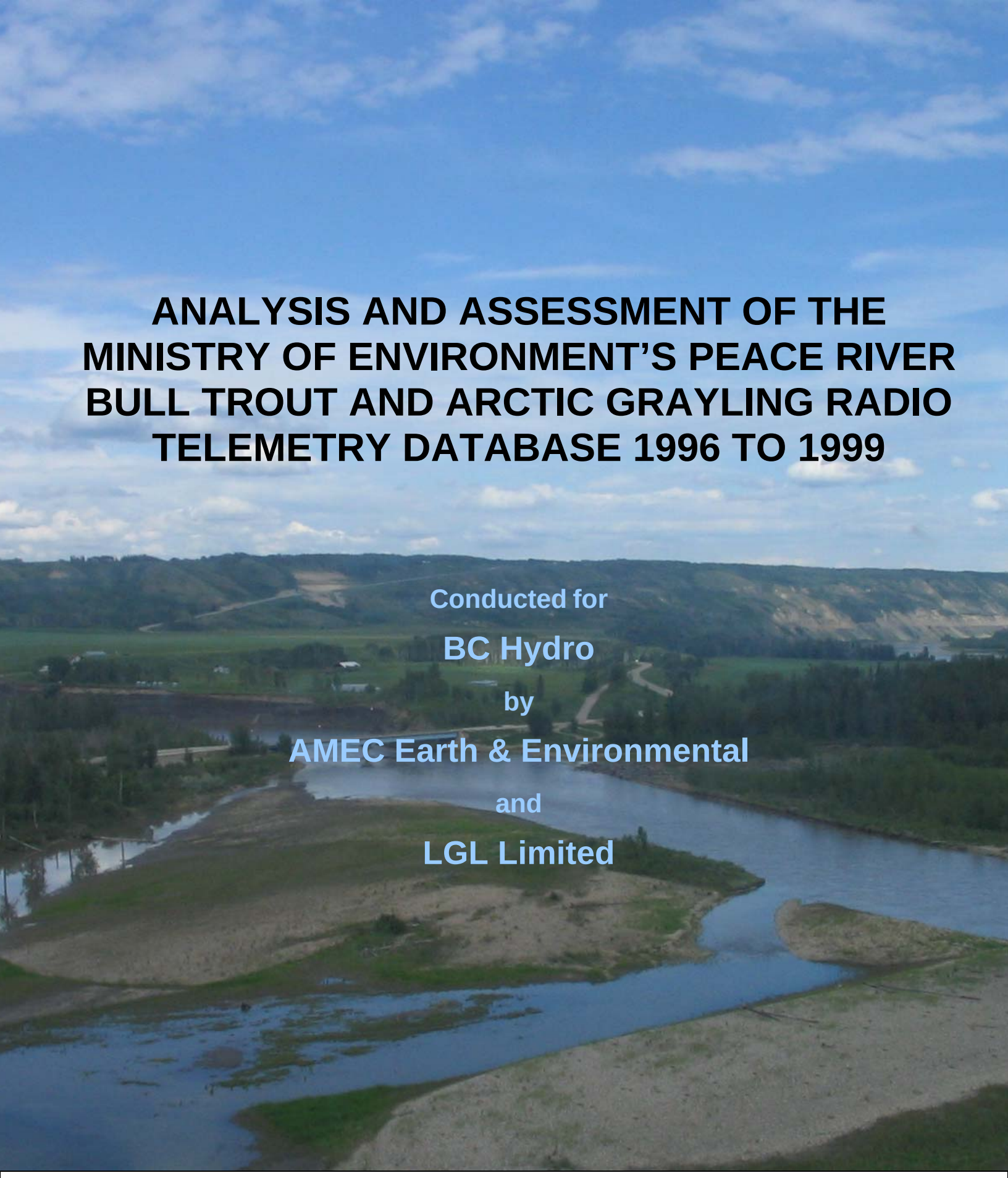

ANALYSIS AND ASSESSMENT OF THE MINISTRY OF ENVIRONMENT'S PEACE RIVER BULL TROUT AND ARCTIC GRAYLING RADIO TELEMETRY DATABASE 1996 TO 1999

Conducted for

BC Hydro

by

AMEC Earth & Environmental

and

LGL Limited

amec

LGL LIMITED
environmental research associates

Analysis and Assessment of the Ministry of Environment's Peace River Bull Trout and Arctic Grayling Radio Telemetry Database 1996 to 1999

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MAY 2010

VE51567

Executive Summary

This report includes the analysis, mapping, and results of the MOE 1996-1999 study on movements of bull trout and Arctic grayling in the upper Peace River watershed. In total, 76 bull trout (primarily from the upper Halfway River) and 49 Arctic grayling (upper Halfway and Sukunka rivers) were radio-tagged, of which 71 and 48 'active' tags, respectively, were tracked (primarily by aerial surveys) to determine fish movements within and among the tributaries and Peace River mainstem. The key findings are:

- 36% (25 of 69) of the bull trout released in the Halfway River watershed did not exit the river, whereas 64% (44 of 69) made at least one foray into the Peace River mainstem.
- The majority (63-77%) of bull trout detected were in the Halfway River watershed from July-September. In all other months, the majority (56-75%) of individuals were detected in the Peace River mainstem.
- Other than the Halfway River, no bull trout were detected in any tributary of the Peace River mainstem
- Only one of the Arctic grayling released in the Halfway River, and none of the Sukunka River fish, emigrated into the Peace River mainstem.
- Arctic grayling released in the Halfway River drainage moved significantly longer distances (median 127 km) than those released in the Sukunka River (median 79 km); the Halfway watershed consisted of minor (<100 km), moderate (100-200 km) and extensive (>200 km) movers.
- Bull trout displacement was primarily upstream in July-August (pre-spawning) and pronouncedly downstream in September (post-spawning); Arctic grayling displacement was clearly upstream from May-July (spawning/feeding), and downstream from August-November (pre over-wintering movement).
- 21% (15 of 71) of the bull trout moved past the potential Site C Dam location.

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1.0 INTRODUCTION

During the 1996-1999 period, the Ministry of Environment (MOE) radio-tagged and tracked a considerable number of bull trout (primarily from the upper Halfway River) and Arctic grayling (upper Halfway and Sukunka rivers) to determine their movements seasonally within and between the tributaries and the Peace River mainstem (Figure 1). The findings of this study were briefly reported by Burrows et al. (2001). To obtain a more detailed understanding of the movements of the MOE-tagged fish, BC Hydro, in agreement with MOE, commissioned AMEC and LGL Limited to analyze this database in more detail and summarize the key findings in a report. The objective was to digitize, map, and re-analyze the MOE database as per the methodology used in recent radio telemetry studies conducted for BC Hydro (e.g., AMEC & LGL 2009). This approach:

- provides more detailed information on the movements of bull trout between the Halfway and Peace rivers;
- provides more detailed information on the movements of Arctic grayling in the Halfway and Pine rivers; and
- facilitates comparison of results with those of recent radio telemetry studies by AMEC and LGL.

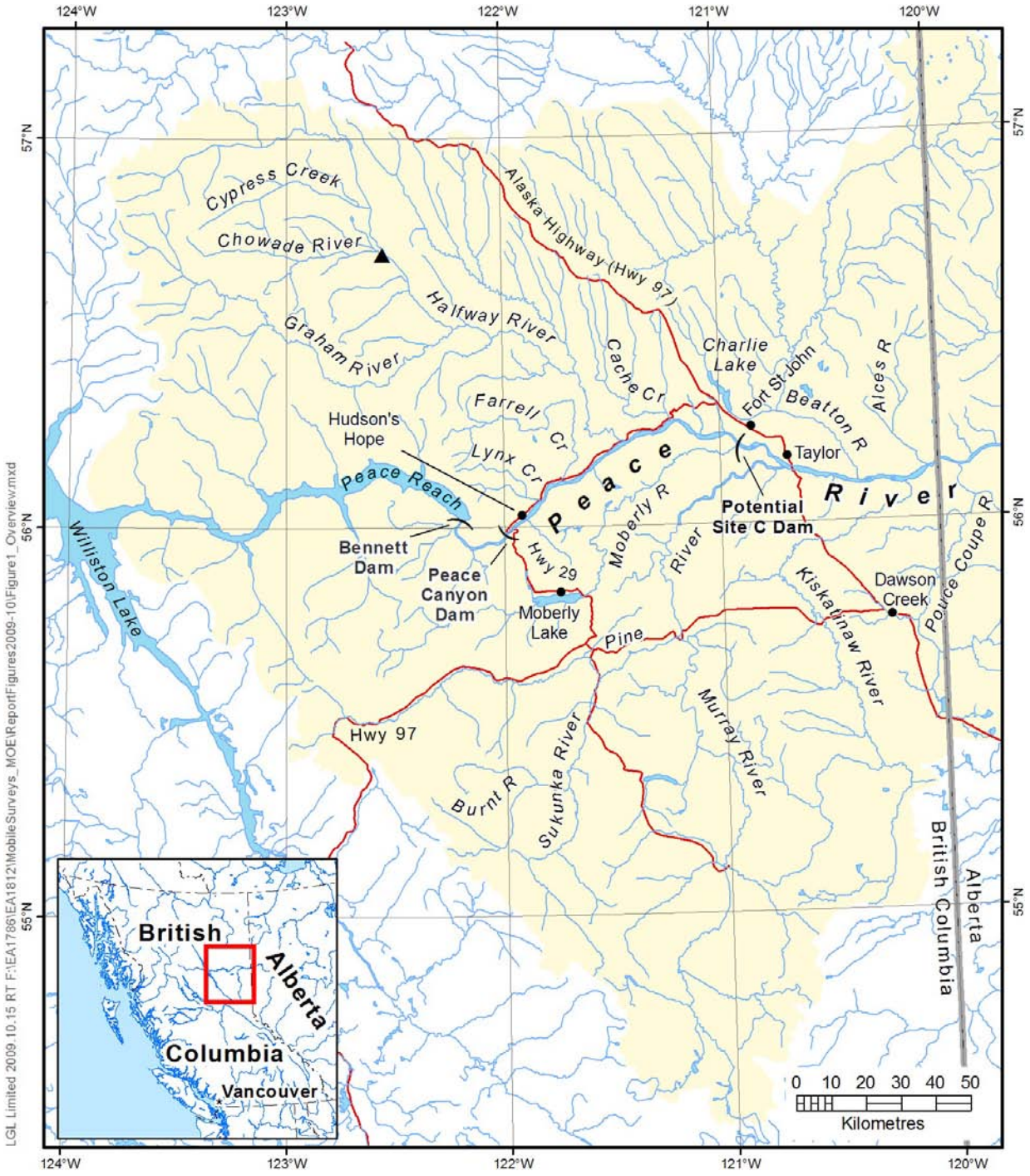


Figure 1: ***Peace River and its tributaries in northeast British Columbia. (▲, location of fixed-station receiver at the confluence of the Chowade River with the Halfway River)***

2.0 METHODS

2.1 Discharge

Discharge information for the Peace (near Taylor, BC; station 07EF001), Pine (station 07FB001), and Halfway (station 07FA006) rivers was obtained from the Water Survey of Canada for 1996 to 1999 (WSC 2008).

2.2 Fish capture, tagging and release

The Ministry of Environment was interested in determining spawning habitat and the movements of bull trout between the Halfway and the Peace River mainstem. To achieve this objective, their sampling targeted upper Halfway River spawning areas when bull trout were present, rather than sampling randomly in time and space over the whole of the Peace/Halfway/Pine watershed complex.

A brief account of the fish capture, tagging and release procedures is taken from Burrows et al. (2001) to describe the field procedures used. All fish were captured by angling with spoons and spinners, and only fish not injured during capture and large enough so that tag weight did not exceed 2% of their body weight were used for tagging. The fish were tagged at the site of capture with Lotek radio transmitters surgically implanted in the abdominal cavity as per standard tag implanting procedures, and released. Fish were released from August 1996 to August 1998, totalling 76 bull trout and 49 Arctic grayling; the numbers released by species by year are summarized in Table 1. The locations and numbers of the fish releases are shown in Figures 2 and 3. Length and weight details of the radio-tagged fish are summarized by species in Table 2. Arctic grayling were considerably smaller than the bull trout in terms of body length and weight.

Table 1: Summary of numbers of bull trout and Arctic grayling released in the upper Peace River watershed, 1996-1998

Year	Month	Bull Trout	Arctic Grayling
1996	August	4	
	September	22	
		26	
1997	April	1	
	August	16	40
	September	12	7
		29	47
1998	April	1	
	July	12	2
	August	8	
		21	2
	Overall	76	49

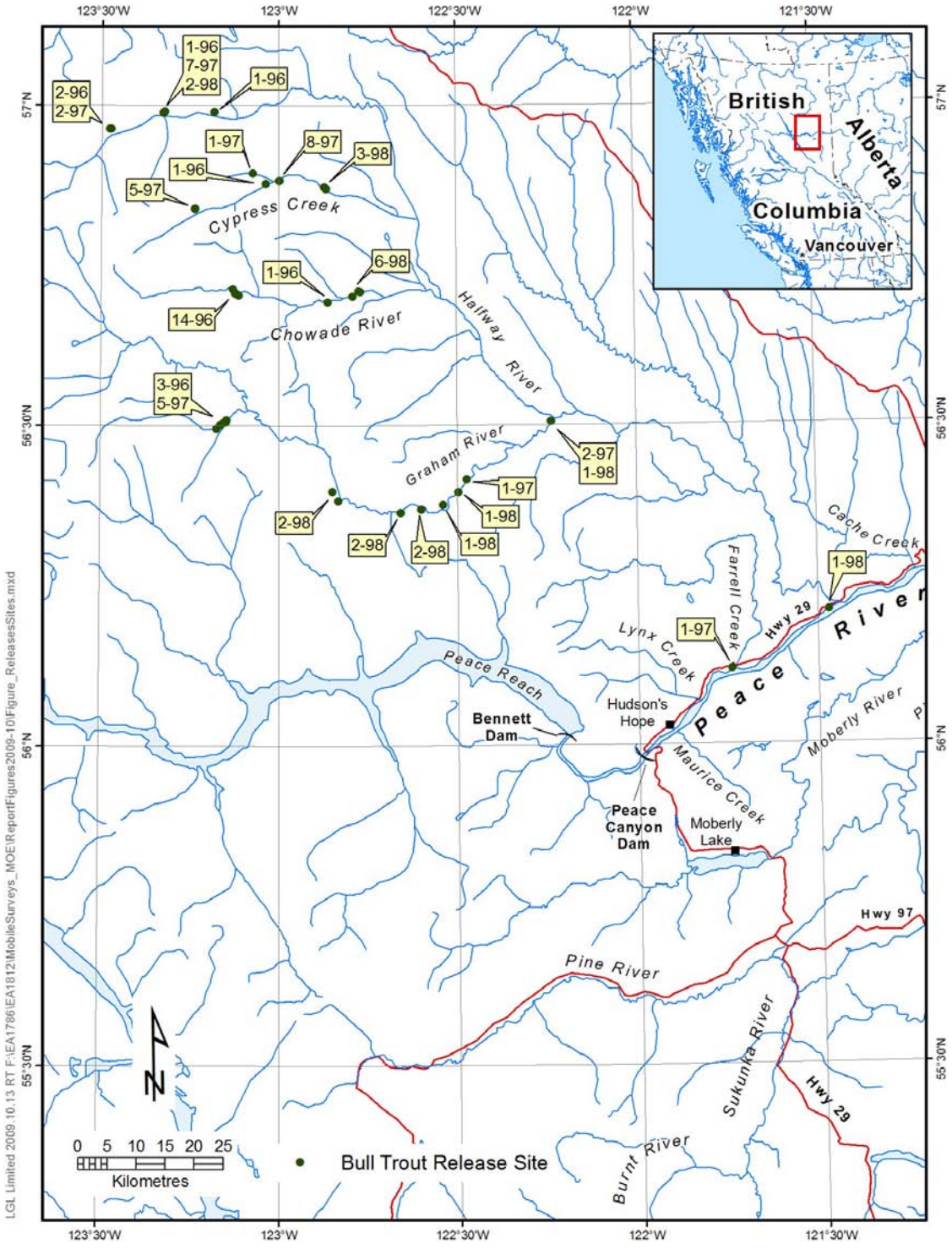


Figure 2: Locations and numbers of radio-tagged bull trout released in the upper Peace River watershed, 1996-1998.

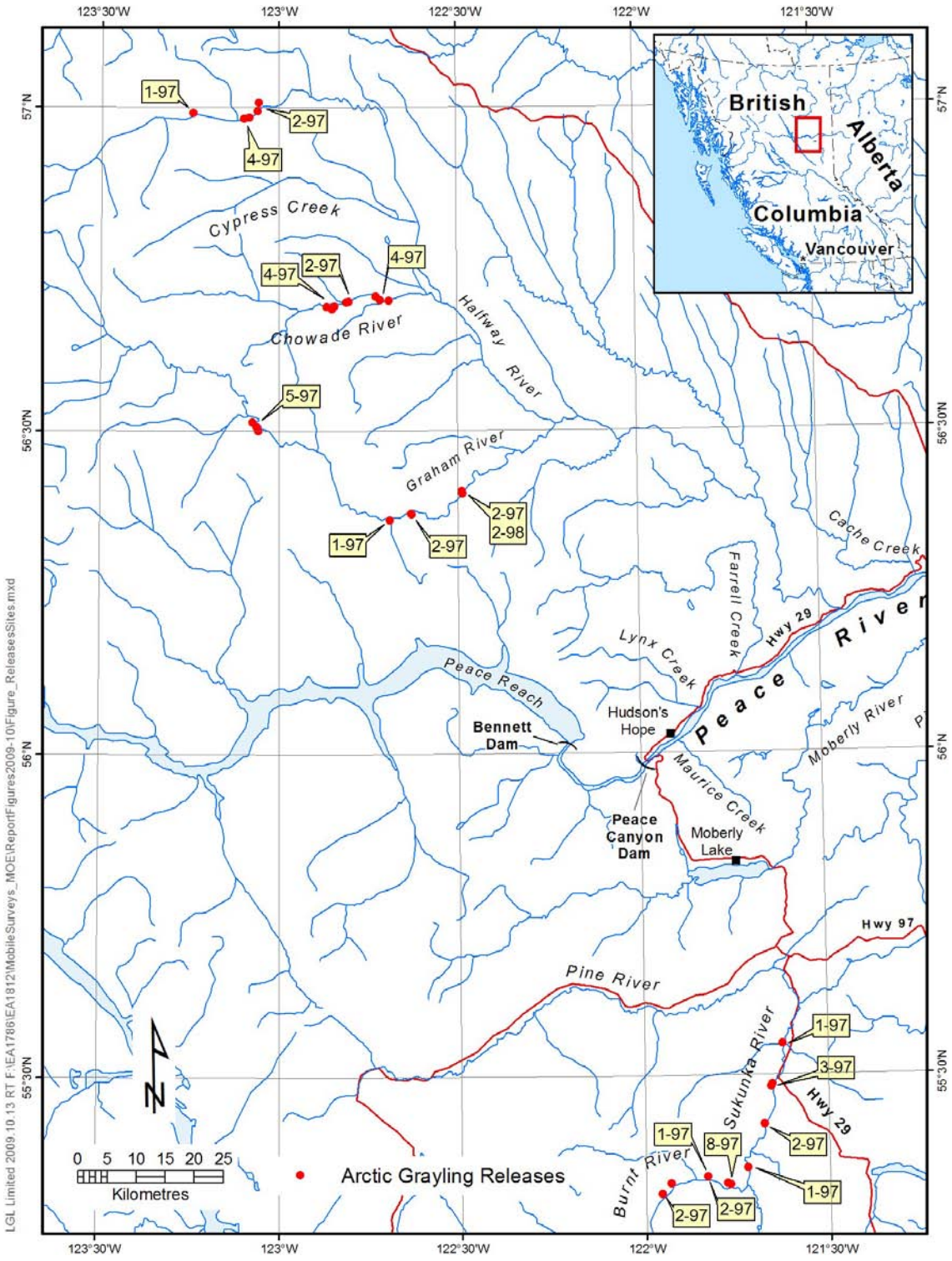


Figure 3: ***Locations and numbers of radio-tagged Arctic grayling released in the upper Peace River watershed, 1996-1998.***

Table 2: Summary of lengths and weights of radio-tagged bull trout and Arctic grayling released in the Peace River watershed, 1996-1998.

			Fork Length (mm)		
Species	**Year**	**N**	**Mean**	**Range**	**Mean Weight (g)**
Bull Trout	1996	26	705	480-885	2238
Bull Trout	1997	29	627	510-815	-
Bull Trout	1998	21	565	349-855	1871
Arctic grayling	1997	47	362	330-405	391
Arctic grayling	1998	2	366	354-378	565
Bull trout	overall	76	636	349-885	1283
Arctic grayling	overall	49	362	330-405	398

2.2.1 Mobile Zones

Figure 4 shows a map of the upper Peace River system showing the geographical boundaries of the zones used in mobile tracking of fish. Zone delineation is described in AMEC & LGL (2008) and Appendix B.

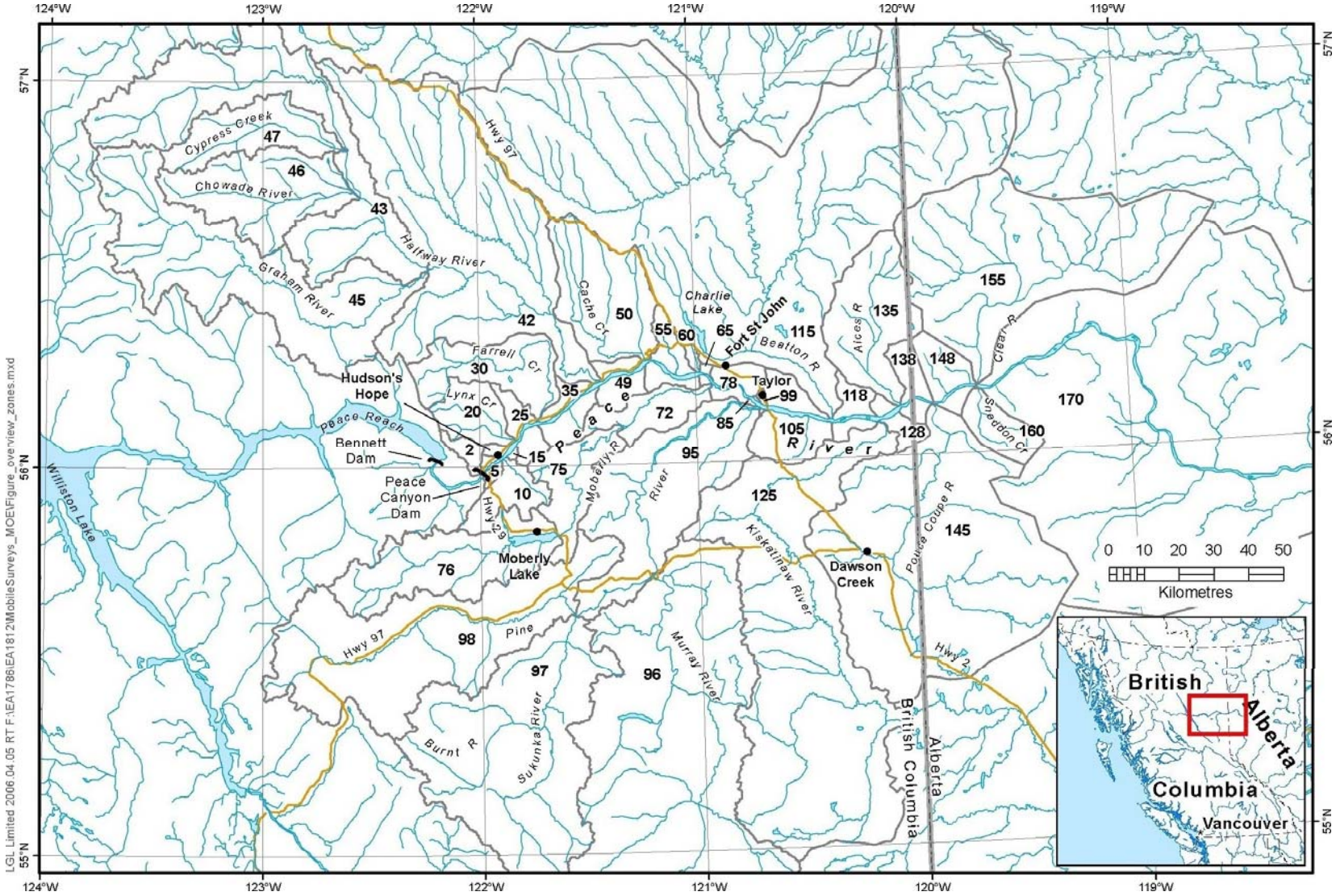


Figure 4: ***Map of upper Peace River system showing the geographical boundaries of the zones used in mobile tracking of fish.***

2.2.2 Monitoring Fish Movement

2.2.2.1 Fixed-station

The movements of tagged fish past the Chowade River confluence with the Halfway River were monitored with a fixed-station setup (see Figure 1 for location of fixed station) consisting of a Lotek SRX 400 radio receiver and three antennas operated from 1 August 1997 to 23 July 1998; the antennas consisted of one directed upstream on the Chowade, one upstream on the Halfway, and one downstream on the Halfway. The aerial tracks provided the bulk of the telemetry data used in this report.

2.2.2.2 Mobile Tracks

With three exceptions, aerial tracks were conducted monthly during the September 1996 to March 1999 period; no tracking was conducted in March 1997, November 1998, and February 1999. In most months, more than one tracking session was carried out per month. From the fish detection data it is evident that the flight paths overlapped in the months with multiple tracks.

We do not have flight path data for any of the tracking sessions for the period September 1996 to July 1998 (58 flights in all for that period), as the flight paths during that period had not been automated with a GPS setup, but recorded manually; from July 1998 onward, full flight path data were recorded by a GPS monitor. Since flight path data are not available for all flights, it was decided only to include the data for the July 1998 to March 1999 period.

For the period that GPS automated flight path data were available (June 1998 to March 1999), none of the flights went beyond Sneddon Creek, Alberta; the same applies to flights prior to June 1998 (confirmed from examination of photocopies of manually recorded flight information for that period).

2.2.3 Data Processing

2.2.3.1 Telemetry Data Processing

The data from mobile tracks and fixed-station downloads were processed and analyzed using LGL's custom database software, "*Telemetry Manager*". *Telemetry Manager* facilitates data organization, record validation, and analysis through the systematic application of user-defined criteria. Raw data were archived so that the temporal or spatial resolution and noise filtering criteria could be changed by the user at any time without altering the raw data. An important aspect of radio telemetry is the removal of false records in receiver files, for example, those that arise from electronic noise. In this study, the following criteria were set for records to be considered valid:

- power levels had to be greater than 50 (on a 1 to 232 scale); and
- detections could not be at zones disparate from similarly-timed sequences of valid detections (i.e., each tag could only be in one place at a time).

Once false records were removed, *Telemetry Manager* created a compressed "operational" database of sequential detections for each fish. Each record included the tag number, zone number (antenna number, fixed-station number, or a general location), the first and last time and date for sequential detections in a specific zone, and the maximum power for all detections in that interval. The compressed operational database was used for all subsequent analyses of fish behaviour and survival.

2.2.3.2 Distance Calculations and Data Cleanup

The result of data processing was an operational database file containing a summary of all release and recovery information, with all valid fixed-station and mobile track detections in chronological order for each fish. UTM co-ordinates were appended for each location record in the database. For mobile detections, the position of the fish was assumed to be that of the aircraft (downloaded from the GPS unit) at the time of the most powerful detection event. Fish detections recorded by the fixed-station receiver were assigned the co-ordinates of the receiver. From the dataset containing sequential positions for each fish, movements, displacements and travel speeds could be calculated.

Movement distances were estimated using a Foxpro script, which either connected sequential UTM co-ordinates with a straight line, or, when sequential positions were in different zones, via a series of nodes thereby forcing the movements to approximately follow the geography of the river system. For each movement event, the start and end timestamps were used to determine the "time at large" (i.e., the duration) of the movement event. Also, the start and end positions of each movement event were used to determine if the direction of movement was upstream or downstream. On occasion, a fish would move both downstream and upstream within the same movement event (e.g., a fish detected in the Beatton River and subsequently in the Alces River had to move downstream in the Beatton River, downstream in the Peace River, and then upstream into the Alces River). In these events, the direction of the final leg of the movement was assigned to the whole of the movement. For each movement, a displacement was calculated as the magnitude of the movement multiplied by 1 for upstream movements, or by -1 for downstream movements. Movement rates were calculated for all sequential detections as the distance moved divided by the time at large. Similarly, displacement rates were calculated as the displacement divided by the time at large.

Once the distance, direction, and duration were calculated, invalid records became apparent. Detection sequences that made fish appear to move too quickly were examined more closely. Also, detection sequences that made fish appear to move too far, especially without being detected by fixed-station receivers in between, were also examined. Most of the unrealistic movements resulted from simultaneous mobile and fixed-station detections. Fish that remained in the detection field of a fixed-station receiver at the time of a mobile track would show artificially high displacement rates because they would be recorded at the UTM co-ordinates of the fixed-station receiver, then instantly appear at the UTM co-ordinates of the mobile survey aircraft,

and then immediately return to the UTM of the fixed-station receiver. To avoid this problem, mobile detections were ignored (for the purposes of movement and displacement analyses) if they occurred simultaneously with a series of fixed-station detections.

Once all of the artificial movements were cleared out of the database, the movement distances, directions, and durations were recalculated. For these final calculations, movement distances were estimated using ARC-GIS software. For each fish, all detection positions were plotted, and each sequential position was connected with a line (making *n-1* lines joining *n* detection positions). Tracking tools in the software were used to confine each of these connector-lines to within the river contours, hence taking all river-curvatures into account. Time at large, movement distance and movement direction (and hence movement rates, displacement, and displacement rates) were all re-calculated using the methods as previously described.

All movement events, with their associated direction, displacement, time at large, and displacement rate, were linked to an individual fish (and hence a species) and to a timestamp for subsequent analyses. Analyses included comparisons between species, between release locations, and among months of displacement rates, total movements, and movement rates. Also, the effect of time at large on displacement was examined.

2.2.3.3 Displacement and Movement Calculations

Various metrics were calculated to describe the movements and displacements of the radio-tagged fish. As described above, ARC-GIS was used to determine the along-river distance between each sequential detection of each fish. To add directionality to the distances, they were multiplied by -1 if the fish moved in the downstream direction, or by +1 for the upstream direction. Distances without directionality were called ‘movements’, those with directional information were called ‘displacements’.

Displacements

Basic displacement rates were calculated for each sequential detection of each fish by dividing the observed displacement by the time between those sequential detections. For each radio-tagged fish, the median overall study-period displacement was calculated. Also, median displacement was calculated for each month for each radio-tagged fish.

Differences between species in displacement rates were calculated using Kruskal Wallis H tests (one-way ANOVA non-parametric equivalent; Zar 1984), where median displacements were used as the dependent variable in order to ensure that each individual was included only once in the analysis. For each species, differences among months were calculated using Kruskal Wallis H tests, with median monthly displacements as the dependent variable, again to ensure that each individual was included in the analysis only once per month.

Displacement rates were also examined by plotting displacement versus time at large. For each species, the displacement between each sequential detection of each fish

was plotted against the time between those sequential detections. The slope of the relationship was calculated for each species. If the slope was negative, then the species tended to move downstream over time, with farther downstream movements observed with longer periods of time-at-large. Differences in slopes between species was tested using ANCOVA, where a significant species by time at large interaction would indicate a difference between species in displacement behaviours.

Movements

For each radio-tagged fish, overall movement was calculated by summing all of the observed movements over the duration of the study period. Note that movements (non-directional) were summed, not displacements. Differences in overall movements among species or between release locations were calculated using Kruskal Wallis H tests.

Statistical Analyses

For all analyses, statistical significance was declared when *P* values were less than 0.05.

2.2.3.4 Basis for Tag Exclusion

Radio-tagged fish confirmed or presumed to be dead and those that were never detected were filtered from the dataset and excluded from further analysis.

Potential Mortality

From position-based telemetry data, it is not possible to determine if a fish is living or dead. A live, sedentary fish would "track" the same as a dead fish, or as an expelled tag on the riverbed. It is generally acceptable to assume, when movements are observed, that an individual is alive. It should be noted, however, that there is error associated with our position estimates (based on the speed of the aircraft used for tracking, the frequency of the tag's signal transmission, etc.) so a tag can appear to "move" from survey to survey even if it is motionless on the riverbed. It is therefore necessary to determine the minimum movement threshold below which any observed "movements" might be spurious.

In other telemetry studies on the Peace River, the minimum movement threshold that was used was 350 m (AMEC and LGL 2008). In this study, all fish were observed to move at least 2 km, thus it was decided that no tags would be treated as potential tagging-related mortalities in this study.

Known Mortalities

One tag (fish 1043, released 10 September 1996 in the Halfway River) was recovered on 22 September 1997. This fish was classified as a "known mortality", and was excluded from subsequent analyses.

Undetected Tags

In total, 5 tags were never detected (4% of the 125 tags released), including 4 bull trout released in 1998, and one Arctic grayling released in 1997 (see Appendix B). This may be related to predation or fishing that removed the tags from the study area.

Expected tag failure based on information from past LGL studies is approximately 0.3%. Note that the survey efforts were adequately intense to expect that tags associated with dead fish would be detected at least once. For this reason, tags that were never detected were not known mortalities, but were nevertheless censored from subsequent analyses; the tags that were censored are summarized in Table 3.

Table 3: List of tags that were censored from some of the data analyses in 2009

Tag No.	Species	Release Year	Censorship Reason
1043	BT	1996	Recovery
1057	BT	1998	Single detection
1062	BT	1998	Single detection
1063	BT	1998	Never detected
1064	BT	1998	Single detection
1068	BT	1998	Never detected
1071	BT	1998	Never detected
1073	BT	1998	Never detected
1108	GR	1997	Never detected
1113	BT	1996	Single detection

2.2.3.5 Fish Movement Past Site C

There was no fixed-station receiver at the proposed Site C location. Nevertheless, movements of fish past the potential Site C location could be determined from sequential position data derived from the mobile tracks. All passage events were associated with a month and an individual (and hence a species) for subsequent analyses. Analyses included comparisons of movement events between species and among months.

3.0 RESULTS

3.1 Environmental Characteristics

Flow data at Water Survey of Canada stream gauges on the Peace River near Taylor, BC and Halfway, and Pine rivers for 1996 to 1999 (WSC 2008) are presented in Appendix A.

Peace River flows were similar from 1997 to 1999 but were much higher in the summer of 1996 (Figure 5). In 1996, discharge reached a peak of approximately 6000 m^3/s when there was a spill event from the W.A.C. Bennett Dam. Although flow regulation is attenuated downstream by discharge from unregulated tributaries, Peace River flows at Taylor are largely determined by flows out of Peace Canyon Dam.

Discharge in the Halfway River was also highest in the summer of 1996 and lowest in the summer of 1998 but was similar during most months between 1996 to 1999 (Figure 6). In the Pine River, monthly discharge was similar among years between

1996 and 1999, with the exception of lower discharge from June to September in 1998 (Figure 7).

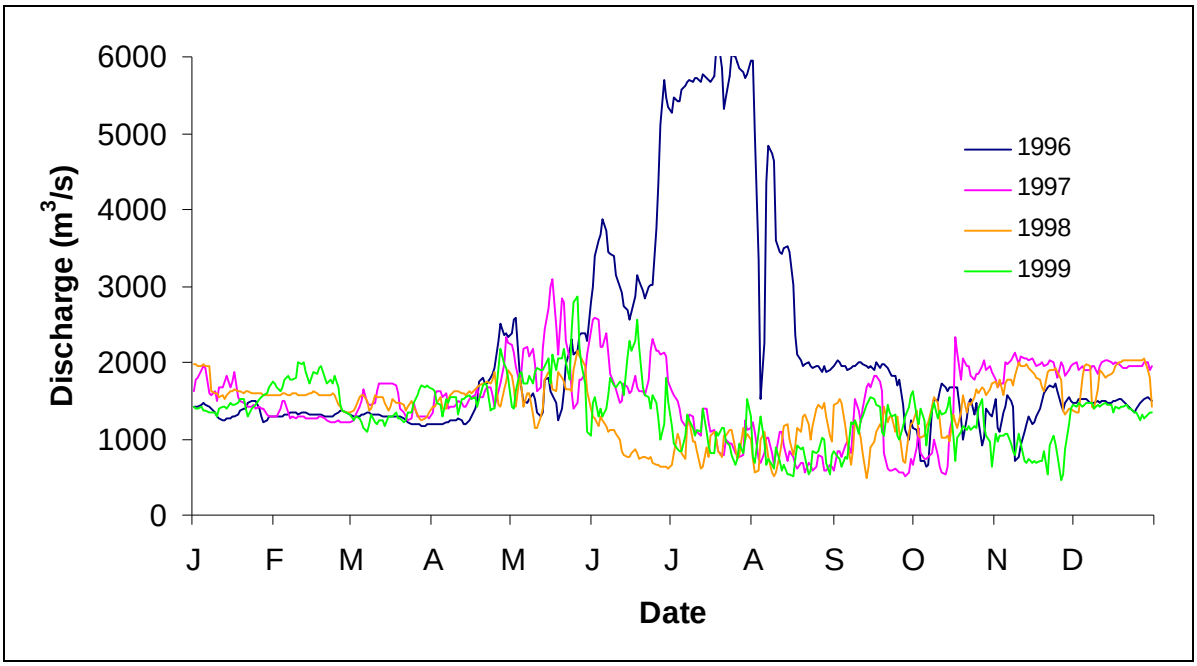


Figure 5: Daily discharge (m^3/s) of the Peace River near Taylor, BC for the period 1996 to 1999

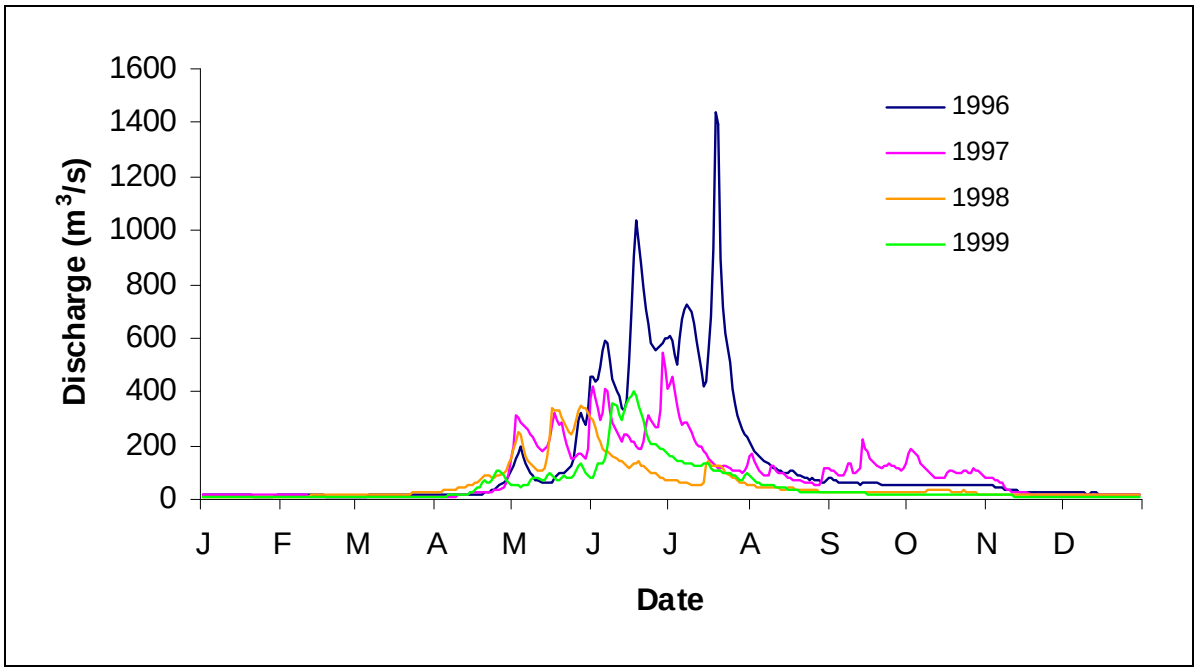


Figure 6: Daily discharge (m^3/s) of the Halfway River for the period 1996 to 1999

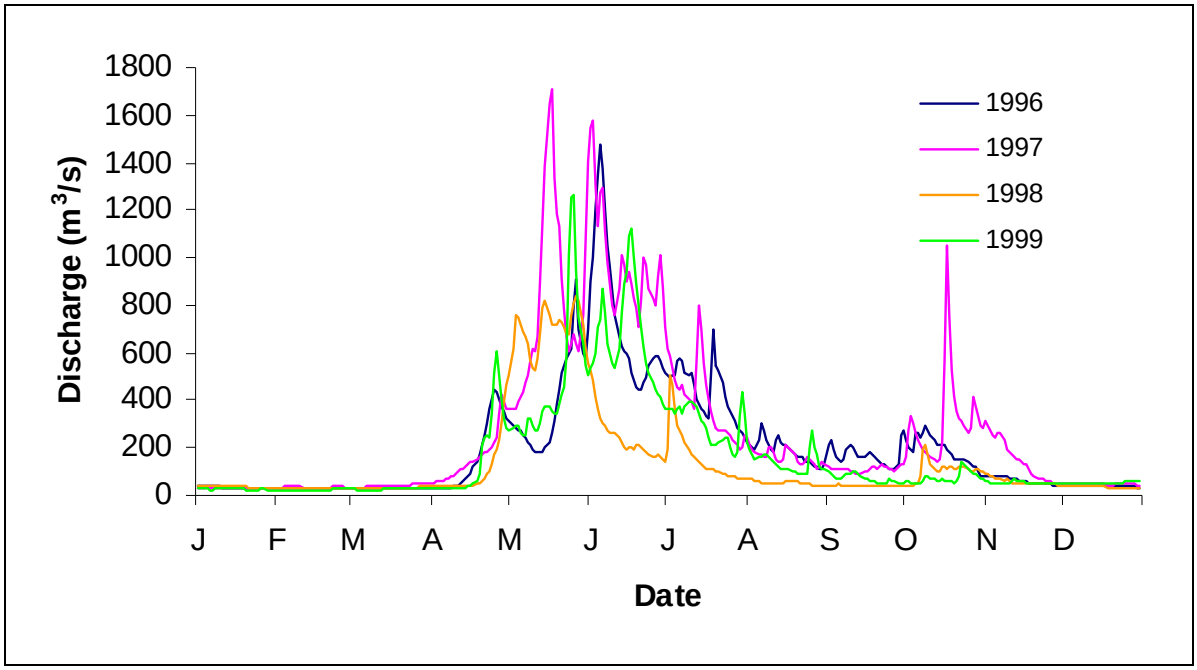


Figure 7: Daily discharge (m^3/s) of the Pine River for the period 1996 to 1999

3.2 Radio Telemetry

3.2.1 Monitoring Fish Movement

3.2.1.1 Fixed-stations

During the 1996-1999 study period, a total of 24 bull trout and 6 Arctic grayling were detected at the fixed-station receiver site at the confluence of the Chowade River with the Halfway River. Of the 24 bull trout detected, 22 were tagged and released in the Halfway River watershed, and represent 31% of the 70 bull trout released there. The remaining two bull trout detected at the fixed-station receiver were tagged and released in the Peace River mainstem, and represent 100% of the bull trout released there. All six of the Arctic grayling that were detected at the fixed-station receiver were tagged and released in the Halfway River watershed, and represent 21% of the 28 grayling released there. None of the 20 Arctic grayling released in the Pine River watershed were detected at the fixed-station receiver (Table 4).

Table 4: ***The percent of radio-tagged fish that was detected at the fixed-station receiver site at the confluence of the Chowade and Halfway rivers, by species and release site, 1996-1999.***

	Bull Trout		Arctic Grayling	
	Halfway	**Peace**	**Halfway**	**Pine**
	n=70	**n=2**	**n=28**	**n=20**
Number Detected	22	2	6	0
Percent Detected	31%	100%	21%	0%

3.2.1.2 Mobile Tracks

The number and percentage of 'active' tags (active tags include all tags released, excluding those that were never detected and those that had been recovered) that were detected in the 72 mobile tracking sessions are summarized by month in Table 5.

The approach to mapping the detections is as follows. First, all detections for bull trout and Arctic grayling for the study period (1996-1999) are shown by species on separate maps (Maps A & B) to convey the overall distribution of detections for each species. Second, the detections by species by month for the entire tracking period are shown on Maps 1 to 28 (see Appendix); the number of tracking sessions shown per map varies with the number of tracks conducted for the month shown on the map (range, 1-7 tracks/month).

Table 5: Numbers and percentages of the tagged fish detected by species during each month of mobile tracking

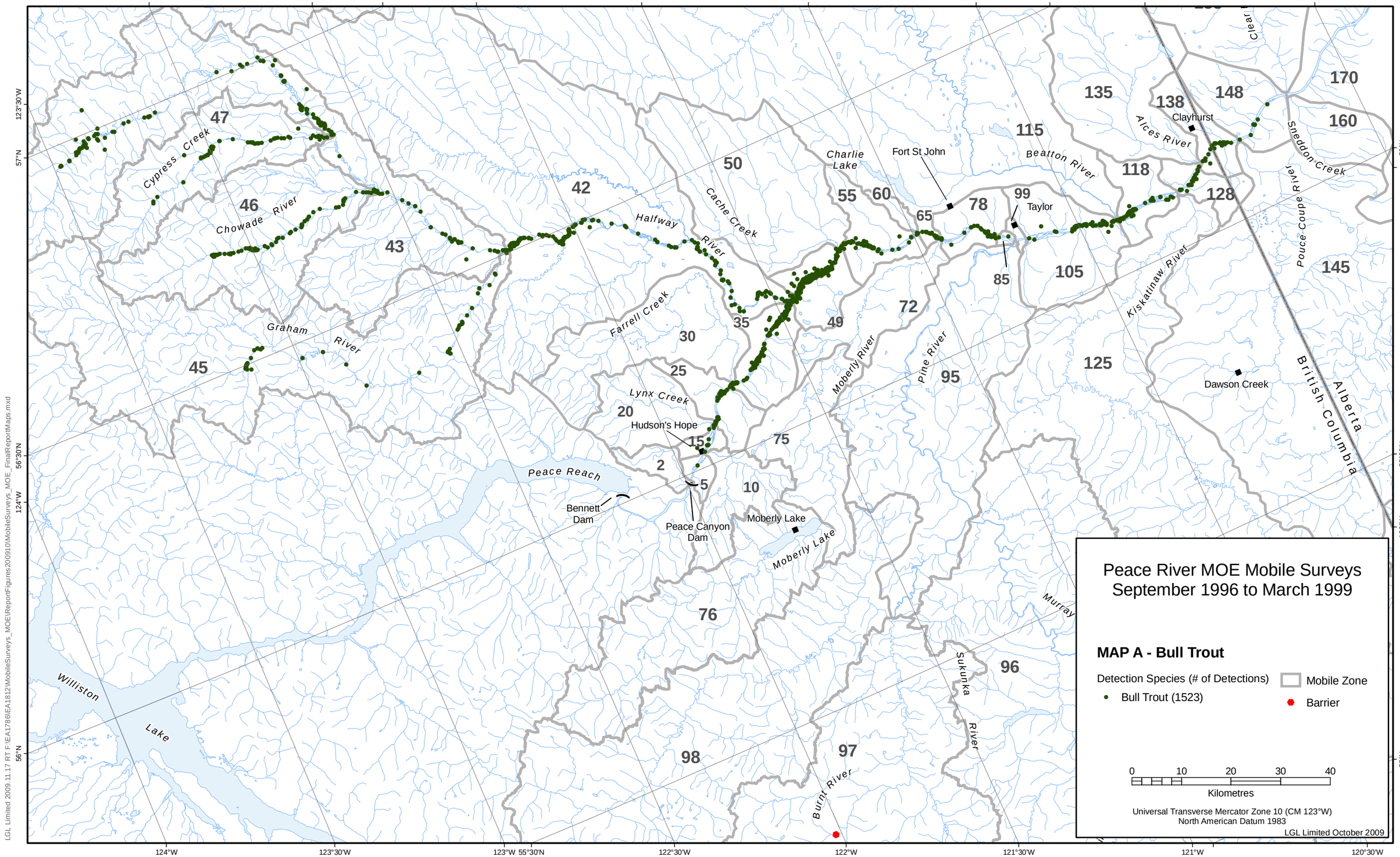
		Species			
Survey Month	**# Flights**	**Bull Trout**		**Grayling**	
Sep 1996	3	100%	(26/26)		(0/0)
Oct 1996	4	100%	(26/26)		(0/0)
Nov 1996	1	77%	(20/26)		(0/0)
Dec 1996	1	77%	(20/26)		(0/0)
Jan 1997	1	77%	(20/26)		(0/0)
Feb 1997	1	73%	(19/26)		(0/0)
Apr 1997	3	81%	(22/27)		(0/0)
May 1997	3	81%	(22/27)		(0/0)
Jun 1997	3	85%	(23/27)		(0/0)
Jul 1997	3	85%	(23/27)		(0/0)
Aug 1997	3	88%	(38/43)	59%	(23/39)
Sep 1997	4	76%	(41/54)	83%	(38/46)
Oct 1997	5	94%	(51/54)	98%	(45/46)
Nov 1997	2	91%	(49/54)	96%	(44/46)
Dec 1997	2	83%	(45/54)	93%	(43/46)
Jan 1998	2	78%	(42/54)	96%	(44/46)
Feb 1998	2	87%	(47/54)	83%	(38/46)
Mar 1998	2	80%	(43/54)	98%	(45/46)
Apr 1998	1	75%	(41/55)	93%	(43/46)
May 1998	7	80%	(44/55)	87%	(40/46)
Jun 1998	5	78%	(43/55)	76%	(35/46)
Jul 1998	3	57%	(37/65)	73%	(35/48)
Aug 1998	2	68%	(48/71)	63%	(30/48)
Sep 1998	1	54%	(38/71)	35%	(17/48)
Oct 1998	2	69%	(49/71)	69%	(33/48)
Dec 1998	2	38%	(27/71)	33%	(16/48)
Jan 1999	2	63%	(45/71)	73%	(35/48)
Mar 1999	2	52%	(37/71)	46%	(22/48)

Note: Percentages are based on the total number of known active tags remaining in the tagged population at the time of survey (ignoring fish that were never detected).

Overview of All Detections by Species

Bull Trout (Map A)

An overview of all tag detections of bull trout for the entire study period is shown on Map A. The majority of bull trout were detected in the Halfway River system (mainstem and headwater tributaries) and the Peace River mainstem from Hudson's Hope to just past the British Columbia/Alberta border. No bull trout were detected in any other tributary of the Peace River mainstem.



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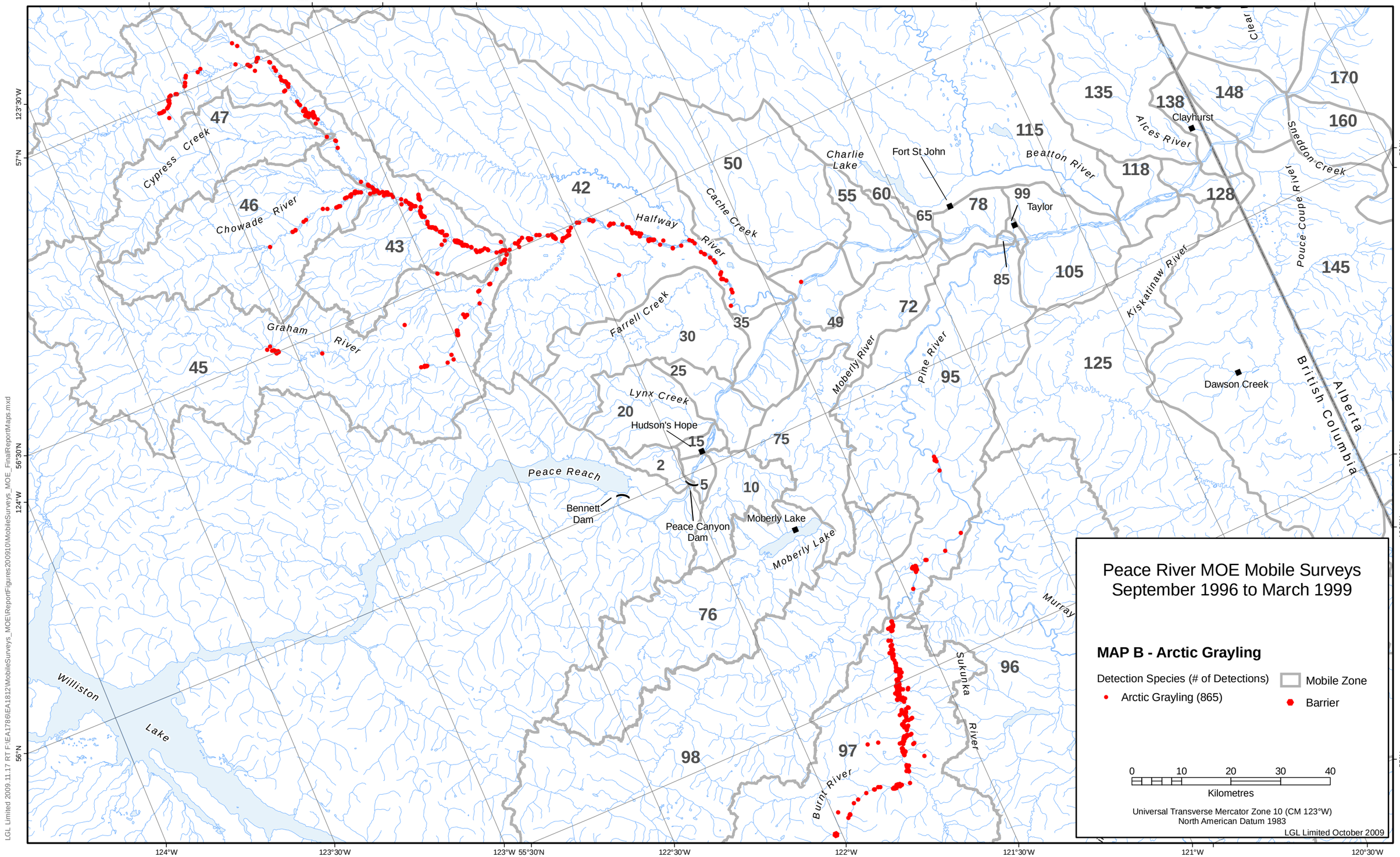
Map A: All mobile survey detections for bull trout, September 1996 to March 1999

Arctic Grayling (Map B)

An overview of all detections for Arctic grayling for the period of study is shown on Map B. The majority of Arctic grayling were detected in the Sukunka River and Halfway River mainstem and headwater tributaries (e.g., Graham, Chowade, Cypress). A few fish (3 unique tags in all) were detected in the Pine River mainstem downstream of the Sukunka River confluence. Only a single Arctic grayling (released in the Halfway River) was detected in the Peace River mainstem.



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Map B: All mobile survey detections for Arctic grayling, September 1996 to March 1999

Detections by Species by Month during the study period

The distribution of tag detections by species by month for the period September 1996 to March 1999 is shown on Maps 1-28 (see Appendix). Maps 1-10 (September 1996-July 1997) show only bull trout detections as no Arctic grayling had been tagged until after July 1997; Maps 11-28 (August 1997-March 1999) include both species.

Bull Trout

Examination of Maps 1-28 shows that in each of the three years of study, the majority of bull trout detected were in the Halfway River system during the July-September period. In all other months, bull trout were more commonly detected in the Peace River mainstem, widely distributed from Hudson's Hope to the vicinity of the BC/Alberta border. A further assessment of bull trout movements is provided in Section 3.2.1.4.

Arctic Grayling

Of the Arctic grayling released in the Sukunka River, none was ever detected in the Peace mainstem. The majority (85%, 17/20) of these fish remained in the Sukunka River, with a minor proportion (15%) detected in the Pine mainstem during winter, although in most cases they returned to the Sukunka during summer.

Only one of the Arctic grayling released in the Halfway River drainage was detected in the Peace mainstem (during winter); all others were in the Halfway River system, with the majority in the mainstem of the river particularly during winter. During the spring-autumn period, Arctic grayling were widely distributed in the Halfway River system, including several headwater tributaries (Graham, Chowade, Cypress) and the upper Halfway River. A further assessment of Arctic grayling movements is provided in Section 3.2.1.5.

3.2.1.3 Mobile and Fixed-Station Tracking Detection Assessment

Individual tracks of the movements of each of the 71 and 48 'active' tags of bull trout and Arctic grayling that were tracked in this study are shown in Appendix B. These tracks show the sequential movements of individual fish from release site to last detection. For several Arctic grayling, the movements are supplemented on a larger scale map to convey short movements into small side streams (some may be spawning related) that are not apparent on the smaller scale maps. Representative examples of the movements of both species are discussed below.

Bull Trout

Of the bull trout released in the Halfway River drainage, approximately one-third (25 of 69 fish, 36%) of them did not emigrate from the system. Of those that did migrate into the Peace mainstem (44 fish), movement occurred in both downstream and upstream directions from the Halfway River confluence. Of these, 15 (34%) fish

subsequently moved downstream past the Moberly River confluence, and three fish (tags 1003, 1004 and 1035, 7%) moved to within the vicinity of the BC/Alberta border.

Fish 1004 is an example of extensive movement by bull trout between the Halfway River and Peace River mainstem (Figure 8). This fish was released in Cypress Creek 10 September 1996, one week later it was detected in the Halfway mainstem approximately 50 km downstream from where it was released, and 10 days later it was detected near the BC/Alberta border, and remained within the vicinity for more than a year (until 19 December 1997); it returned to Cypress Creek in July 1998, where it was last detected 14 January 1999.

Fish 1019 is an example of movement of a bull trout that did not emigrate from the Halfway River watershed (Figure 9). This fish was released in the Chowade River in September 1996, it then moved downstream in the Halfway River mainstem to the vicinity of the Graham River confluence where it spent more than a year, and was last detected at the mouth of the Chowade River in August 1998.

Fish 1049 is the movement of a bull trout that was released in the Peace mainstem (Figure 10). This fish, released at the Farrell Creek confluence in April 1997, moved downstream in the Peace mainstem, entered the Halfway River in mid June and moved up into the Chowade River where it was detected on six occasions between 24 July and 18 August 1997, and shortly after returned to the release location where it was repeatedly detected from 3 October 1997 to 4 June 1998. The movements of this fish suggest it spawns and feeds in the Chowade River and over-winters in the Peace mainstem.

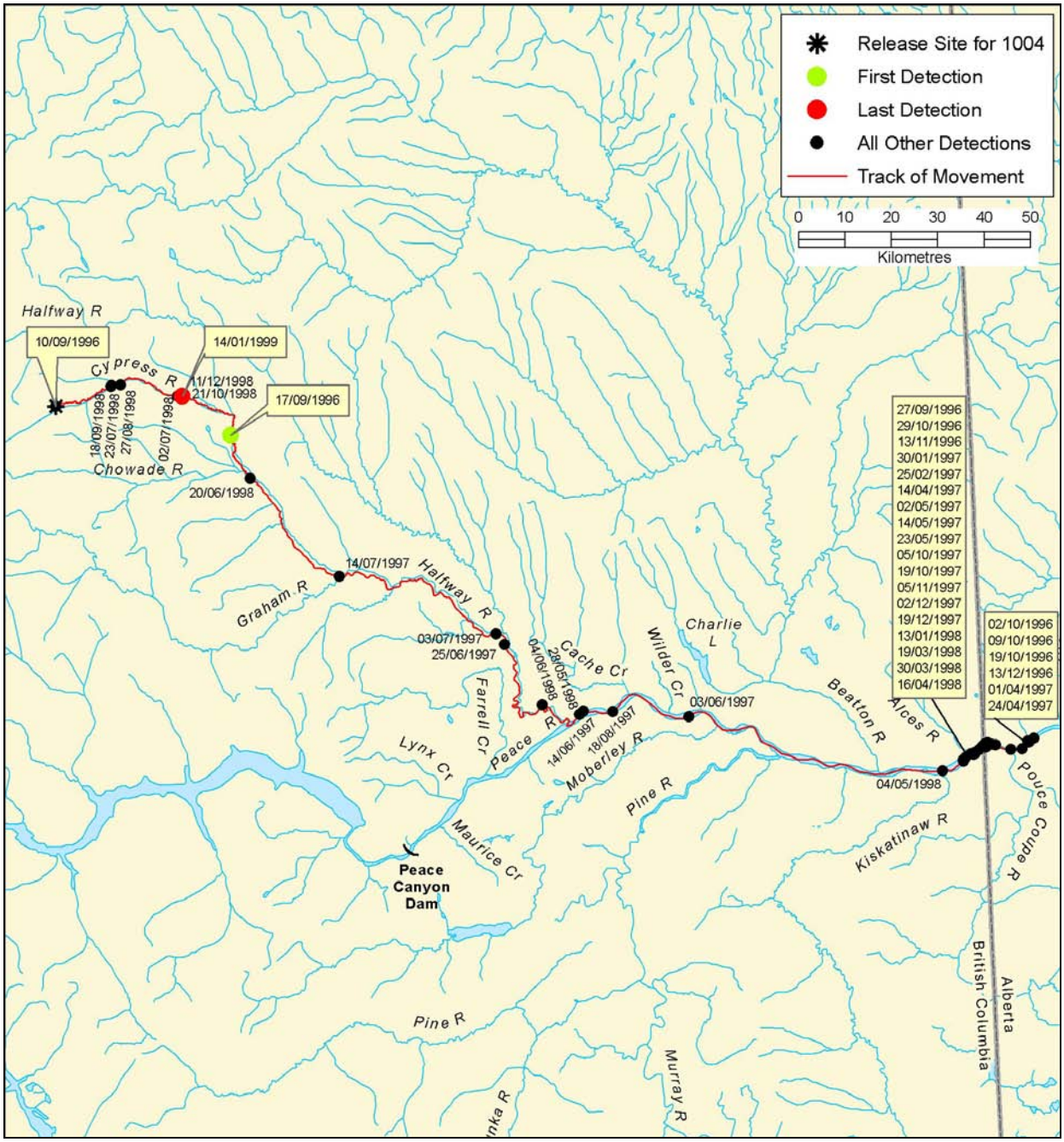

Figure 8: ***Individual track of a bull trout (Fish 1004) that moved from the Halfway River to the Peace mainstem, and returned; total distance tracked, 1,089 km.***

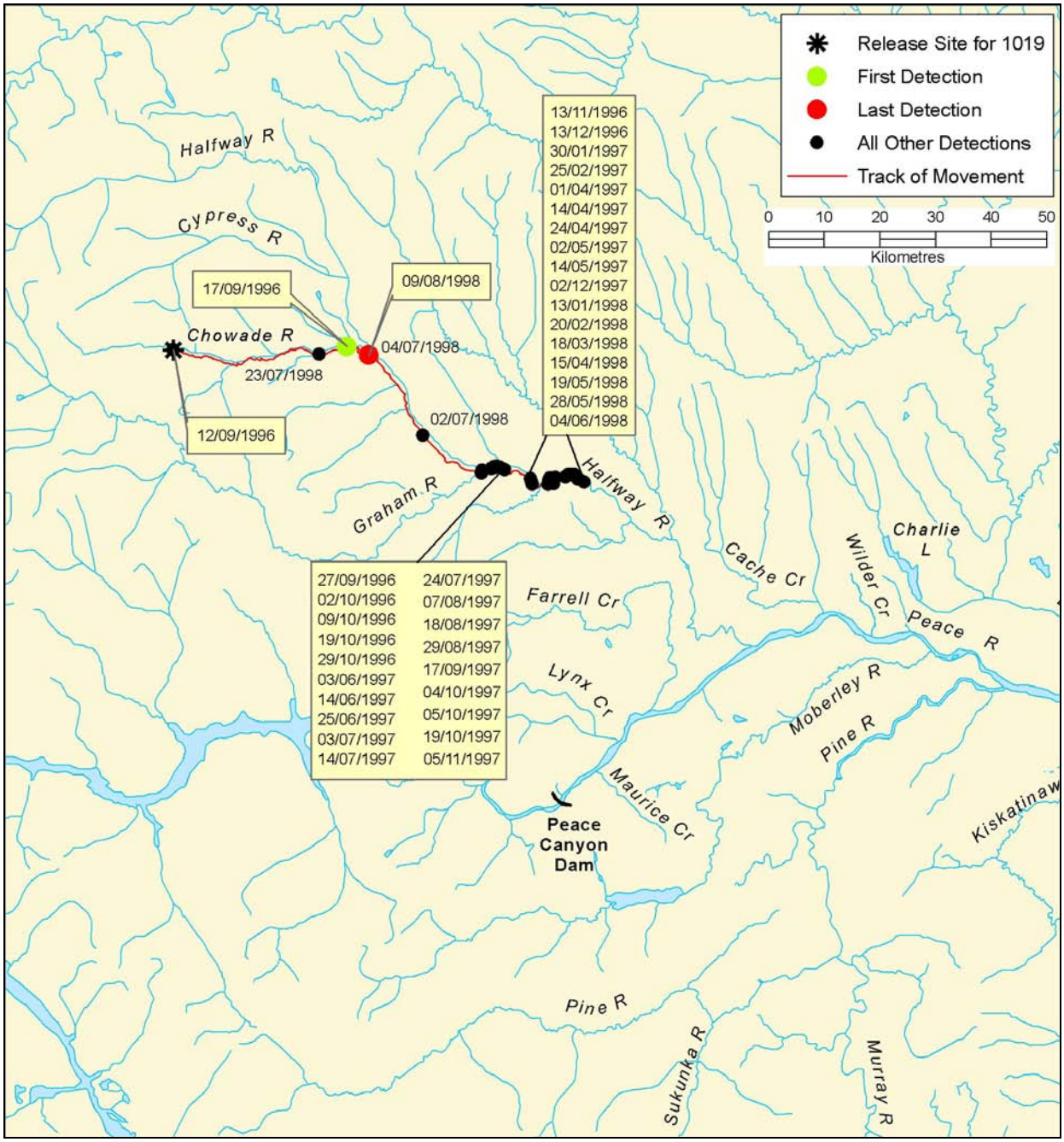

Figure 9: ***Individual track of a bull trout (Fish 1019) that did not emigrate from the Halfway River watershed; total distance tracked, 233 km.***

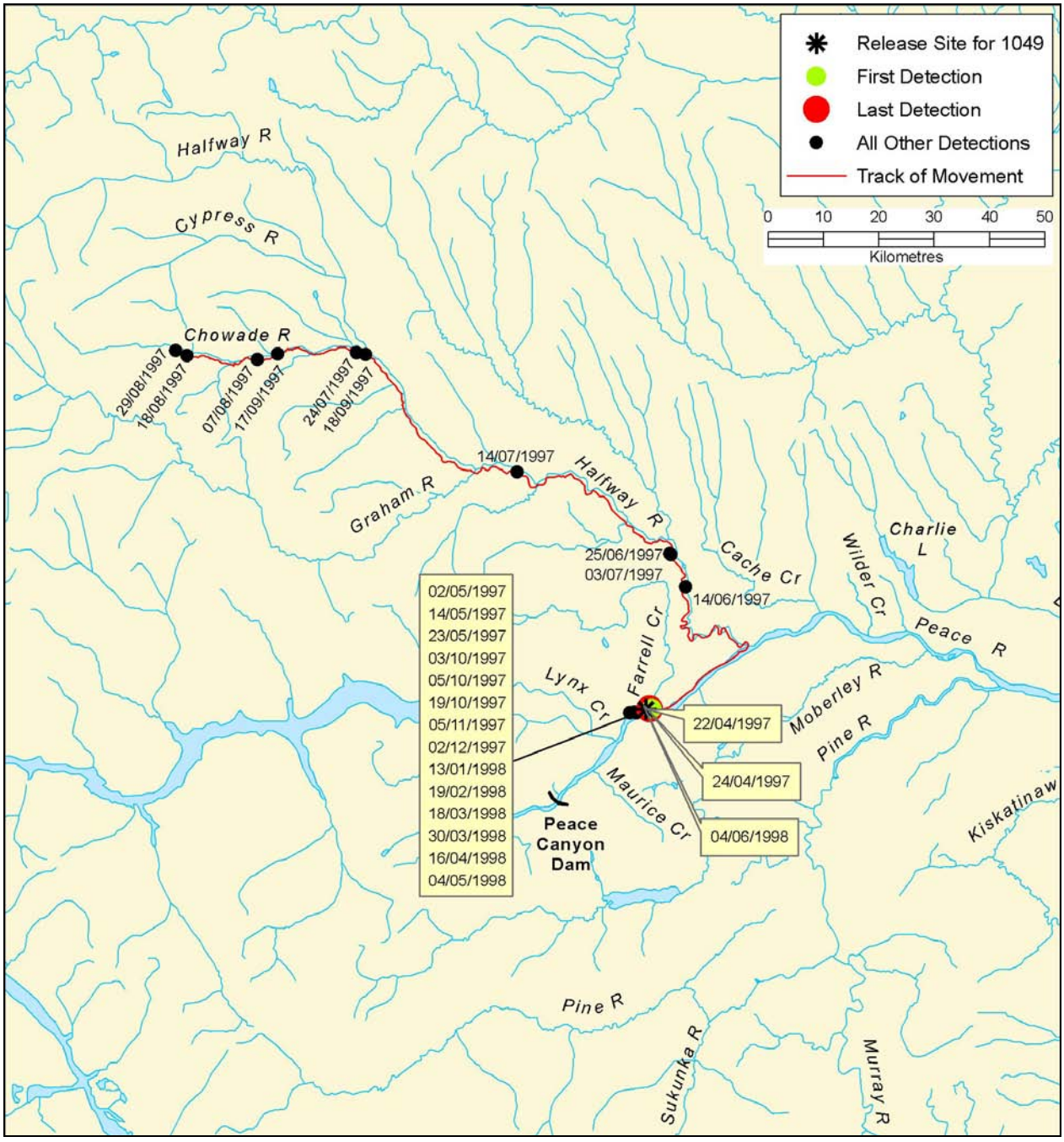

Figure 10: Individual track of a bull trout (Fish 1049) that moved from the Peace mainstem to the Halfway River watershed, and returned; total distance tracked, 394 km.

Arctic Grayling

In general, Arctic grayling released in the Sukunka River watershed moved relatively little compared with those released in the Halfway River watershed. Very few Arctic grayling emigrated from the Sukunka River into the Pine mainstem, and of those that

did, most returned. On the other hand, movements of Arctic grayling in the Halfway system varied considerably, comprising a mix of minor (<100 km), moderate (100-200 km) and extensive (>200 km) distances travelled seasonally between headwater tributaries and the mainstem. Representative examples of movements of fish in both the Halfway and Sukunka drainages are presented below.

Halfway River drainage:

Fish 1120 is an example of minor movement (Figure 11). This fish was released in the lower Chowade River in August 1997. It was subsequently detected on numerous occasions within a distance of about 20 km in the Halfway River mainstem below the Chowade River confluence from October 1997 through January 1999, when it was last detected.

Fish 1116 is an example of moderate movement (Figure 12): This fish, like the above example, was released in the Chowade River in August 1997. From late August 1997 to late March 1999, when it was last detected, it 'milled about' considerably in both upstream and downstream directions in the Halfway River mainstem between the Chowade and Graham rivers.

Fish 1121 is an example of extensive movement (Figure 13). This fish, released in the upper Halfway River in August 1997, progressively moved down the mainstem to within 15 km of the mouth of the Halfway by mid March 1998, then headed up to the Chowade River mouth where it was detected on five occasions between 19 May 1998 and 26 March 1999 when it was last detected; its upstream movement to the Chowade in spring 1998 may have been spawning related.

Sukunka River drainage:

Fish 1129 is typical of the minor movement by Arctic grayling in the Sukunka River watershed (Figure 14). This fish, released below the Burnt River confluence in early September 1997, did not emigrate from the Sukunka River. It was repeatedly detected in the Sukunka mainstem over a distance less than 20 km in length from September 1997 to March 1999.

Fish 1133 is an example of the movements of an Arctic grayling that emigrated from the Sukunka, and returned (Figure 15). This fish, released at the Burnt/Sukunka confluence at end August 1997, exited the Sukunka and entered the Pine where it was frequently detected from October 1997 to May 1998; it returned to the Sukunka in June, and was last detected at the release location in March 1999.

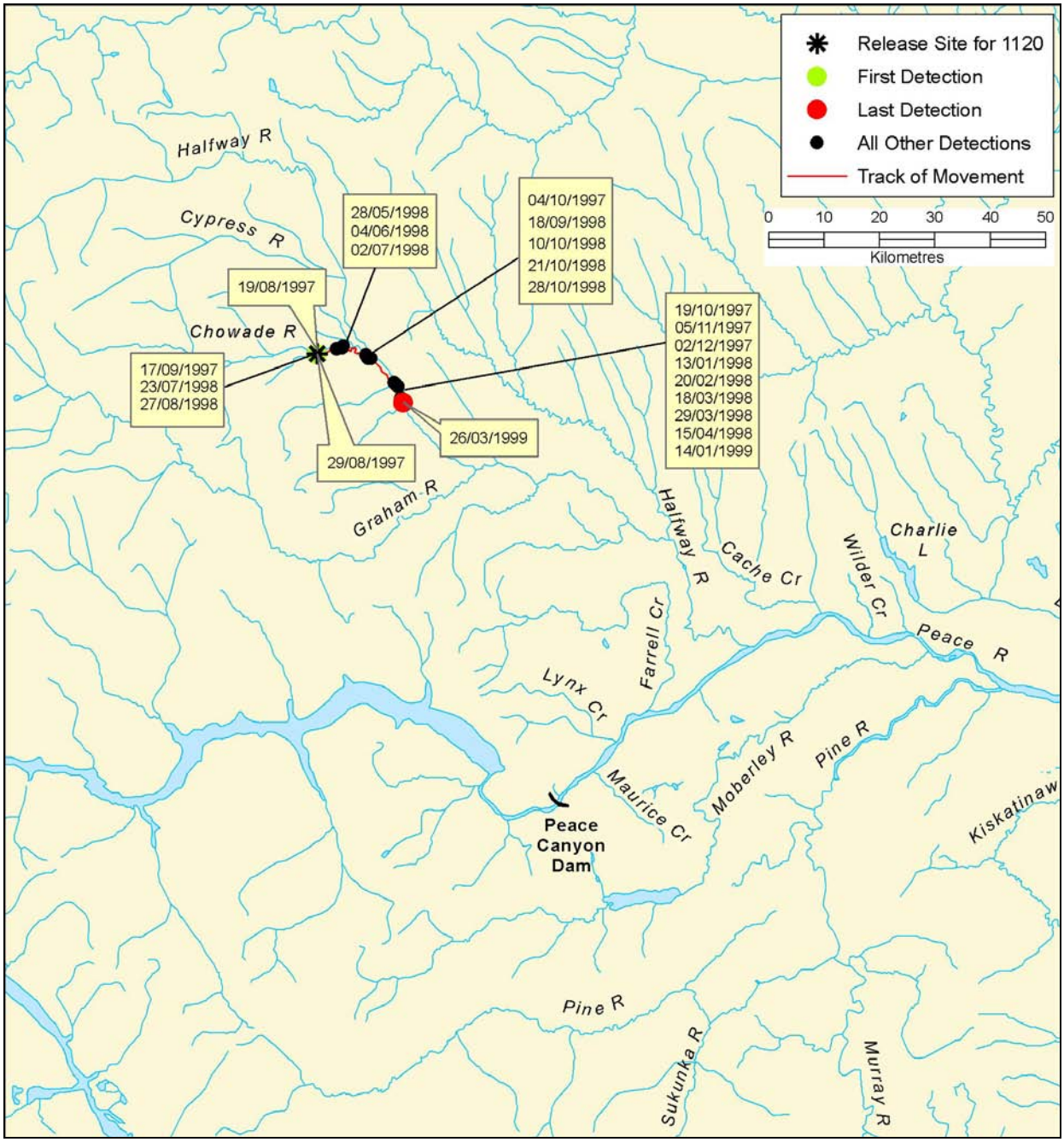

Figure 11: Individual track of minor movement by Arctic grayling (Fish 1120) in the Halfway River watershed; total distance tracked, 75 km.

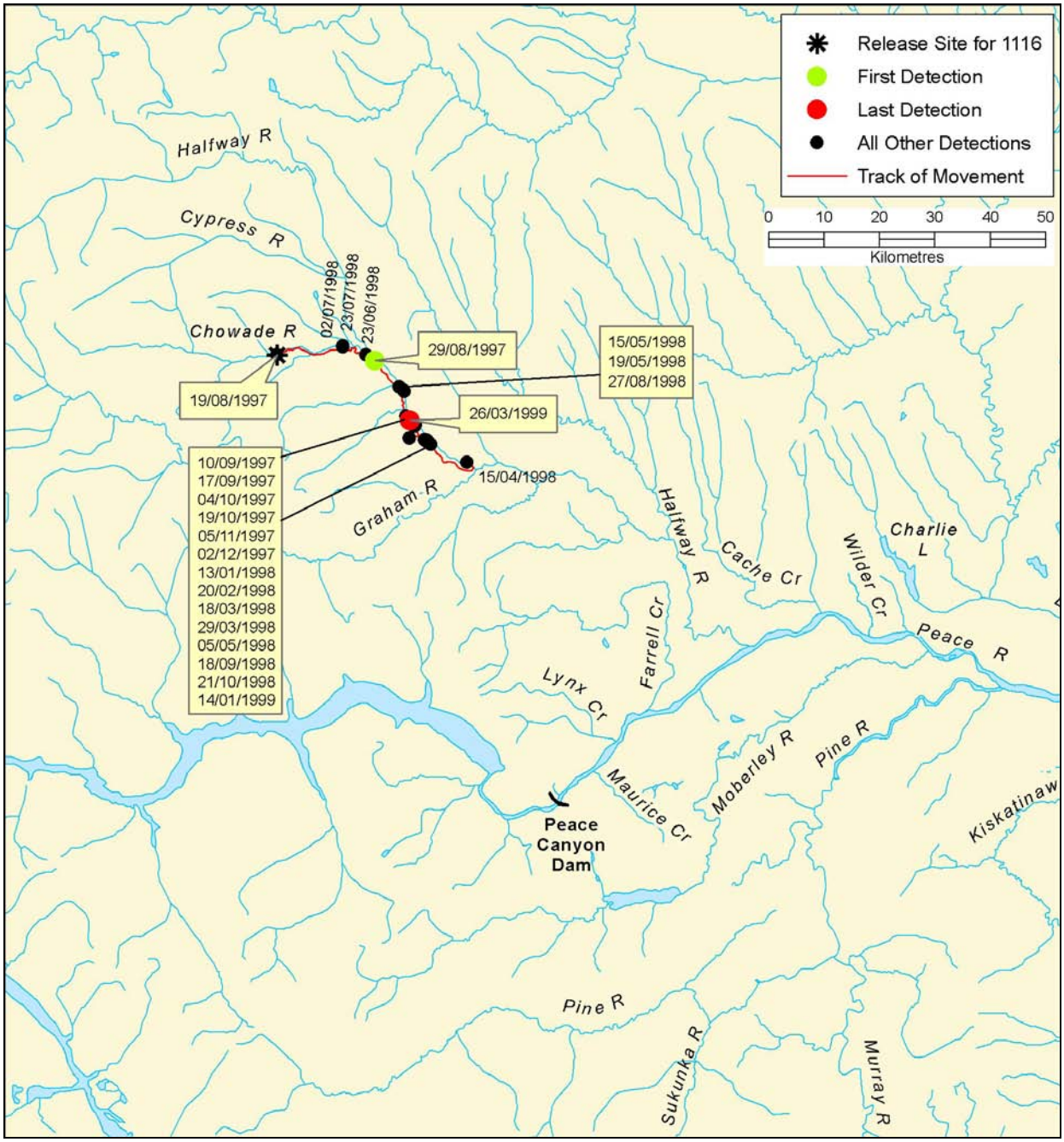

Figure 12: Individual track of moderate movement by Arctic grayling (Fish 1116) in the Halfway River watershed; total distance tracked, 135 km.

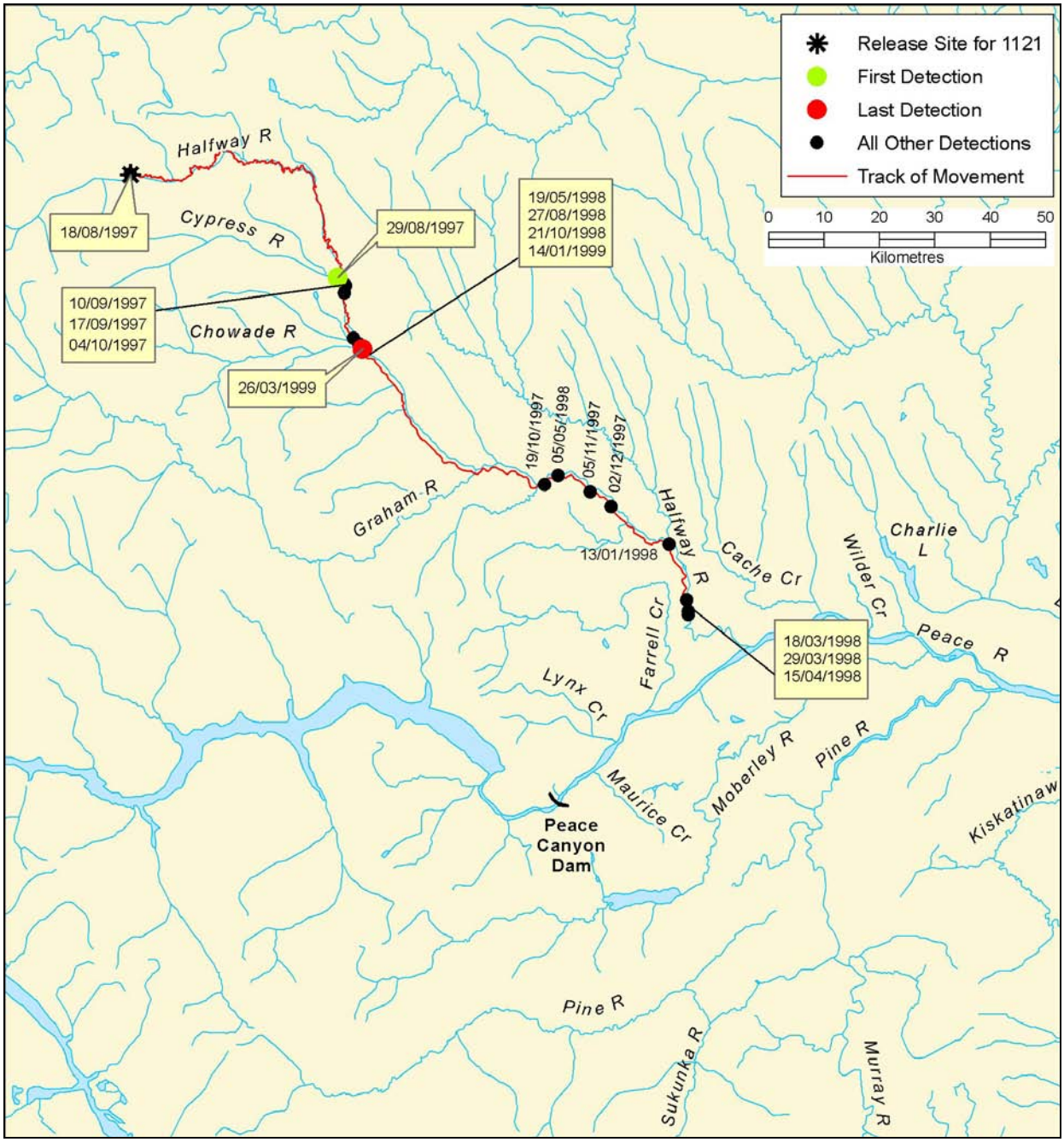

Figure 13: Individual track of extensive movement by Arctic grayling (Fish 1121) in the Halfway River watershed; total distance tracked, 299 km.

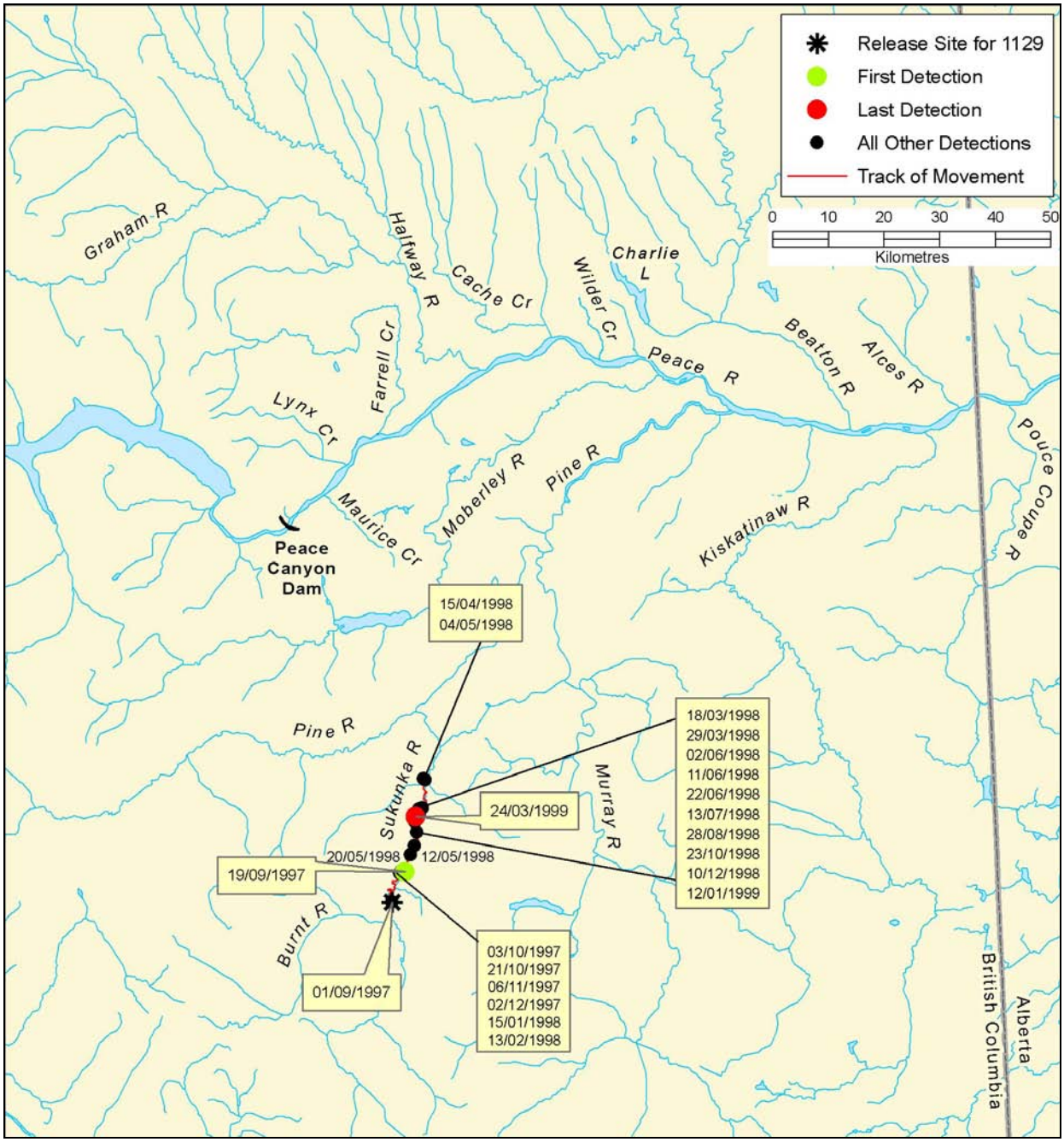

Figure 14: Individual track of an Arctic grayling (Fish 1129) that did not emigrate from the Sukunka River watershed; total distance tracked, 78 km.

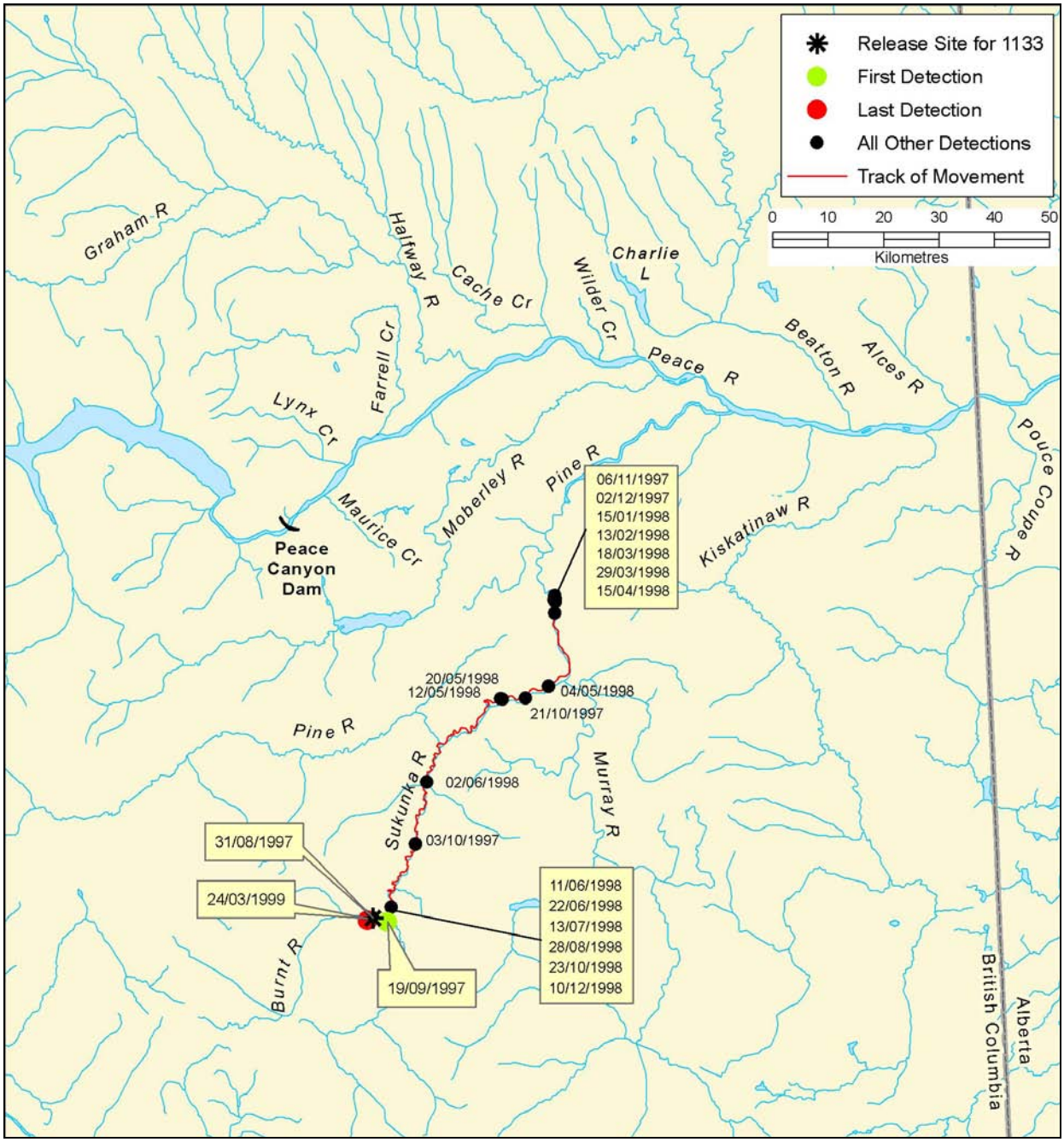

Figure 15: Individual track of an Arctic grayling (Fish 1133) that emigrated from the Sukunka River watershed, and returned; total distance tracked, 208 km.

3.2.1.4 Further Assessment of Bull Trout Movement

Bull trout tag detections were further assessed to summarize seasonal movements within and between watersheds of the Peace River system. For this investigation, the study area was divided into two divisions:

1) Halfway River drainage (including the Graham, Chowade, and Cypress drainages); and,

2) Peace River mainstem.

Figure 16 shows the relative proportions of bull trout that were detected in these two divisions, by month. Fish that were detected in more than one division during a given month were coded as 'moving' between divisions.

During surveys conducted in July-September, the majority of bull trout detected were in the Halfway River system (overall: 193 of 273 detections; monthly percentages ranged from 63-77%). In all other months, the majority of bull trout detections were in the Peace River mainstem (overall: 488 of 734 detections; monthly percentages ranged from 56-75%) Nevertheless, 36% (25 of 69 'active' tags[1]) of the bull trout that were released in the Halfway River drainage did not emigrate from that river, indicating that suitable overwintering sites exist. The other 44 (64%) bull trout that were released in the Halfway River drainage made at least one foray into the Peace River mainstem. Of these, 15 (34%) migrated downstream past the Moberly River confluence.

Two bull trout were tagged in the Peace River mainstem, and both moved into the Halfway for the summer. One fish, tagged in April 1997, moved into the Halfway River drainage from June to September 1997, and returned to the Peace in October. The other fish, tagged in April 1998 moved into the Halfway River drainage in May 1998, and was last detected in the Chowade in July 1998.

[1] The 69 'active' tags include the 74 that were released in the Halfway River watershed, less the 4 that were never detected, and the one that was recovered soon after release.

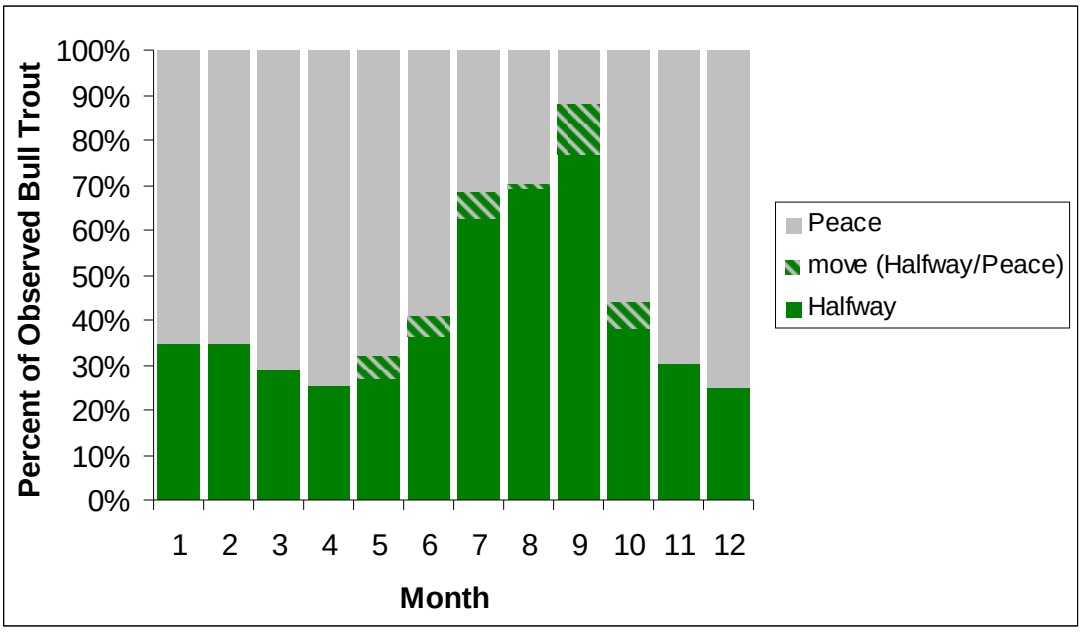

Figure 16: Seasonal pattern in the distribution of bull trout, 1996-1999.

3.2.1.5 Further Assessment of Arctic Grayling Movement

Arctic grayling tag detections were further assessed to summarize seasonal movements within and between watersheds of the Peace River system. For this investigation, the study area was divided into four divisions:

1) Halfway River drainage (subdivided into the mainstem, Graham, Chowade, and Cypress drainages);

2) Peace River mainstem;

3) Sukunka River; and,

4) Pine River.

Figure 17 shows the relative proportions of Arctic grayling that were released in the Sukunka River, that were detected in these four divisions, by month. The majority of the Arctic grayling never left the Sukunka River. However, from October to May, some grayling made forays into the Pine River, but in most cases, these fish returned to the Sukunka for the summer months.

Figure 18 shows the relative proportions of Arctic grayling that were released in the Halfway River drainage. Only one of these fish was detected outside of the drainage (one Arctic grayling released in the Graham River in 1997 was last detected in the Peace mainstem in January 1999). The majority of the Arctic grayling were located in the Halfway River mainstem, especially during the winter months. Detections in the Chowade and Graham rivers were largely restricted to the warmer months of the year.

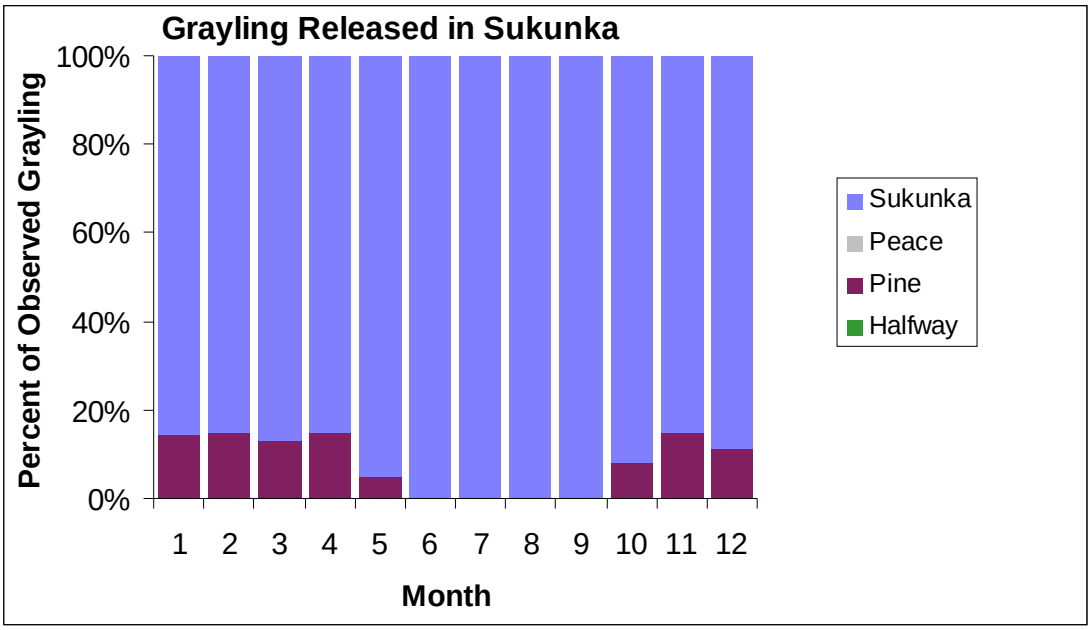

Figure 17: ***Seasonal pattern in the distribution of Arctic grayling that were released in the Sukunka River, 1996-1999.***

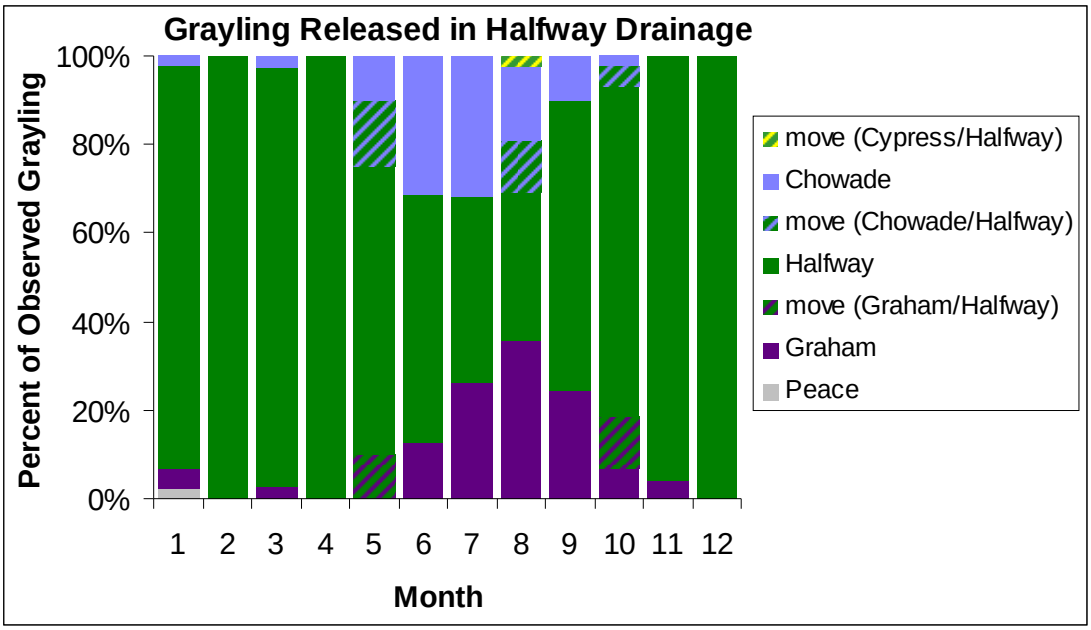

Figure 18: ***Seasonal pattern in the distribution of Arctic grayling that were released in the Halfway River drainage, 1996-1999.***

3.2.2 Magnitude, Direction and Seasonal Variability of Movement by Species

3.2.2.1 Displacement

There was no significant difference in the median displacement rates between bull trout (0 m/d) and Arctic grayling (-3.5 m/d) during the study period ($H_1 = 0.7$; $P = 0.4$); median displacement rate for bull trout was zero because, an equal number of bull trout had median displacement in the downstream direction as those in the upstream direction. Nevertheless, the relationships between displacement and time at large (shown in Figure 19) varied significantly between species (ANCOVA: species X time at large interaction $F_{1,2377} = 14.7$; $P = 0.0001$). A statistically significant positive slope was observed for bull trout, indicating a tendency for increased upstream displacement with increasing time at large. In contrast, a statistically significant negative slope was observed for Arctic grayling, showing a tendency for longer downstream displacements with increasing time at large.

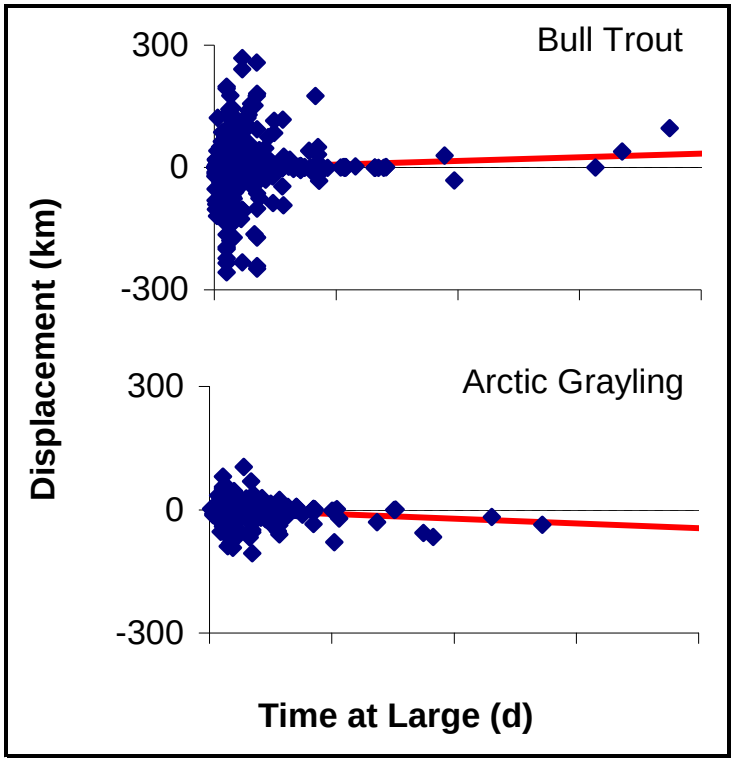

Figure 19: Displacements (km) as a function of time at large (d), by species. Slopes are shown with solid bold red lines. The solid horizontal lines show mean displacements (are close to zero).

For both species, median displacements showed significant variation among months (Figure 20; bull trout: $H_{11} = 71.0$; $P < 0.0001$; Arctic grayling: $H_{11} = 162.4$; $P < 0.0001$). For bull trout, there was a striking downstream displacement observed in September. Arctic grayling displacements showed a pattern in which upstream displacement was common in May-July; downstream displacements were more often observed from August to November.

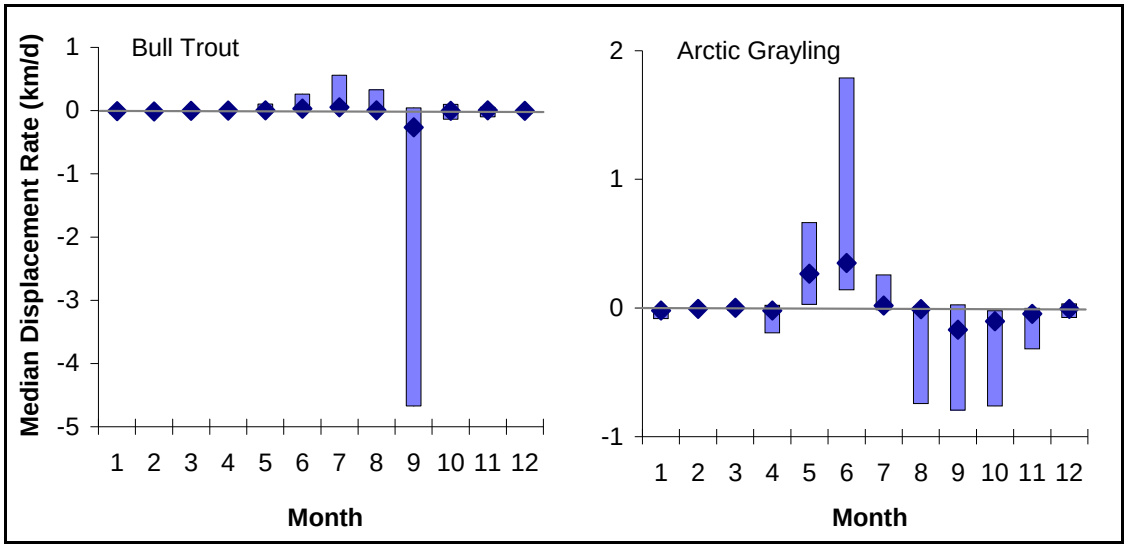

Figure 20: ***Distribution of observed median individual displacement rates (km/d) by species and month (to ensure that each individual is counted only once per month, all observations for a given individual within a given month were characterised using their median). Note the variable Y axes. Diamonds indicate medians, boxes enclose the 25th to 75th percentiles.***

3.2.2.2 Distances Moved

Over the duration of the study, bull trout were observed to move between 2 km and 1089 km. Arctic Grayling, which were not tagged until mid 1997, moved between 8 and 392 km between release and the end of the monitoring period.

For comparisons between species, analyses were restricted to movements observed after July 1997 (i.e., after all tagging was completed). During that period, distances moved varied between species, but the difference was not statistically significant (H_1 = 3.6; P = 0.06); bull trout moved longer distances (median 183 km) than Arctic grayling (median 111 km).

For bull trout, median distances moved by fish released in the Peace mainstem (193 km) did not differ significantly from those of bull trout released in the Halfway River drainage (183 km; H_1 = 0.3; P = 0.86; Figure 21). In contrast, Arctic grayling released in the Halfway River drainage moved significantly longer distances, on average (median 127 km), than those released in the Sukunka River (79 km; H_1 = 4.8; P = 0.03; Figure 21).

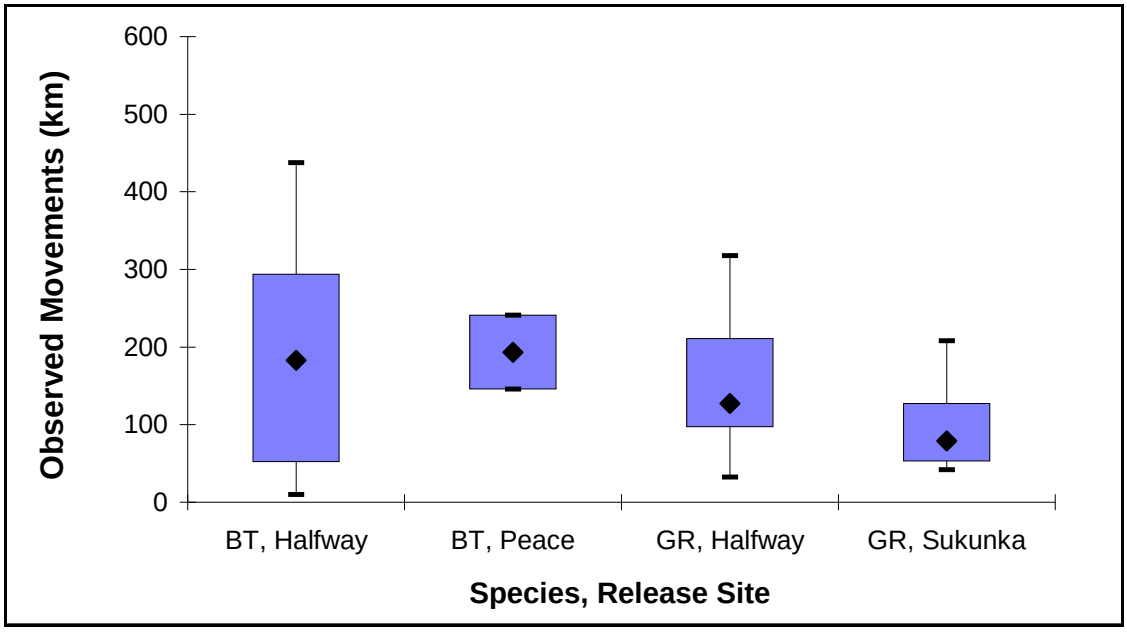

Figure 21: ***Distribution of observed movements (km) summed by species and release site. A total was calculated for each individual, and this figure shows the distribution of those totals. Diamonds indicate medians, boxes enclose the 25th to 75th percentiles, bars extend to the 10th and 90th percentiles.***

3.2.3 Magnitude and Seasonal Variability of Fish Movement Past Site C

The proportion of radio-tagged fish that passed Site C differed significantly between species (Figure 22; $H_1 = 11.5$; $P = 0.007$). In total, 15 bull trout and no Arctic grayling were known to pass the proposed Site C location. The 15 bull trout (21% of 71 active tags) moved past Site C a total of 29 times. Passage events were more common in spring (12 from March to May) and fall (11 from September to November), and less common in summer (4 from June to August) and winter (2 from December to February). In total, 18 bull trout passage events were in a downstream direction and 11 were in an upstream direction (Figure 23); seven bull trout presumably remained downstream of Site C.

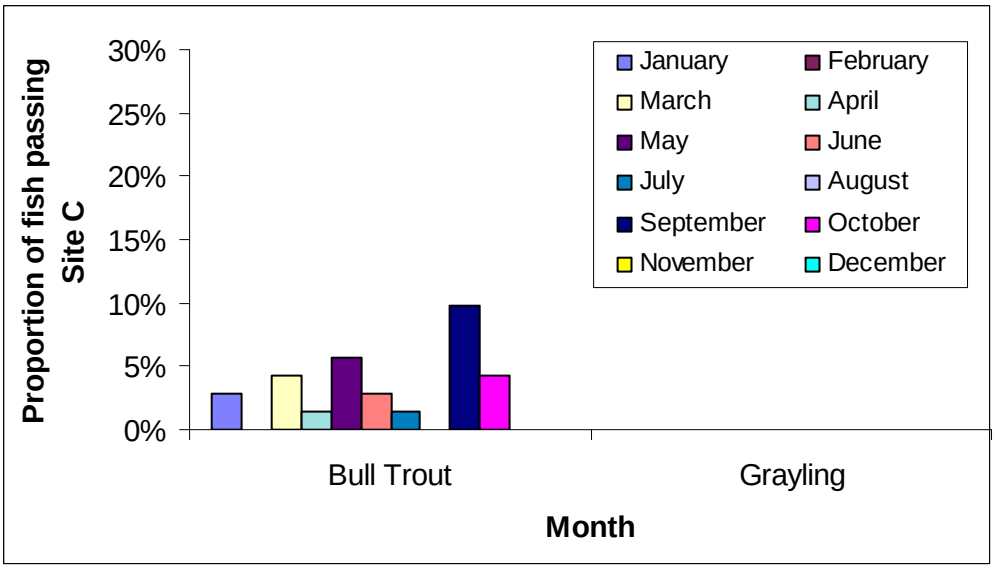

Figure 22: ***Proportion of radio-tagged fish that moved past Site C, by species and month.***

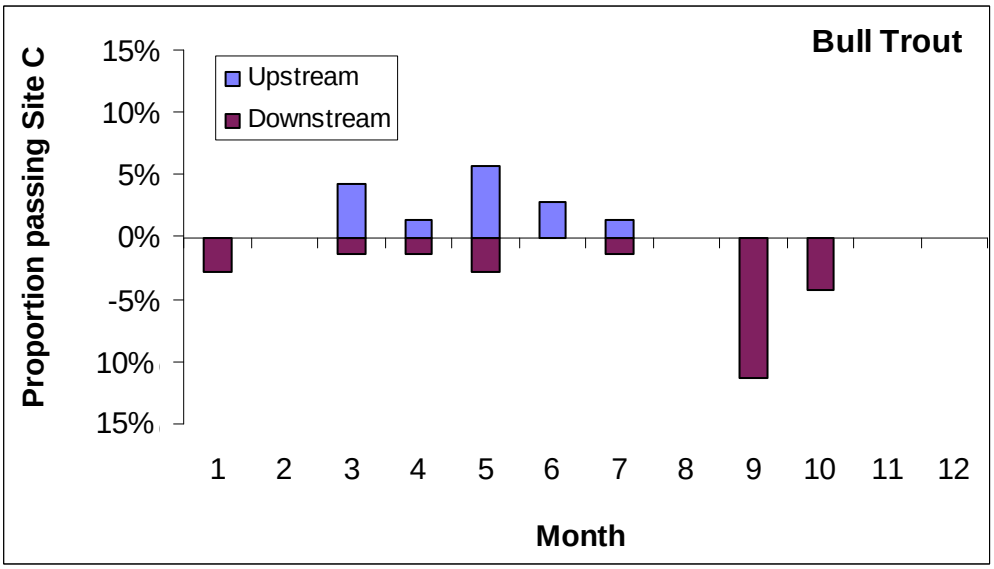

Figure 23: ***Proportion of radio-tagged bull trout that moved past Site C, by month, and by direction of movement.***

4.0 DISCUSSION

The objective of this study was to update the analysis, mapping, and reporting of the MOE 1996-1999 database on movements of adult bull trout and Arctic grayling based on radio-telemetry studies in the upper Peace River watershed. The results reported are now comparable with those of recent radio telemetry studies conducted by AMEC and LGL for BC Hydro, and provide more detailed information on the movements of these two species than previously reported (Burrows et al. 2001). The updated findings add significantly to our understanding of the movements of bull trout and Arctic grayling and provide valuable comparative information with recent AMEC and LGL studies on fish movements in the upper Peace River system. A brief discussion of the findings for each of these two species is given below. A more detailed integrated discussion of these findings with those from the overall results obtained during AMEC and LGL 2005-2009 tracking studies, as well as from studies by others, is included in our report on the findings of fish tracking in 2009.

4.1 Bull Trout

The updated findings provide supporting evidence that both resident and migratory bull trout occur in the Halfway River watershed. Of the bull trout released in the Halfway River, 36% (25 of 69) did not emigrate from the river during the duration of study and seven of them never left the spawning grounds (3, 1, 2 and 1 fish remained in Upper Halfway River, Graham River, Chowade River, and Cypress Creek, respectively), whereas 64% made at least one foray (probably to forage) into the Peace River mainstem. Of those 44 that exited the Halfway, 27 migrated upstream and 32 migrated downstream (adds to >44 fish because some did both) and 25 passed Site C (17 did not). Of the 44 fish that exited the Halfway during the period of study (1996-1999), 12 (27%) of these were later detected in tributaries of the Halfway River suggesting they were repeat spawners. The majority of bull trout were in the Halfway River watershed during July to September (probably to spawn), but in all other months they were proportionally more abundant in the Peace mainstem.

Movement of bull trout that exited the Halfway River occurred in both upstream and downstream directions from the confluence with the Peace River, extending upstream as far as Hudson's Hope and downstream to the vicinity of the BC/Alberta border. Bull trout may have moved farther downstream undetected. For the period that GPS automated flight path data were available (June 1998 to March 1999), none of the flights went beyond Sneddon Creek, Alberta; the same applies to flights prior to June 1998 (confirmed from examination of photocopies of manually recorded flight information for that period).

The abnormally high flows (~6000 m^3/s; some threefold higher than average) in the Peace River during July and August in 1996 due to a spill from the dams upstream, may have had some effect on bull trout movements and habitat use in the river. However, we have no way of assessing the potential effects as bull trout tagging did not begin until September 1996.

Overall, 21% of the tagged bull trout passed the potential Site C dam site, although more frequently when moving downstream than upstream (62% vs 38% of 29 crossings). Movement downstream occurred mostly in September (post-spawning period), whereas movement upstream was mostly in July and August (pre-spawning period). This timing of movement upstream parallels that reported by McPhail (2007) for bull trout pre-spawning migrations from larger mainstem rivers into smaller tributaries in late summer.

The overall distances moved varied greatly (2 to 1089 km) among the tagged fish, with the median distance being 242 km. Several large bull trout moved extensively between the Halfway River and Peace River mainstem, with three of them returning to where they were released in the upper Halfway tributaries, indicating homing; one particular individual (Fish 1004, a male, 680 mm FL, released in Cypress Creek), twice made the round trip from the headwaters of the Halfway to the Peace mainstem during the period of study. Immature bull trout (assumed to be <540 mm fork length) moved significantly less than mature fish ($X^2 = 11.7$, $P = 0.0006$).

4.2 Arctic Grayling

The updated findings support the notion by AMEC and LGL (2008 and 2009) that Arctic grayling in the headwaters of the Halfway and Pine rivers constitute resident fish populations. Almost exclusively, these fish did not exit into the Peace River mainstem, but remained in these large tributary systems year-round during the study period; fish from these resident Arctic grayling populations are not likely to pass the potential Site C dam location. During the period of study, only one of the fish released in the Halfway exited the river, and none of the fish released in the Sukunka exited the Pine River.

The overall distances moved by Arctic grayling in the Halfway River watershed varied considerably, comprising a mix of minor (<100 km), moderate (100-200 km), and extensive (>200 km) movers. In contrast, movements of Arctic grayling in the Sukunka watershed were generally minor (<100 km). A few fish moved between the Sukunka and Pine rivers; these movements were similar to the more extensive distances (>200 km) travelled by some of the Halfway fish. The median distance moved for Sukunka and Halfway fish was 79 km and 127 km, respectively.

Overall, displacement upstream by Arctic grayling occurred from May to July, whereas displacement downstream more commonly occurred from August to November. The timing of these movements may be related to spawning and post-spawning feeding forays, with fish moving from the mainstem upstream into small tributaries in spring to spawn and feed, and returning in late summer-autumn to overwinter. Similar timing of movements seasonally was observed for radio-tagged Arctic grayling moving between the Peace mainstem and Moberly River in 2006 and 2007 (AMEC & LGL 2008), presumably related to spawning, feeding, and overwintering stages.

5.0 CONCLUSIONS

From the overall findings of the updated analyses of the MOE 1996-1999 database, it is concluded that:

- Both resident and migratory bull trout occur in the Halfway River watershed. Of the bull trout released in the Halfway River system during the study period, 36% (25 of 69 'active' tags) did not exit the river, whereas 64% (44 fish) made at least one foray (probably to forage) into the Peace River mainstem. Their movement in the Peace mainstem extended upstream from the Halfway River confluence to the Peace Canyon Dam and downstream from the Halfway River confluence to the vicinity of the Alberta border.
- Arctic grayling in the headwaters of the Halfway and Pine rivers are most probably resident fish populations and unlikely to pass the potential Site C dam location. Of the fish released in these watersheds, only one fish exited the Halfway River during the period of study.

6.0 ACKNOWLEDGEMENTS

AMEC and LGL Ltd. would like to thank the following individuals for their contribution to this report:

Bruce Mattock, and Carol Lamont of BC Hydro, Generation Environment, are acknowledged for their support and valuable input during project initiation and study design.

Jeff Burrows, Ted Eucher and Nick Baccante of the BC Ministry of Environment designed and conducted the fieldwork for this study. Brendan Anderson and Gerry Leering provided us with the dataset for this report. Jeff Burrows provided us with copies of the notes recorded during the tracking sessions and helped us resolve various queries in the database.

Archived water discharge data from hydrometric stations in the Peace River and its tributaries were collected by Water Survey of Canada.

Data analyses were performed by: Gordon Glova, Dave Robichaud, Shawn Tyerman, Tony Mochizuki, and Rachel Keeler. Robin Tamasi and Lucia Ferriera of LGL provided GIS support.

This report was prepared by Gordon Glova, Dave Robichaud and Rachel Keeler. Carol Lavis of AMEC formatted and prepared the document.

7.0 CLOSURE

Recommendations presented herein are based on an evaluation of the findings of the fish and aquatic investigations described. If conditions other than those reported are noted during subsequent phases of the study, AMEC and/or LGL Ltd. should be notified and given the opportunity to review and revise the current recommendations, if necessary.

This report has been prepared for the exclusive use of BC Hydro for specific application to the area within this report. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. AMEC and LGL Ltd. accept no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. It has been prepared in accordance with generally accepted practices. No other warranty, expressed or implied, is made.

AMEC and LGL Ltd. appreciate the opportunity to assist BC Hydro with this project. If you have any questions, or require further assistance, please do not hesitate to contact the undersigned.

Respectfully submitted,

LGL Limited	**AMEC Earth & Environmental, a division of AMEC Americas Limited**
_____	_____
Gordon Glova, PhD, R.P.Bio.	Rachel Keeler, MSc, R.P.Bio.

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