sep	466	1536	48
Section 3			
01-Sep	341	286	16
02-Sep	123	624	3
07-Sep	188	1042	24
08-Sep	273	1042	19
13-Sep	267	1433	37
14-Sep	193	1434	30
18-Sep	565	1811	70
22-Sep	651	1919	81
Section 5			
03-Sep	145	348	7
04-Sep	178	354	8
09-Sep	181	649	27
10-Sep	125	652	10
15-Sep	232	913	30
16-Sep	136	918	19
19-Sep	417	1227	50
24-Sep	444	1273	42

Table 3.21 Population estimates by section for mountain whitefish during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	Bayesian Mean	MLE	95% Highest Probability Density		Standard Deviation	CV (%)
			Low	High		
One	14,436	14,270	12,350	16,620	1092	7.6
Three	12,985	12,900	11,580	14,440	730	5.6
Five	9120	9030	7930	10,370	621	6.8
Total	36,541		33,693	39,389	1453	4.0

3.6.2 Arctic grayling

The mark-recapture data were extracted by section from the database using all available marks with and a minimum length of 250 mm. Table 3.22 lists Arctic grayling examined for marks and recaptures by date and section. No Arctic grayling were recaptured in Section 1; thus, no population estimates were generated for the section. There was no movement between sections. Given the sparse recoveries, length histograms and a growth regression were not conducted. The releases by section and date are given in Table 3.23. The compilations of marks available (Equation 6), fish examined (Equation 7), and recaptures

(Equation 8) assuming 0.0 removal and 0% undetected mark rate are listed in Table 3.24. The population estimate using the Bayesian closed model is given in Table 3.25, the associated sequential posterior probability plots are provided in Appendix F (Figures F4 and F5) and the final posterior distributions are drawn in Figure 3.50. Because of sparse recoveries, the only comparable study was made in 2004. A bar plot of the population estimates for the 2004 and 2007 studies with sections common to 2007 are provided in Figure 3.51.

Table 3.22 Sample size and recaptures of Arctic grayling by section and date during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	Section						Total	
	One		Three		Five			
	Sample	Recapture	Sample	Recapture	Sample	Recapture	Sample	Recapture
22-Aug	3	0	0	0	0	0	3	0
23-Aug	1	0	0	0	0	0	1	0
24-Aug	0	0	0	0	0	0	0	0
25-Aug	0	0	0	0	19	0	19	0
26-Aug	0	0	0	0	50	0	50	0
27-Aug	0	0	0	0	0	0	0	0
28-Aug	0	0	0	0	0	0	0	0
29-Aug	0	0	21	0	0	0	21	0
30-Aug	0	0	7	0	0	0	7	0
31-Aug	1	0	0	0	0	0	1	0
01-Sep	0	0	5	0	0	0	5	0
02-Sep	0	0	0	0	0	0	0	0
03-Sep	0	0	0	0	26	6	26	6
04-Sep	0	0	0	0	9	0	9	0
05-Sep	1	0	0	0	0	0	1	0
06-Sep	1	0	0	0	0	0	1	0
07-Sep	0	0	1	0	0	0	1	0
08-Sep	0	0	11	0	0	0	11	0
09-Sep	0	0	0	0	14	0	14	0
10-Sep	0	0	0	0	4	1	4	1
11-Sep	0	0	0	0	0	0	0	0
12-Sep	1	0	0	0	0	0	1	0
13-Sep	0	0	10	1	0	0	10	1
14-Sep	0	0	4	1	0	0	4	1
15-Sep	0	0	0	0	14	2	14	2
16-Sep	0	0	0	0	7	0	7	0
17-Sep	0	0	0	0	0	0	0	0
18-Sep	0	0	7	0	0	0	7	0
19-Sep	0	0	0	0	14	4	14	4
20-Sep	0	0	0	0	0	0	0	0
21-Sep	0	0	0	0	0	0	0	0
22-Sep	0	0	8	1	0	0	8	1
23-Sep	0	0	0	0	0	0	0	0
24-Sep	0	0	0	0	16	2	16	2
Total	8	0	74	3	173	15	255	18

Table 3.23 Arctic grayling marks applied by section and date during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	Section			Total
	One	Three	Five	
22-Aug	3.0	0.0	0.0	3
23-Aug	1.0	0.0	0.0	1
24-Aug	0.0	0.0	0.0	0
25-Aug	0.0	0.0	18.0	18
26-Aug	0.0	0.0	47.0	47
27-Aug	0.0	0.0	0.0	0
28-Aug	0.0	0.0	0.0	0
29-Aug	0.0	20.0	0.0	20
30-Aug	0.0	6.0	0.0	6
31-Aug	1.0	0.0	0.0	1
01-Sep	0.0	5.0	0.0	5
02-Sep	0.0	0.0	0.0	0
03-Sep	0.0	0.0	19.0	19
04-Sep	0.0	0.0	9.0	9
05-Sep	1.0	0.0	0.0	1
06-Sep	0.0	0.0	0.0	0
07-Sep	0.0	1.0	0.0	1
08-Sep	0.0	11.0	0.0	11
09-Sep	0.0	0.0	14.0	14
10-Sep	0.0	0.0	3.0	3
11-Sep	0.0	0.0	0.0	0
12-Sep	1.0	0.0	0.0	1
13-Sep	0.0	9.0	0.0	9
14-Sep	0.0	3.0	0.0	3
15-Sep	0.0	0.0	12.0	12
16-Sep	0.0	0.0	5.0	5
17-Sep	0.0	0.0	0.0	0
18-Sep	0.0	7.0	0.0	7
19-Sep	0.0	0.0	7.0	7
20-Sep	0.0	0.0	0.0	0
21-Sep	0.0	0.0	0.0	0
22-Sep	0.0	5.0	0.0	5
23-Sep	0.0	0.0	0.0	0
24-Sep	0.0	0.0	9.0	9
Total	7.0	67.0	143.0	217

Table 3.24 Arctic grayling sample, cumulative marks available for recapture and recaptures in Sections 3 and 5 during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	Sample	Marks	Recaptures
Section 3			
01-Sep	5	20	
07-Sep	1	31	
08-Sep	11	31	
13-Sep	10	43	1
14-Sep	4	43	1
18-Sep	7	55	
22-Sep	8	62	1
Section 5			
03-Sep	26	65	6
04-Sep	9	65	
09-Sep	14	93	
10-Sep	4	93	1
15-Sep	14	110	2
16-Sep	7	110	
19-Sep	14	127	4
24-Sep	16	134	2

Table 3.25 Population estimate in Sections 3 and 5 for Arctic grayling during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	Bayesian Mean	MLE	95% Highest Probability Density		Standard Deviation	CV (%)
			Low	High		
Three	1648	650	200	4790	1571	95.3
Five	783	690	430	1210	210	26.8
Total	2431	1500	800	5580	1585	65.2

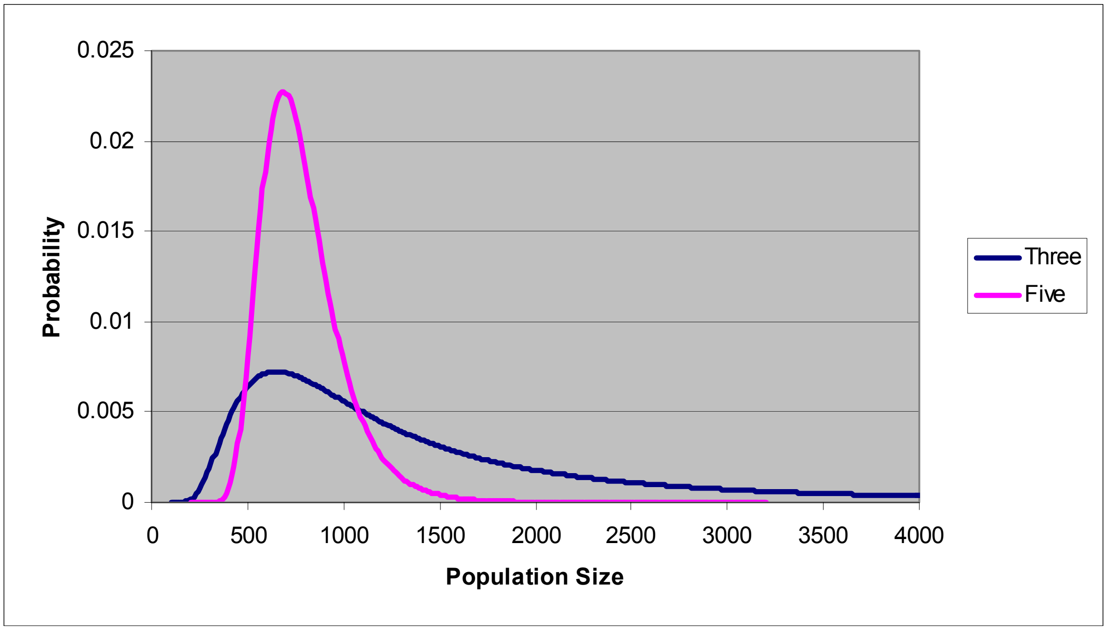


Figure 3.50 Final posterior distributions in Sections 3 and 5 for Arctic grayling during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

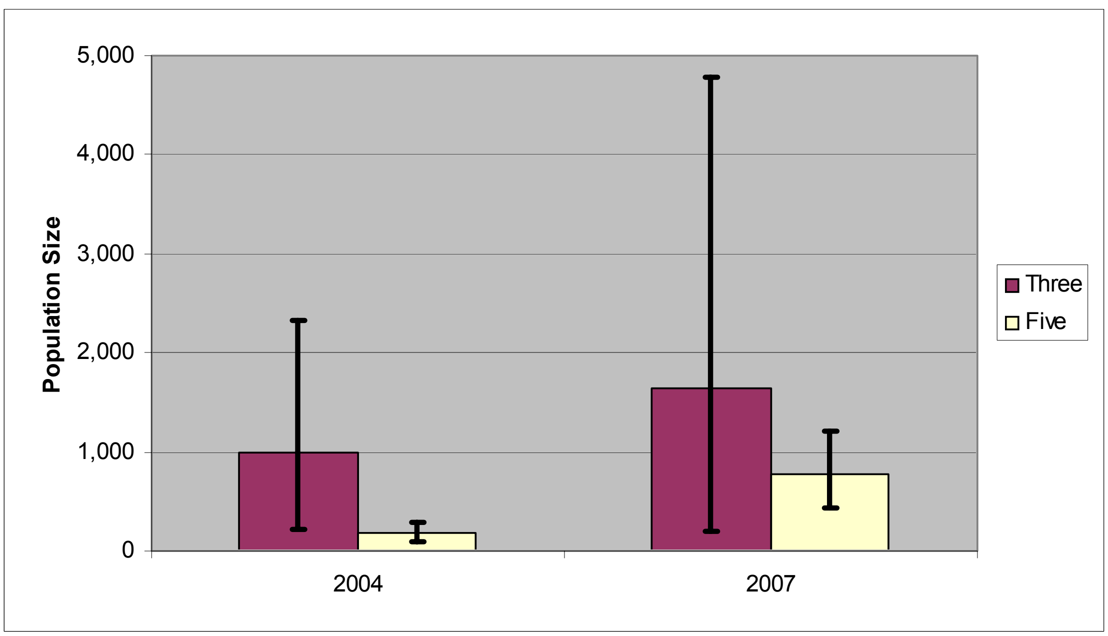


Figure 3.51 Arctic grayling population estimates by section for 2004 and 2007 during the Peace River Fish Community Indexing Program (vertical bars represent 95% confidence intervals).

3.6.3 Bull trout

The mark-recapture data were extracted by section from the database using all marks applied with a minimum length of 250 mm. Table 3.26 lists bull trout examined for marks and recaptures by date and section. No bull trout were recaptured in Section 1; thus, no population estimates were generated for the section. There was no movement between sections. The releases by section and date are given in Table 3.27. The compilations of marks available (Equation 6), fish examined (Equation 7), and recaptures (Equation 8) assuming 0.0 removal and 0% undetected mark rate are listed in Table 3.28.

Table 3.26 Sample size and recaptures of bull trout by section and date during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	Section						Total	
	One		Three		Five			
	Sample	Recapture	Sample	Recapture	Sample	Recapture	Sample	Recapture
22-Aug	1	0	0	0	0	0	1	0
23-Aug	1	0	0	0	0	0	1	0
24-Aug	0	0	0	0	0	0	0	0
25-Aug	0	0	0	0	8	0	8	0
26-Aug	0	0	0	0	3	0	3	0
27-Aug	0	0	0	0	0	0	0	0
28-Aug	2	0	0	0	0	0	2	0
29-Aug	0	0	5	0	0	0	5	0
30-Aug	0	0	4	0	0	0	4	0
31-Aug	2	0	0	0	0	0	2	0
01-Sep	0	0	7	0	0	0	7	0
02-Sep	0	0	3	0	0	0	3	0
03-Sep	0	0	0	0	2	0	2	0
04-Sep	0	0	0	0	3	1	3	1
05-Sep	1	0	0	0	0	0	1	0
06-Sep	3	0	0	0	0	0	3	0
07-Sep	0	0	2	1	0	0	2	1
08-Sep	0	0	9	1	0	0	9	1
09-Sep	0	0	0	0	3	0	3	0
10-Sep	0	0	0	0	0	0	0	0
11-Sep	4	0	0	0	0	0	4	0
12-Sep	4	0	0	0	0	0	4	0
13-Sep	0	0	3	0	0	0	3	0
14-Sep	0	0	8	0	0	0	8	0
15-Sep	0	0	0	0	7	0	7	0
16-Sep	0	0	0	0	4	0	4	0
17-Sep	4	0	0	0	0	0	4	0
18-Sep	0	0	12	4	0	0	12	4
19-Sep	0	0	0	0	4	2	4	2
20-Sep	6	0	0	0	0	0	6	0
21-Sep	0	0	0	0	0	0	0	0
22-Sep	0	0	4	0	0	0	4	0
23-Sep	0	0	0	0	0	0	0	0
24-Sep	0	0	0	0	10	1	10	1
Total	28	0	57	6	44	4	129	10

The subsequent population estimates using the Bayesian closed model are given in Table 3.29, the associated sequential posterior probability plots are provided in Appendix F (Figures F6 and F7) and the final posterior distributions are drawn in Figure 3.52. Only Section 3 has recoveries in previous years to enable comparison of population estimates. A bar plot of the population estimates for Section 3 are provided in Figure 3.53.

Table 3.27 Bull trout marks applied by section and date during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	**Section**			**Total**
	One	**Three**	**Five**	
22-Aug	1	0	0	0
23-Aug	1	0	0	0
24-Aug	0	0	0	0
25-Aug	0	0	0	0
26-Aug	0	0	0	0
27-Aug	0	0	0	0
28-Aug	2	0	0	0
29-Aug	0	0	5	0
30-Aug	0	0	4	0
31-Aug	2	0	0	0
01-Sep	0	0	7	0
02-Sep	0	0	3	0
03-Sep	0	0	0	0
04-Sep	0	0	0	0
05-Sep	1	0	0	0
06-Sep	3	0	0	0
07-Sep	0	0	2	1
08-Sep	0	0	9	1
09-Sep	0	0	0	0
10-Sep	0	0	0	0
11-Sep	4	0	0	0
12-Sep	4	0	0	0
13-Sep	0	0	3	0
14-Sep	0	0	8	0
15-Sep	0	0	0	0
16-Sep	0	0	0	0
17-Sep	4	0	0	0
18-Sep	0	0	12	4
19-Sep	0	0	0	0
20-Sep	6	0	0	0
21-Sep	0	0	0	0
22-Sep	0	0	4	0
23-Sep	0	0	0	0
24-Sep	0	0	0	0
Total	28	0	57	6

Table 3.28 Bull trout sample, cumulative marks available for recapture and recaptures in Sections 3 and 5 during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Date (2007)	**Sample**	**Marks**	**Recaptures**
Section 3			
01-Sep	7	3	
07-Sep	3	7	
08-Sep	2	15	1
13-Sep	9	15	1
14-Sep	3	23	
18-Sep	8	23	
22-Sep	12	29	4
Section 5			
03-Sep	2	10	
04-Sep	3	10	1
09-Sep	3	13	
10-Sep	7	16	
15-Sep	4	16	
16-Sep	4	26	2
19-Sep	10	28	1
24-Sep	2	10	

Table 3.29 Population estimate in Sections 3 and 5 for bull trout during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

Section	**Bayesian Mean**	**MLE**	**95% Highest Probability Density**		**Standard Deviation**	**CV (%)**
			Low	**High**		
Three	231	160		78	463	117
Five	303	162		65	735	225
Total	534	386		213	890	253

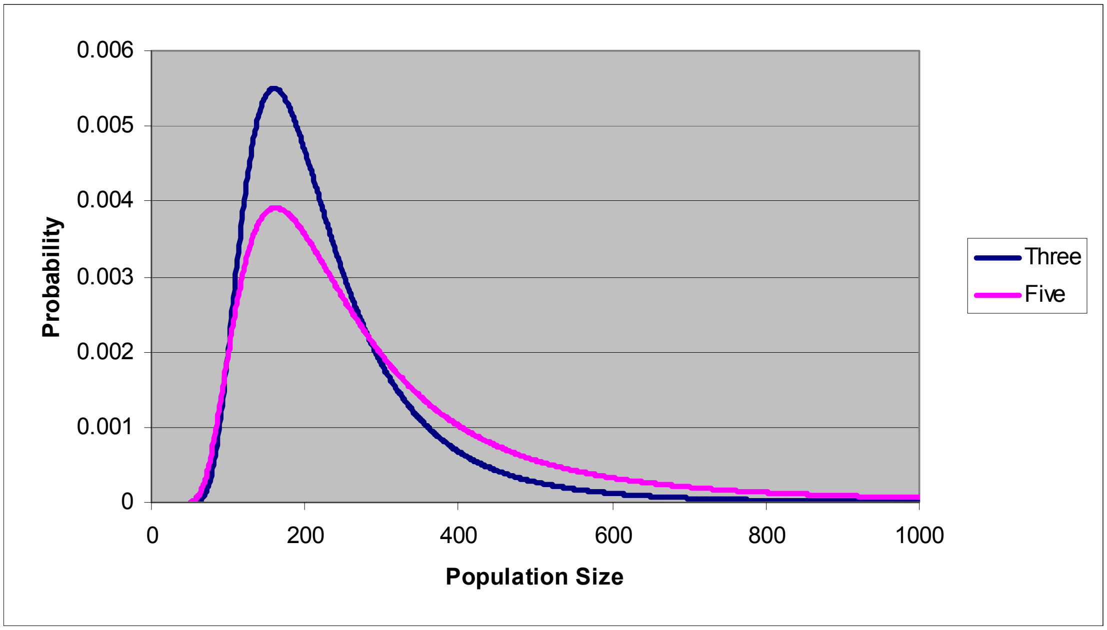


Figure 3.52 Final posterior distributions in Sections 3 and 5 for bull trout during Phase 7 of the Peace River Fish Community Indexing Program, 2007.

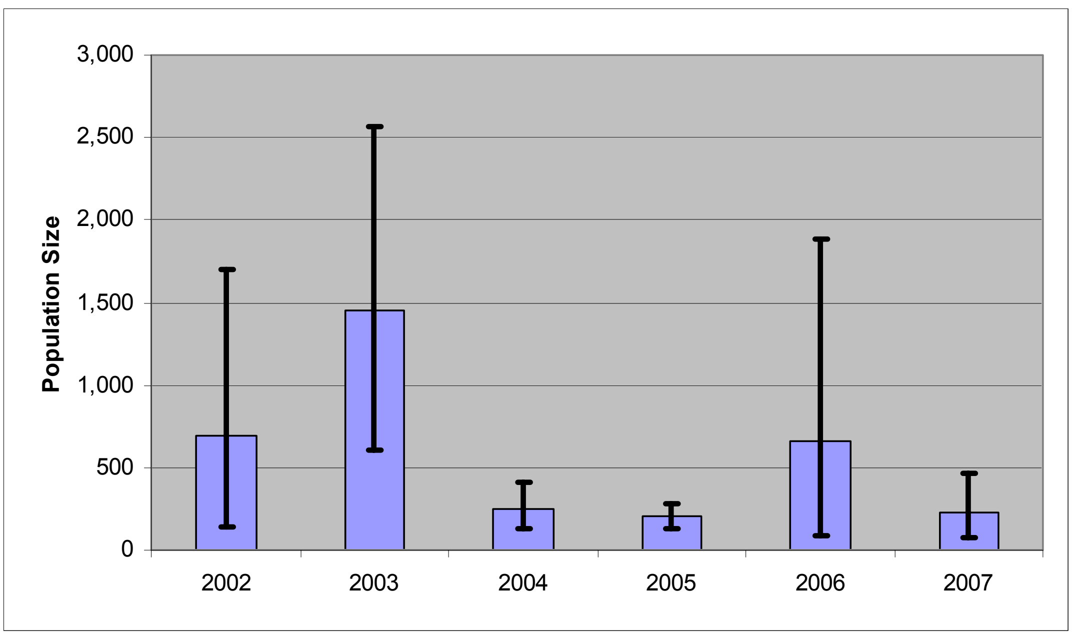


Figure 3.53 Bull trout population estimates in Section 3 from 2002 to 2007 during the Peace River Fish Community Indexing Program (vertical bars represent 95% confidence intervals).

3.6.4 Evaluation as a Monitoring Tool

3.6.4 1 Sample Design and 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.* Only a very few mountain whitefish were recaptured in river sections other than the section of release (0.6%, approximately). This finding includes the 2007 investigation of fish movements into control sections located immediately adjacent to the standard sections (14 recaptures in control sections and 3 recaptures in other sampled sections). The population estimation model accounts for fish that move; however, the movement is assumed to be fully determined by the history of recaptured marks. While few Arctic grayling and bull trout were recaptured, none was observed to move to a different river section. Because mountain whitefish reside in the sampled sections, fish are not expected to immigrate or emigrate to/from those sections. Mortality and growth recruitment were not expected to be issues because the study period was short.
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 in catchability, lack of mixing, marks applied or population size. As found in previous studies significant heterogeneous capture probabilities by tag type and year of application were observed (Table 3.12 and Figure 3.35). However, empirical evaluations of recaptures, using additional parameters to represent heterogeneous effects, were less likely than constant recapture probability (Table 3.16). The consistency of the catchability coefficient across various population sizes and flow conditions in Section 1 (see Section 3.7) argues that any impact from heterogeneity of recaptured fish was small.
3. *Fish do not lose their marks over the period of the study.* Each captured fish was examined for the presence of a scar. No fish with recent scarring (marked in 2007 with PIT tags) were observed. Six old scars on mountain whitefish (assumed to be marked in 2006 or before) out of 635 captures (0.9%) were observed. No scarred Arctic grayling or bull trout were observed. The impact on the 2007 closed population estimation model from lost marks should be small.
4. *All marked fish are reported on recovery.* Only fish brought on board were included in the number of fish examined for a mark; thus, it is unlikely that a tagged fish would escape detection.

3.6.4.2 Effort Needed to Detect Change

Because there is little movement of fish between the river sections, sampling intensity can be isolated to a section. Figure 3.54 plots the precision as a function of electrofishing effort (hours) using Equations 12, 13, and 14 for mountain whitefish in Section 1. For reference, the 2007 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.

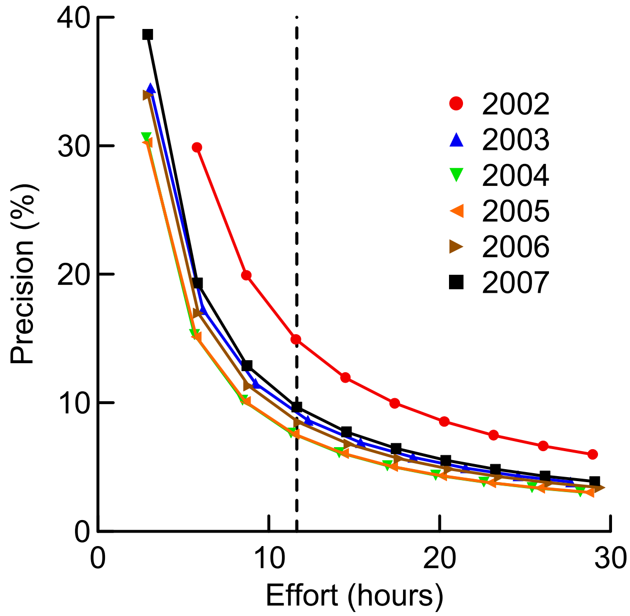


Figure 3.54 Precision (percentage of the mean) of the population estimate of Section 1 at various effort levels for mountain whitefish by year during the Peace River Fish Community Indexing Program, 2002 to 2007.

3.7 CATCHABILITY

A key objective of the indexing program is to develop an index of abundance (i.e., catch-per-unit-effort) to use as a monitoring tool. The index should remain proportional to abundance across locations (river sections) and under various abundance levels. Catchability is simply catch-per-unit-effort standardized (divided) by abundance (proportionality constant between catch-per-unit-effort and abundance, see equation 9) and thus the ideal is constancy over time and location.

Only mountain whitefish had sufficient number of recaptures for the computation of catchability based on population estimates. The catchability coefficients and associated population estimates, standard deviation estimates and effort (Equations 9 to 11) by section are listed in Tables 3.30 and 3.31 using effort measured in kilometers traveled or the hours of electrofishing to collect the samples. Figure 3.55 plots the catchability coefficients using both effort measures and the associated 95% confidence intervals. Note that catchabilities are consistent across studies (years) and sections when the population estimates were deemed to be reliable.

Table 3.30 Catchability of mountain whitefish by section (effort in kilometres) during the Peace River Fish Community Indexing Program, 2002 to 2007.

Statistic	Section					Total
	One	Two	Three	Four	Five	
2002 Study						
Sample	2845	2611	2363	2105		9924
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	2145	1896	2546	1883		8470
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	3514		2972		1549	8035
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	2777		3624		2132	8533
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		9.47E-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	2532	2120	1887			
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%			
2007 Study						
Sample	2565		3292		2218	8075
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%

Section 1 catchability is consistent over all years sampled even though there was a two-fold difference in the population size, different flow regimes between the years and there was a substantial ability (high power) to differentiate small changes in catchability (a CV of less than 10.3% in any year).

Table 3.31 Catchability of mountain whitefish by section (effort in hours) during the Peace River Fish Community Indexing Program, 2002 to 2007.

Statistic	Section					Total
	One	Two	Three	Four	Five	
2002 Study						
Sample	2845	2611	2363	2105		9924
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	2145	1896	2546	1883		8470
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	3514		2972		1549	8035
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	2777		3624		2132	8533
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		9.47E-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	2532	2120	1887			
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%			
2007 Study						
Sample	2565		3292		2218	8075
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%

Similarly, Section 3 in 2002, 2003, and 2007 confirmed consistent catchability coefficients. Catchability was significantly smaller in 2004 because water clarity was below the threshold identified (50 cm) as having an effect on catchability (Mainstream and Gazey 2005). In 2005, Section 3 experienced an in-migration of fish; however, Mainstream and Gazey (2006) argued that if there were no substantial mortality or emigration, then the population estimate and associated catchability estimate may reflect a mean estimate weighted by mark application and sampling intensity. Indeed, the 2005 Section 3 catchability coefficient was consistent with other years and sections that were deemed to be reliable. In 2006, the Section 3 closed population estimate was judged to be unreliable because of unstable survival estimates and sequential posterior distributions over the study period. For Section 5, 2007 was the only study deemed to be reliable; however, similar to Section 3, the 2007 and 2005 catchability coefficients were similar.

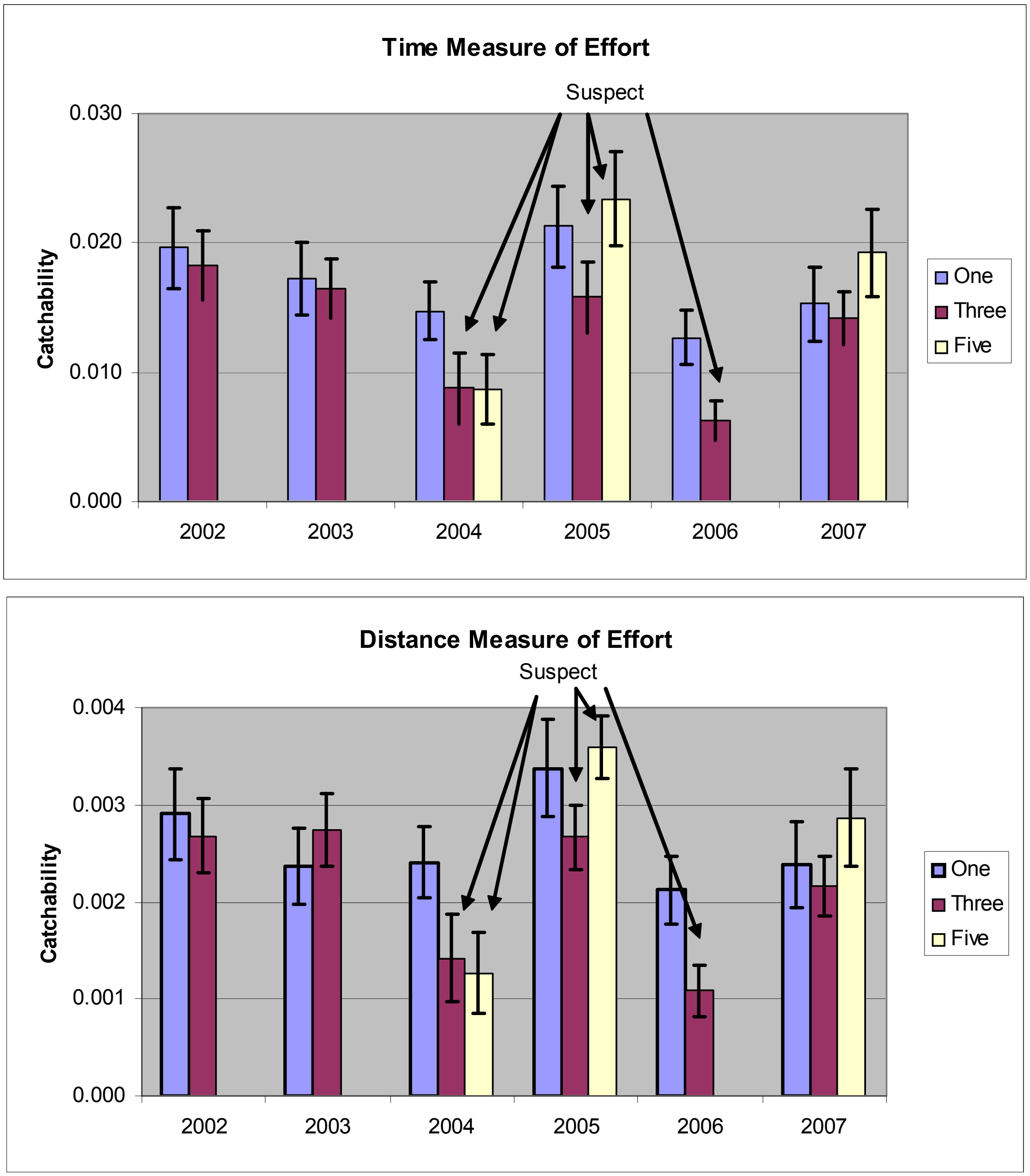


Figure 3.55 Catchability using time (hours - top graph) and distance (km – bottom graph) by section for mountain whitefish during the Peace River Fish Community Indexing Program, 2002 to 2007 (vertical bars represent 95% confidence intervals).

Catchabilty estimates for mountain whitefish generated during the present study (excluding the invalidated population estimate for Section 3) were consistent among years and sections (Figure 3.56). Catchability using distance as the measure of effort was approximately 3.000 x 10^{-3}.

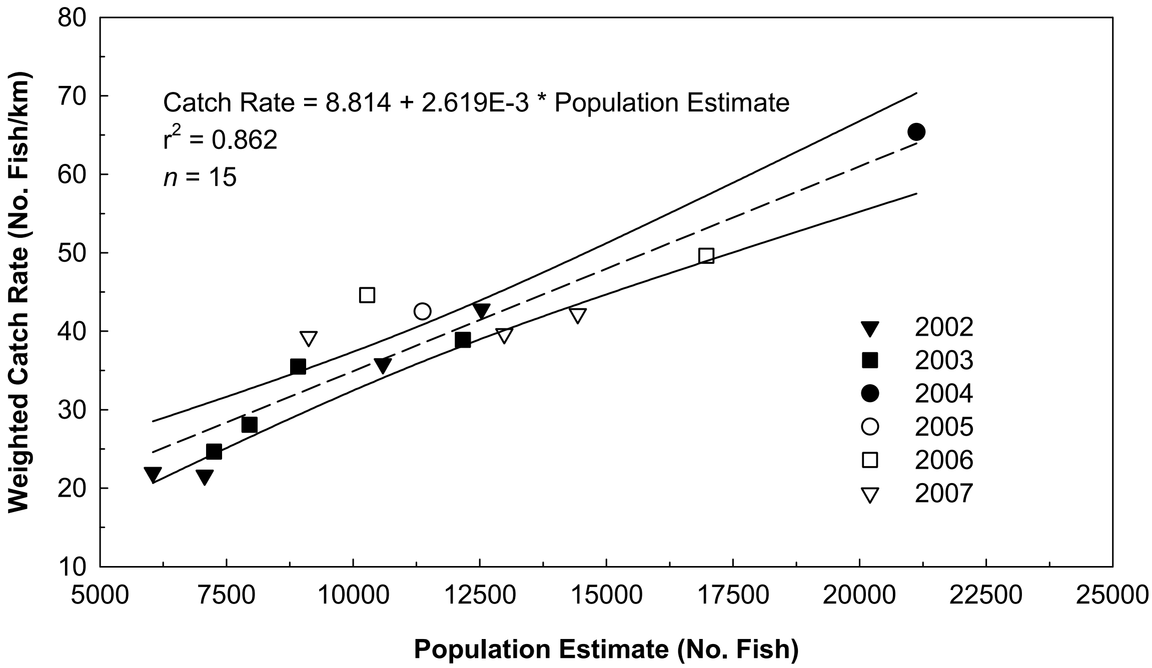


Figure 3.56 Relationship between population estimate and weighted catch rate of mountain whitefish during the Peace River Fish Community Indexing Program, 2002 to 2007 (solid lines represent 95% confidence intervals).

4.0 SUMMARY

4.1 SAMPLING CONDITIONS

Mean daily discharge was approximately 1000 cms at the beginning of the field program and gradually increased for the duration of the session. Water clarity was generally high and remained above the 50 cm threshold that potentially affected capture efficiency for most of the program. In addition, water temperatures remained above the threshold that initiates mountain whitefish spawning activity (7.5^{o}C). As such, these factors likely did not influence fish catch rates.

4.2 FISH COMMUNITY CHARACTERISTICS

Fish community characteristics documented in 2007 were similar to findings of previous investigations. Fifteen large-fish species were recorded and mountain whitefish dominated numerically. Most species were widely distributed. Exceptions included the cool-water sportfish species burbot, northern pike, walleye, and yellow perch, which were restricted to downstream sections.

4.3 BIOLOGICAL CHARACTERISTICS

Arctic grayling

In total, 365 Arctic grayling were sampled for biological characteristics: 10 in Section 1 and 142 in Section 3, and 213 in Section 5. The fork length of sampled populations ranged from 96 mm to 446 mm and represented fish Age 0 to Age 5. Age 0 fish were recorded only in Section 5 (n = 2). There were spatial differences in length and age distributions of Arctic grayling. The sample was dominated by Age 1 fish in Section 3, while in Section 5 Ages 2 to 4 accounted for most of the sample.

The growth and body condition of Arctic grayling was similar among Sections 3 and 5. The exception was length of Age 1 fish. There was a significant difference in mean length of Age 1 fish between Sections 3 and 5, which was consistent with previous investigations. The apparent annual mortality of the Arctic grayling sample population was 59%.

There were annual differences in length and age distributions of Arctic grayling in Sections 3 and 5. There has been an increase in the numerical importance of larger, older fish since 2005. Recruitment of younger fish into the sample populations may partially explain these differences. Annual differences in recreational angling harvest may provide an alternate explanation for the results.

There were annual differences in the growth of Age 1 Arctic grayling. Lengths of Age 1 fish in 2004 and 2006 were significantly larger than lengths of Age 1 fish in 2003, 2005, and 2007. The results may be related to the flow regime of the Peace River. Discharges at the time of the field programs were lower in 2004 and 2006 compared to discharges in 2003, 2005, and 2007.

Bull trout

In total, 118 bull trout were sampled for biological characteristics; 34 from Section 1, 73 from Section 3, and 59 from Section 5. Fork lengths ranged from 164 mm to 865 mm with ages ranging from Age 1 to Age 10.

Length and age distributions of bull trout were similar among sections. Younger fish dominated in all sections (Age 3 fish was the most prominent group) and bull trout older than Age 6 were not well represented. A single Age 1 fish was recorded during the study; the fish was encountered in Section 3. Comparisons of mean length-at-age and age-specific body condition indicated few differences between sections, which was consistent with previous investigations. The apparent annual mortality of the bull trout sample populations was 41%.

In general bull trout age and length distributions remained stable between 2002 and 2007. In all sections in most years subadults dominated (Age 2 to Age 5). The absence of older fish during most years likely was caused by use of spawning tributaries by the adult cohort during the study period and did not reflect the actual age structure of the Peace River population. Age 1 fish were poorly represented in most years, which may reflect use of tributary systems for early rearing by this population and/or low capture efficiency of these smaller fish. Highest recruitment of Age 1 and Age 2 fish occurred in 2005, 2006, and 2007.

Mountain whitefish

In total, 8094 mountain whitefish fish were measured; 2449 from Section 1, 3428 from Section 3, and 2217 from Section 5. Fork lengths ranged from 74 mm to 520 mm with ages ranging from Age 0 to Age 13. Only two Age 0 fish were recorded; both from Section 5.

There were spatial differences in length and age distributions of mountain whitefish in 2007, which was consistent with findings during previous investigations. Fish in Section 1 exhibited a truncated length distribution caused by the preponderance of Age 4 to Age 6 fish. Younger fish (Age 1) and older fish

(> Age 6) were largely absent. In contrast, mountain whitefish in Sections 3 and 5 exhibited multi-modal length distributions that represented a wide range of ages.

Similar to findings during previous investigations there were spatial differences in mountain whitefish growth and body condition. Older age-classes in Section 1 had significantly lower mean lengths compared to fish in Sections 3 and 5. Body condition of younger fish (Age 1 to Age 4) was higher in Section 1 compared to Sections 3 and 5. The opposite was the case for Age 5 to Age 9 fish.

The annual mortality of mountain whitefish differed between sections. The apparent annual mortality was highest in Section 1 (62%), intermediate in Section 3 (46%), and lowest in Section 5 (39%)

Length and age distributions in 2007 were consistent with previous studies. Length distributions in Section 1 were unimodal and there was weak representation by Age 1 and Age 2 fish. Length and age distributions of mountain whitefish in Sections 3 and 5 represented a wide range of ages.

There were annual differences in mountain whitefish growth. Growth rates of younger fish (Age 2 to Age 4) varied, but appeared to be in general decline. In contrast, growth rates of older mountain whitefish (Age 5 to Age 8) were stable for the duration of the program. Comparisons of annual mean length-at-age of mountain whitefish suggest strong year effects for some age classes. Beginning with Age 3 fish, there was a general downward trend in mean length-at-age starting in 2003. The results for anabolic constants suggested a decline in growth between 2002 and 2004, and then generally stable growth from 2005 to 2007.

Annual differences in body condition were evident for younger (Age 2 to 4) and older (Age 5 to 8) mountain whitefish. In Section 1, body condition of both groups increased from 2002 to 2004, declined in 2005, and then increased to 2007. In Section 3, body condition of both groups increased from 2002 to 2004, and then remained stable. No changes were recorded in Section 5.

<u>Summary</u>

The program was able to quantify several parameters used to describe the biological characteristics of each target species population. The results of the 2007 program were consistent with those of previous investigations with some exceptions. The population structure of Arctic grayling appears to be shifting towards stronger representation by older fish. This change may be related to recruitment of younger fish and/or effects of recreational angler harvest.

Annual comparisons of mountain whitefish biological characteristics indicated a downward trend in growth rate of younger fish as well as a downward trend in length-at-age for most age classes suggesting an apparent decline in population health. In contrast, other estimates of population growth (anabolic constant) remained stable and body condition appeared to increase or remain stable. In addition, age distributions of sample populations remained generally stable. The contradictory results make interpretation difficult. The apparent downward trend in some parameters could reflect annual variation in population health or adverse effects related to program activities.

4.4 CATCH RATE

General

The results of Phase 7 demonstrated that established sampling protocols were appropriate to generate reliable data and findings were consistent with previous investigations. In general, catch rates differed between species, section, and habitat. Catch rates for Arctic grayling and bull trout were low in all sections and were much less than those of mountain whitefish. Arctic grayling and bull trout catch rates tended to be higher in SFC habitats compared to SFN habitats, while the reverse was true for mountain whitefish.

Mean catch rates differed between sections. Arctic grayling were scarce in Section 1, but were relatively numerous in Sections 3 and 5. Bull trout exhibited a low abundance in all three sections. Catch rates of mountain whitefish were higher in Sections 1 and 3 compared to Section 5.

Confounding Factors

Discharge, water clarity, and water temperature were not confounding factors in 2007.

Comparison to Previous Investigations

Mean catch rates of target species populations changed between years. Arctic grayling catch rates in Sections 3 and 5 continued to increase since the beginning of structured sampling in 2002. Mountain whitefish catch rates in Section 1 in 2007 represented a continued decline from the high recorded in 2004. Catch rates recorded during the present study were similar to catch rates recorded in 2002 and 2003. In Section 3, mountain whitefish catch rates in 2007 rebounded from the drop recorded in 2006. Mean catch rates during the present study were slightly below the highest value recorded in 2005. Results from Section 5 did not suggest a substantive change in mountain whitefish abundance. Bull trout catch rates remained low in 2007, which was consistent with previous studies.

The relative contribution of younger and older fish to sample populations within each section varied annually. For Arctic grayling in Section 3, the relative contribution of younger fish (≤ Age 2) was stable since 2002, but the contribution of older fish varied considerably. In Section 5, the relative contribution of younger Arctic grayling decreased since sampling in that section was initiated in 2004; the opposite occurred for older Arctic grayling.

The relative contribution of younger bull trout (≤ Age 2) remained low and variable in all sections; however, there has been an increase since 2004. The relative contribution of older fish varied each year within each section.

Trends in the relative contribution of younger mountain whitefish (≤ Age 3) differed between sections over the period of record. Values in Section 1 increased after the low recorded in 2004. In Sections 3 and 5 values for younger fish were generally stable after 2004. The relative contribution of older mountain whitefish was generally stable in all sections.

4.5 SAMPLING EFFECTS

The anabolic constants derived from incremental growth of Floy and PIT marked mountain whitefish were different for the 2005, 2006, and 2007 studies. The incremental growth of PIT marked fish were not different from the age-length derived intervals for unmarked fish for 2005 and 2006; but it was lower than the age-length derived intervals for unmarked fish in 2007. In addition the anabolic constants of Floy and PIT marked mountain whitefish decreased over the three studies indicating lower growth rates. The apparent decline in growth of Floy and PIT marked mountain whitefish over time and the lower growth of PIT marked fish compared to unmarked fish in 2007 may have been an artifact of sample methodology or adverse effects of PIT marks on mountain whitefish growth. The former is the more likely reason for the results, but additional studies should be completed to confirm or refute this position.

4.6 POPULATION ESTIMATES

Overall, the program was highly successful for mountain whitefish but much less so for Arctic grayling and bull trout. Population estimates were made using a Bayesian sequential closed population model and with an open Jolly-Seber model for the three species. Since marks were applied only to fish greater than 250 mm, estimates are only applicable to that portion of the population. Population estimates were generated for three river sections (1, 3, and 5) using minimum time-at-large of three days, 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%. Population estimates for Arctic grayling and bull trout were not available in Section 1 because no marked fish were recaptured. We believe that all population estimates made in this study are defensible. Similar to previous studies, significant heterogeneous capture probabilities were observed; however, the addition of parameters to account for heterogeneity did not improve model fit (Akaike information criteria). Also, the consistency of the catchability coefficient across various population sizes and flow conditions argues that any impact from heterogeneous capture should be small.

Sampling in control sections immediately upstream and downstream of each standard section recorded very limited numbers of marked fish (n = 2). As such, short distance movements by substantial numbers of marked fish out of standard sections did not occur during the 2007 field program and it is unlikely that short distance movements during the sample period influenced capture probabilities.

For mountain whitefish, the large number of marks applied and recaptured and the structured sequential sampling design allowed the following findings:

1. Empirical evaluation of the assumptions required for population estimation.
2. Population estimates must be stratified by river section.
3. Verification that catchability is constant between river sections and years (thus catch rates are comparable and representative of the vulnerable population) where compliance with the closed population assumption allows for rigorous comparison and where water clarity is not an issue.
4. The population vulnerable to sampling in 2004 was different than that in other study years.
5. Sampling effort should be standardized (sample with same array of sites, intensity, and period) if high precision is required.

For Arctic grayling and bull trout, population estimates were available and the overall precision was poor (CV = 65.2% and 47.4%, respectively). There is not sufficient data to forecast effort levels needed for reliable population estimates for either species.

In order to put the current study into perspective with previous mark-recapture studies conducted in the general area, a summary of population size estimates by species is provided in Table 4.1. The effort column refers to the total number of hours of electrofishing expended in the study. Precision is defined here as half the 95% HPD expressed as a percentage of the Bayesian mean. Note the very large precision values (e.g., greater than 80%) implies that any point estimates are highly unreliable. Also, direct comparison of population estimates between years is not feasible because different sections were sampled.

Table 4.1 Historical population estimates generated during the Peace River Fish Community Indexing Program (2001 to 2007) and fisheries inventories in 1989 and 1990.

	Effort (hrs)	Arctic grayling	Mountain whitefish	Lake whitefish	Rainbow trout	Walleye	Bull trout
1989[a]	95.9						
Recoveries		18	126	3	19	6	
Mean		4359	117,593	33,814	1418	2591	
Precision (%)		47.1	17.4	136.6	41.3	86.1	
1990[b]	110.9						
Recoveries		37		7	19	7	
Mean		4,160		82,012	5,995	2,881	
Precision (%)		32.9		65.5	39	64.7	
2001	26.2						
Recoveries		2	3				
Mean		7700	560,000				
Precision (%)		175.0	140.0				
2002	61.9						
Recoveries		3	954				12
Mean		1283	36,232				2049
Precision (%)		137.6	6.5				105.4
2003	65.8						
Recoveries		2	901				9
Mean		2136	36,283				1447
Precision (%)		196.0	6.4				67.7
2004	61.9						
Recoveries		15	492				17
Mean		1165	53,442				774
Precision (%)		54.3	4.6				42.3
2005	44.3						
Recoveries		6	871				27
Mean		4582	29,967				512
Precision (%)		44.7	3.2				44.2
2006	45.4						
Recoveries		2	550				4
Mean		2898	42,093				660
Precision (%)		87.9	4.6				88.5
2007	42.2						
Recoveries		18	635				10
Mean		2431	36,541				534
Precision (%)		65.2	4.0				47.4

[a] Pattenden *et al.* 1990.
[b] Pattenden *et al.* 1991.

4.7 CATCHABILITY

The catchability estimate for mountain whitefish remained robust despite a range of conditions encountered among sample years and sections. As such catch rate can be used as an index of absolute abundance. Fifteen data points are now available to quantify the relationship.

Three caveats should be acknowledged regarding use of catch rate as an index of abundance as follows:

4. Sampling protocols (methods, equipment, and approach) must be consistent.
5. Water clarity must remain above 50 cm.
6. The target population must remain closed during the sampling period.

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5.0 RECOMMENDATIONS

The stated overall objective of the Large River Program is:

“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 findings of the Peace River Phase 2 and 3 programs indicated that the monitoring protocols were suitable to meet the objective of the program, particularly for mountain whitefish. Biological characteristics were suitable to monitor Arctic grayling and bull trout, but deficiencies related primarily to low fish numbers hinder use of catch rates and population estimates as monitoring tools for these two target species populations. Phases 4, 5, 6, and 7 results confirmed these findings with two exceptions. These exceptions are as follows:

1. Water clarity less than 50 cm reduces capture efficiency, thereby negating use of catch rate as an index of absolute abundance under those sampling conditions.
2. One or more as yet unknown factors in some index sections cause mountain whitefish movement that invalidate results of the closed population estimate model.

Because the program is aware of these confounding factors and has the sensitivity to identify these and other issues as they occur, the Peace River Fish Indexing Program as presently designed meets the overall objective of the Large River Program.

During each year of study, results were reviewed to identify issues of concern and recommendations were made to address those issues. The tasks of each subsequent study were limited to the main objective of refining sampling protocols. The Peace River Fish Community Program will continue to adhere to this overriding objective. To this end we recommend the following for the Phase 8 program:

<u>General</u>

1. Repeat the standard program to extend the time series data.
2. Maintain the current study design and sampling protocols with the following adjustments:
    a. Continue the control fish program to provide a random sample of fish to evaluate non-tag effect sampling activities on target fish populations. Parameters examined should include growth and body condition.
    b. Use the collected data to evaluate monitoring program activities on mountain whitefish population health.

Population Estimates

3. Sample Sections 1, 3, and 5 to extend the sampling history. The continuous six year record of consistent and rigorous sampling is a valuable baseline for the mountain whitefish population. Adding years to the data set will increase its value.
4. Conduct a mark-recapture "robust design" analysis for mountain whitefish to allow estimates of survival and the total population size which includes the population that is not subject to sampling each year.
5. Build an age-structured model that will serve to synthesize catch-per-unit-of-effort, age and abundance information. If such models are to be maintained and used for the evaluation of dam operation impacts there will be a need to collect long term information on population dynamics (e.g., mortality and stock-recruitment functional form). The continued application of long-lasting marks (e.g., PIT tags) will assist in this endeavor.

These recommendations do not address a number of data gaps/issues that may compromise the ability to interpret the ecological significance of the indexing data. Data gaps/issues identified during the present and previous investigations are as follows:

6. Develop a catchability coefficient for low water clarity conditions.
7. Collect data (i.e., fish movements, angler harvest, and river productivity) in order to interpret ecological meaning of the indexing information.
8. Collect information to quantify recruitment of younger-aged fish into the target fish populations (i.e., dedicated small fish sampling program).

As recommended during previous investigations, consideration should be given to expanding the scope of the Peace River Fish Community Indexing Program in order to address these data gaps/issues.

6.0 LITERATURE CITED

Arnason, A.N., C.J. Schwarz, and G. Boyer. 1998. POPAN-5: A data maintenance and analysis system for mark-recapture data. Scientific Report, Department of Computer Science, University of Manitoba, Winnipeg. viii + 318 p.

Busacker, G.P., I.R. Adleman, and E.M. Goolish. 1990. Growth. Pages 363-387 *in* C.B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Cone. 1989. The need to reconsider the use of condition indices in fishery science. Transactions of the American Fisheries Society 118: 510 - 514.

Gallucci, V.F. and T.J. Quinn. 1979. Reparameterization, fitting and testing a simple growth model. Transactions, 108: 14-25.

Gazey, W.J. 1994. Population size estimation for sparse data. Biometrics 50: 301-303.

Gazey, W.J. and M.J. Staley. 1986. Population estimation from mark-recapture experiments using a sequential Bayes algorithm. Ecology 67: 941-951.

Koch, J.D. and M.C. Quist. 2007. A technique for preparing fin rays and spines for age and growth analysis. North American Journal of Fisheries Management 27: 782-784,

Mackay, W.C., G.R. Ash, and H.J. Norris. (editors). 1990. Fish ageing methods for Alberta. RL&L Environmental Services Ltd. in association with Alberta Fish and Wildlife Division and University of Alberta, Edmonton. 113 p.

Mainstream Aquatics Ltd. and W.J. Gazey Research. 2004. Peace River Fish Community Indexing Program – Phase 3 Studies. Prepared for B.C. Hydro. Report No. 03008F: 104 p + Appendices.

Mainstream Aquatics Ltd. and W.J. Gazey Research. 2005. Peace River Fish Community Indexing Program – Phase 4 Studies. Prepared for B.C. Hydro. Report No. 04008F: 135 p. + Appendices.

Mainstream Aquatics Ltd. and W.J. Gazey Research. 2006. Peace River Fish Community Indexing Program – Phase 5 Studies. Prepared for B.C. Hydro. Report No. 05016F: 118 p. + Appendices.

Mainstream Aquatics Ltd. and W.J. Gazey Research. 2007. Peace River Fish Community Indexing Program – Phase 6 Studies. Prepared for B.C. Hydro. Report No. 06011F: 116 p. + Appendices.

McPhail, J.D. 2007. The freshwater fishes of British Columbia. The University of Alberta Press. 620 p.

P&E Environmental Consultants Ltd. 2002. Peace River Fish Community Indexing Program – Phase 1 Studies. Unpublished report prepared by P&E Environmental Consultants Ltd., Edmonton, Alberta and LGL Ltd., Sidney, British Columbia for BC Hydro Power Supply Environmental Services. 76 p + appendices.

P&E Environmental Consultants Ltd. and W.J. Gazey Research. 2003. Peace River Fish Community Indexing Program – Phase 2 Studies. Prepared for BC Hydro. P&E Report No. 02011F: 86 p + Appendices.

Pattenden R., C. McLeod, G. Ash and K. English. 1990. Fish Movement and Population - Status (Draft) in Peace River Site C Hydroelectric Development Pre-construction Fisheries Studies. Unpublished report by RL&L Environmental Services Ltd. for BC Hydro Environmental Resources.

Pattenden R., C. McLeod, G. Ash and K. English. 1991. Fish Movement and Population Status 1990 Studies (Interim Final Report) in Peace River Site C Hydroelectric Development Pre-construction Fisheries Studies. Unpublished report by R.L.&L. Environmental Services Ltd for BC Hydro Environmental Resources.

Post, J. R.., C. Mushens, A. Paul, and M. Sullivan. 2003. Assessment of Alternative Harvest Regulations for Sustaining Recreational Fisheries: Model Development and Application to Bull Trout. North American Journal of Fisheries Management 23: 22-24

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada. Bulletin 191. 382 p.

RL&L Environmental Services Ltd. 2001. Peace River fish habitat utilization study. Prepared for BC Hydro - Environmental Services, Burnaby, BC. RL&L Report No. 725F: 72 p. + Appendices.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. Second edition. Edward Arnold, London.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Co., San Francisco. 859 p.

Taylor, C.C. 1963. Growth equations with metabolic parameters. J. Cons. Int. Explor. Mer. 30: 270-286

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell and C.E. Cushing. 1980. The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37: 130-137.

White, G.C. 2006. Program MARK (version 4.3): Mark Recapture Survival Rate Estimation. Department of Fishery and Wildlife, Colorado State University, Fort Collins, Colorado.