


The Wet'suwet'en Fisheries

Bulkley/Morice River Steelhead Tagging Project at Moricetown Canyon

SUMMARY REPORT for 2010


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Executive Summary

Since 1999, the Moricetown Salmon Tagging Program has been conducted on the Bulkley River by the Wet'suwet'en Fisheries and Fisheries and Oceans Canada, with the inclusion of data collection for steelhead (*Oncorhynchus mykiss*) under assistance from the Ministry of Environment, Skeena Watershed Initiative, the Pacific Salmon Foundation, and the British Columbia Living Rivers Trust Fund. Since the initiation of this program, the annually collected steelhead data have gained value and importance as the sampling experience and program have developed. This mark and recapture project has involved sampling by beach seine for tag application immediately downstream of Moricetown Canyon (i.e. referred to as "campground") and re-sampling by dip net at the base of Moricetown Falls and fishway (i.e. referred to as "canyon"). In 2010, steelhead catch at both the campground (N=3510) and at the canyon (N=6323) reached record levels for the second consecutive year. Based on the recapture of 452 steelhead of the 2946 tags that were applied at the campground and the 6323 steelhead that were re-sampled at the canyon, the stratified abundance estimates for steelhead arriving at Moricetown were 33 047 (95% C.I. 29 599 – 36 495) using Maximum Likelihood Darroch (ML Darroch) and 37 851 using Schaeffer estimates, compared to 41 140 (95% C.I. 38 058 – 44 934) using the pooled Petersen estimate that has commonly been referred to for inter-annual comparisons of steelhead abundance in previous years. Although the ML Darroch estimate of 33 047 steelhead may have less bias than the pooled-Petersen estimate due to the heterogeneity of catchability identified among temporal strata in the 2010 data, it is also not as precise and may be an under-estimate. Excluding pooled-Petersen estimates for 1999 and 2000 which had few recaptures and poor accuracy (>50% error), the estimate of 41 140 steelhead arriving at Moricetown Canyon in 2010 is 50% greater than the next highest abundance recorded since 2001 (i.e. 27 484 in 2008).

Some manipulations of the pooled-Petersen estimates have been included to present the number of steelhead that actually migrated upstream of Moricetown Canyon as of the final date of sampling at the canyon in comparison to the estimate of steelhead that arrived at the campground. Based on the 2009 acoustic telemetry study estimating 34% of steelhead that arrived at the campground but did not migrate upstream of Moricetown Canyon while the dipnet fishery was operating (Welch et al. 2009 & 2010), a range of rates of fallback (i.e. 10%, 20% and 40%), have been used as examples of the range of adjustments suggested to estimate steelhead abundance upstream of Moricetown. The corrected pooled-Petersen estimates for steelhead migrating upstream of Moricetown are suspected to be 37 026 with 10% fallback, 32 912 with 20% fallback, and 24 684 with 40% fallback of steelhead that were tagged at the campground and predicted not to have migrated past the canyon as of October 22nd in 2010.

Overall, the Wet'suwet'en Tagging Program continues to improve year after year and will hopefully progress with the commitment that it has had, in conjunction with some additional, consistent, base funding from applicable funding sources. A number of suggestions for additions and modifications to the project design and methodologies have been presented to improve the precision of the results, better identify the biases of the different abundance methods, limit the effects of handling on steelhead condition, and to develop tools and understanding that will make in-season results useful. Development and acceptance of an abundance estimate model that incorporates temporal stratification and accounts for the temporal heterogeneity of catchability into an in-season estimator of steelhead abundance appears to be the key to future use of this data for in-season forecasts of annual returns of this mix of Bulkley and Morice steelhead in comparison to historical records or possibly other indices such as the Tyee Test Fishery Steelhead Index.

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Acknowledgements

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1.0 INTRODUCTION

The Moricetown Steelhead Tagging Project on the Bulkley River, conducted by the Wet'suwet'en Fisheries in conjunction with various contributions from Fisheries and Oceans Canada (FOC), the British Columbia Ministry of Environment (BCE), and the British Columbia Living Rivers Trust Fund (LRTF), was continued in 2010 for its 12th consecutive year. The Skeena Watershed Initiative Planning Committee (Pacific Salmon Foundation and BC Fisheries) has reviewed the project and administered funds from the LRTF for SKR Consultants Ltd. to provide field monitoring, weekly updates on the status of steelhead abundance throughout the field portion of the study, and a technical report summarizing the 2010 steelhead tagging results. The summary report of the 2010 results includes:

- summaries of field monitoring activities, quality assurance and corrections of the 2010 data that was entered by the Wet'suwet'en Fisheries office prior to analysis,
- intra and inter-annual comparisons of cumulative steelhead catch by beach seine and dip net sampling methods,
- a review of temporal stratification from tag application immediately downstream of the canyon (i.e. beach seine) to catch at the canyon falls and fishway (i.e. canyon),
- presentation of the 2010 steelhead abundance estimates, and
- discussion and recommendations for modifications to past methodologies with regard to potential improvements to fish handling, study design and abundance estimates.

2.0 METHODS

Sampling methods for the Moricetown Steelhead Tagging Project were consistent with previous years' methodologies, and included beach seine sampling at two sites (i.e. "campground" or sites 1 and 2, *see* Figure 1) located immediately downstream of the Moricetown Canyon, and dip net sampling approximately 450 metres upstream at the base of Moricetown Falls, almost exclusively on river left from the fish-way entrance to the falls (i.e. "canyon" or site 3, *see* Figure 1). Steelhead were marked using a combination of anchor tags and lower and upper caudal punches for the downstream and upstream locations, respectively. The caudal punches were applied to assess tag loss. The sampling in 2010 was conducted from Monday to Friday each week (i.e. weekdays), excluding statutory holidays, with no additional efforts on weekends, which has occurred in some previous years when applied tag numbers were lower. Sampling efforts at both the campground and the canyon were reduced to one crew for the final 5 weeks in 2010, and no sampling was conducted at either location on September 26th or 27th due to high flow conditions. For steelhead abundance estimates of the mix of Bulkley and Morice river steelhead arriving at Moricetown, the canyon (i.e. site 3) near the base of the Moricetown Falls has been considered to be the re-sampling site for the steelhead tagged downstream of the Moricetown canyon at the campground (i.e. sites 1 and 2).

At the campground, beach seine crews consisted of five individuals, with the two crews sharing the hours from sunrise to sunset on weekdays up to September 17th, and then working as a single mixed crew from 0900 hours to 1700 hours on weekdays up to October 15th in 2010. A trail leading from the campground to the beach was used to access the beach seine area on foot. A boat launch located downstream of the campground was utilized to access the beach seine area by boat. The beach seine was set at the campground side on most days (river right), and a beach on the island was used on some days as water levels changed the efficiency of each capture location. A 90 metre long by 8 metre deep net with a 5 cm (2") diagonal mesh size was used for beach seining purposes. The upstream side of the net was tied off to shore, and the net was spread out in a semicircle along the shore by jet boat, and pulled into shore. The net was pulled into shore manually, ensuring that the lead and float lines did not tangle. Captured fish were identified to species. Steelhead, coho, chinook and sockeye were measured (fork length), checked for tags (anchor tags, fin clips or punches), and their condition and gender was recorded. Individually numbered tags were applied to the left base of the caudal fin and a lower caudal punch was also applied. Tag colour and number were recorded for all fish with tag applied or recaptured. The beach seine location was allowed to rest for a minimum of 15 minutes between consecutive sets. The daily number of successful beach seine sets varied, and depended on several factors including day length, weather conditions, number of fish caught (i.e. handling time), mending requirements, and potential twisting, tangling or snagging during individual sets.

For re-sampling at the canyon (i.e. site 3, Figure 1), two dip-net crews split the hours on weekdays from sunrise to sunset up to September 17th, and then worked as a single mixed crew from 0900 hours to 1700 hours on weekdays up to October 22nd in 2010. Canyon crews consisted of five individuals, including two fishermen, a runner, a tagger and a recorder. Fish were captured by dip-netting in the canyon, and were transported to a tagging trough for processing. Fish were identified to species, measured (nose-fork length), sexed and examined for marks (anchor tags, fin clips and punches) and condition. Captured steelhead, coho and sockeye were anchor tagged and upper caudal punched. Chinook were either harvested or released untagged. Caudal punch, tag colour and number and condition were recorded for all fish with tags applied or recaptured. Daily dip netting effort varied, and was affected by several factors, such as day length, weather and flow conditions, number of fish caught (i.e. handling time), and mending requirements.

Photo from Google Earth 2009

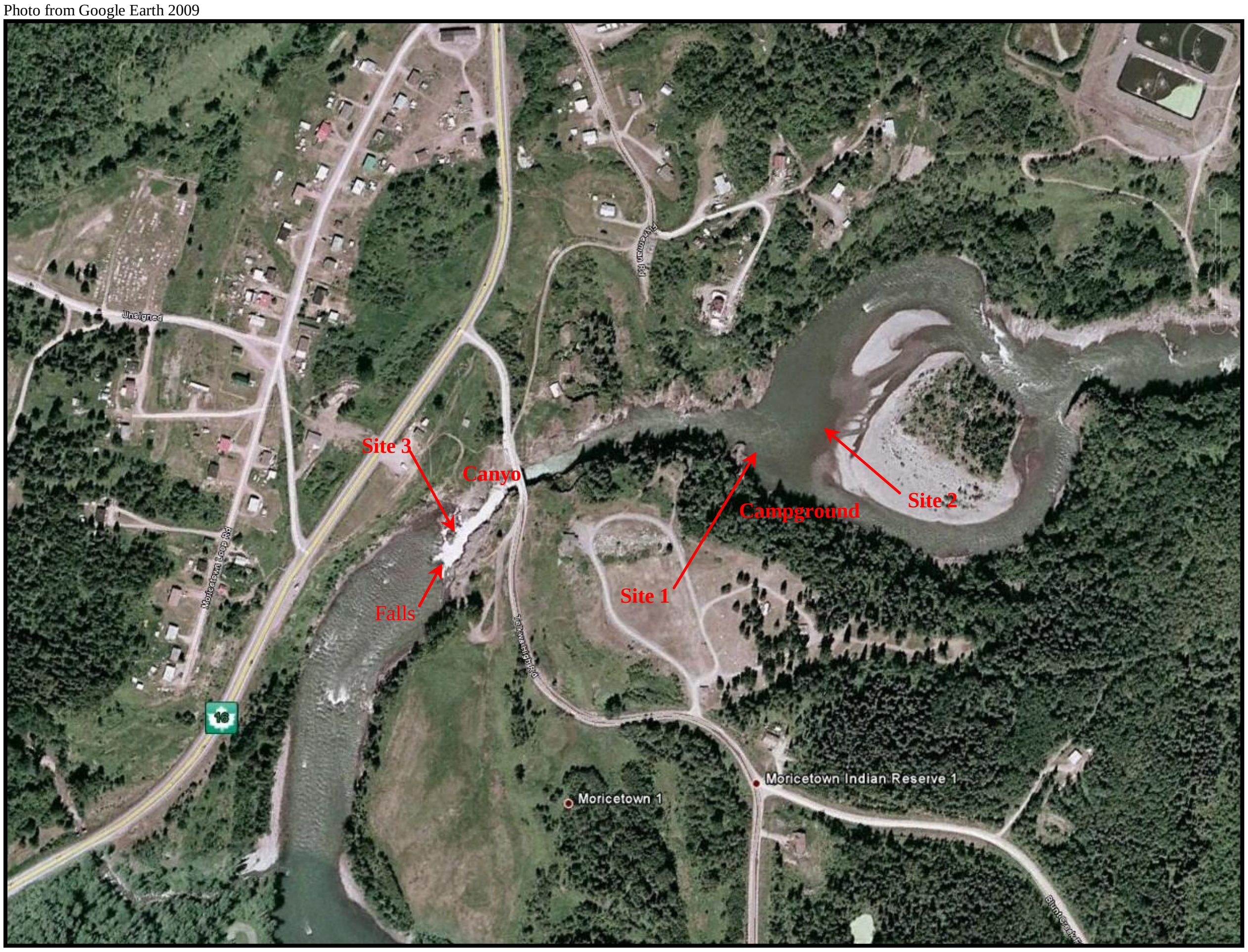


Figure 1. Aerial Photograph of Campground (Site 1) Campground/Island (Site 2) Beach Seine locations and the Canyon Dip Net location (Site 3) on the Bulkley River in Moricetown, B.C. .

2.1 DATA COLLECTION

Field data forms for dip net and beach seining activities were submitted daily throughout the field season to the Wet'suwet'en Fisheries office in Moricetown, B.C. and copies of the submitted steelhead data were obtained weekly by SKR Consultants Ltd for quality assurance and weekly updates of the status of steelhead abundance. Wet'suwet'en Fisheries staff entered all data collected into a Microsoft Access data entry tool designed by Walter Joseph (Wet'suwet'en Fisheries), and modified by SKR Consultants Ltd.. Newly marked fish and recaptured fish were differentiated in the database. "Applied tag" was the tag status entered for all newly tagged fish; "recaptured" was the tag status entered for recaptured fish. Recaptured fish that had lost their tag, as identified by the presence of a caudal punch, were identified in the database with "lost" entered as the tag status. Individual records also requested date, time, harvested (yes/no), tag number and tag colour applied or recaptured, sex (male, female or unknown), fork length (cm), adipose clip present (yes/no), caudal punch (top/bottom), and comments. For 2010, detailed check boxes for fish condition were added to the field forms and database including: scale loss, net marks, torn tail, torn fins, bleeding gills, bite marks, cysts, fungus, and sea lice.

2.2 Quality Assurance

Field support and quality assurance visits were conducted weekly from August 15th to October 22nd in 2010. Field visits were conducted to assess on site data record keeping, fish handling techniques, species identification, sampling effort, and to deliver necessary supplies for steelhead tagging. In conjunction with field visits, copies of all field data forms from the previous week were collected and assessed for common errors or missing information. Data entry checks based on detailed comparisons of every field data form to the entered steelhead data were conducted and all corrections were noted on hard copies and corrected in the database provided on January 18th by the Wet'suwet'en Fisheries office prior to data analysis for the summary report.

2.3 Steelhead Abundance Assessments

The experimental design for the Moricetown salmon tagging project was originally intended to be used for mark-recapture estimates of Pacific salmon at their spawning locations, but little data for steelhead abundance upstream of Moricetown Canyon has been collected. In an attempt to acquire annual estimates of steelhead abundance at Moricetown Canyon, three methods for mark-recapture estimates have been attempted (i.e. *pooled Petersen*, *Schaefer*, and the *Maximum Likelihood Darroch*) based on tag application at the campground in conjunction with re-sampling at the canyon (i.e. the base of the Moricetown Falls and fishways). Since the initiation of annual data analysis for steelhead returns to Moricetown canyon, estimates of steelhead abundance have been most commonly derived using a pooled Petersen estimate (Ricker 1975, Krebs 1999) with 95% confidence intervals (CI) derived from poisson or normal approximations (i.e. <50 and >49 recaptures, respectively) for each year (Krebs 1982):

$$N = \frac{(M+1)(C+1)}{(R+1)} - 1$$

$$CI_{lower} = \frac{M}{\frac{R}{C} + \left\{1.96\left[\sqrt{\frac{(1-R/M)(R/C)(1-R/C)}{(C-1)}}\right] + \frac{1}{2C}\right\}}$$

$$CI_{upper} = \frac{M}{\frac{R}{C} - \left\{1.96\left[\sqrt{\frac{(1-R/M)(R/C)(1-R/C)}{(C-1)}}\right] + \frac{1}{2C}\right\}}$$

Where: N = Petersen estimate at time of last marking
M = Number of individuals marked below canyon by beach seine
C = Total captured at canyon by dip net
R = Total recaptures at canyon by dip net

The Stratified Population Assessment System (SPAS, Arnason *et al.*, 1996) has recently been applied using data collected since 2004 in an attempt to account for the open population and temporal stratification attributes of this sampling design. SPAS provides Schaeffer estimates (Ricker1975) for comparison to Petersen estimates. Maximum Likelihood Darroch (ML Darroch) estimates have also been added in further attempts to account for heterogeneity of catch in different temporal strata and to provide confidence intervals for some interpretation of accuracy and comparison to Petersen estimates of the same year. Temporal Strata for Schaeffer and ML Darroch estimates using the 2010 mark-recapture steelhead data were based on 7 day units starting with July 19th to 25th (week 1) to October 18th to 24th (week 14) and applied tags were corrected for 2.5% tag loss that was estimated based on the number of lost tag recaptures at the canyon that had lower caudal punches (i.e. secondary markings from the campground).

3.0 RESULTS AND DISCUSSION

For the 2010 Moricetown salmon and steelhead mark-recapture program, tag application was conducted from July 9th to October 15th at the campground, and re-sampling and additional tag application was conducted at the canyon from July 9th to October 22nd. In 2010, notably higher numbers of steelhead were tagged at the campground (2933 applied or recaptures from previous years) and re-sampled at the canyon (6323) in comparison to all previous records, when the numbers of tags applied were less than half of the 2010 numbers at both locations. Summaries with discussion regarding the results of the present sampling methods, the cumulative steelhead catch at the campground using beach seining and at canyon using dip nets, and the available options for abundance estimates are provided in the following sections.

3.1 SAMPLING METHODS

The sampling methodologies for the Moricetown salmon and steelhead tagging program had only minor modifications in 2010 from the methods used in 2009 (*see* SKR 2010). Based only on observations during weekly site visits, there appeared to be more selection for steelhead suitable beach seine settings at the campground due to flow conditions, experience and species selection, and more systematic and sequential dip net sampling at the canyon. Overall, sampling conditions were suitable for sampling methods except for approximately one week of apparently reduced catch efficiency at both the campground and canyon locations due to the flood event on the Bulkley River that occurred on September 25th. The following sections include:

- a summary of the field monitoring and data quality assurance,
- a comparisons of fork lengths to assess a potential bias in abundance estimates as a result of using different sampling methods at the tag application and re-sampling locations, and
- a summary of data related to the condition of steelhead when sampled using the two sampling methodologies.

3.1.1 Quality Assurance

During weekly site visits from August 15th to October 22nd in 2010, field crews were always on site and sampling efforts were consistent with the prescribed methodologies. Data was well kept by all crews with few errors on days when visited. Due to shortages of available tags, the distribution of steelhead tags was not well organized and duplicate tag numbers with the same colour were accidentally used for approximately 200 tags applied at the canyon in 2010. Field crews were diligent toward recording fish condition during site visits, but all condition check boxes appeared blank on some field data forms for a few of the days without field monitoring which may create some bias for future assessments and comparisons for improvements of fish sampling techniques.

A very thorough review was conducted for the data entry, with comparison of all data on every steelhead field form in conjunction with corrections to mistakenly entered data. The main error identified was the occurrence of mistakenly labelled check boxes for condition that resulted in a multitude of errors. Some minor but common errors include misplaced data (e.g. fork lengths in gender fields), incorrect dates entered, duplicates of data, and approximately 100 of 9872 records not entered. The approximately 200 duplicate numbers with the same colour were used to tag steelhead in 2010 and required a comparison of recaptured fork lengths to applied fork lengths to allow a conversion of applied tag colours to "pink" and "pink2" in the database. Overall, data entry validation was manageable for 2010, and appeared very good following corrections to all the identified errors.

3.1.2 Steelhead Fork Lengths at Different Sampling Locations

The two different sampling methodologies used for tag application and re-sampling (i.e. beach seine versus dip net) and the occurrence of sampling at two different locations with different habitat characteristics (i.e. slow versus high velocity river flow) has been hypothesized to bias the mark recapture abundance estimate due to potential size selectivity. Based on the 2010 results (Table 1), steelhead size comparisons identified a significant difference between mean fork lengths recorded at the canyon (N= 5242 steelhead with tags applied) and at the campground (N=2886 steelhead with tags applied) based on a non-parametric analysis (K-S Test = 0.151, $p < 0.001$). A non-parametric analysis was used due to the presence of multiple age classes creating a multi-modal distribution in steelhead fork lengths (*see* Figure 2). The mean fork lengths between steelhead tagged at the campground (*mean* =66.6 cm) is lower compared to steelhead sampled at the canyon (i.e. excluding all recaptures, *mean* = 69.2 cm) or recaptures of campground tagged steelhead (*mean* = 67.1 cm) at the canyon (Figure 2). The distributions of fork lengths of tagged (campground), re-sampled (canyon) and recaptured steelhead appear similar in shape. The broader range of fork lengths sampled at the canyon (i.e. 36 – 105 cm) encompasses the entire suspected range of steelhead in the Bulkley River and the range of tags applied at the campground were distributed within 99% of this range. In addition, the lack of differences in skewness and kurtosis between the two sampling methods (*see* Figure 2), even among the evident steelhead age classes, suggests that the identified size differences between the two sampling methodologies are simply associated to the different conditions and measuring apparatus used at the two locations. Despite the difference in mean fork lengths obtained at the canyon and campground sampling sites, the results obtained from the large samples obtained in 2010 suggest that the Moricetown mark recapture program has incorporated all of the different size/age classes of steelhead for the abundance estimate.

Further analysis of the differences identified between fork lengths recorded for application and recaptures from both the canyon and campground locations are presented in Figure 3 to evaluate the differences in steelhead fork lengths recorded at the canyon and campground locations. Interestingly, the fork lengths recorded for recaptures at the canyon of tags applied at the campground and recaptures at the campground of tags that were applied at the canyon had mean differences of 1.58 cm (N=451) and -1.68 cm (N=295), respectively. This difference in measurements further supports that the re-sampling of steelhead at the canyon better incorporates the size range of steelhead that were tagged at the campground than appears in figure 2 since the offset of tags applied at the campground (i.e. green bars) should likely be shifted to the right due to inaccuracies of the measurement apparatus. In addition, the tighter (i.e. platykurtic) distribution of the differences of fork lengths for steelhead tagged and recaptured at the campground compared to other comparisons where either or both measurements were taken at the canyon (Figure 3) clearly indicates better precision for fork length measurements at the campground than at the canyon in 2010.

Table 1. Summary of fork lengths of steelhead sampled or recaptured at the canyon and campground sites in 2010.

Sample Location	*Canyon*	*Canyon*	*Canyon*	*Campground*	*Campground*	*Campground*
Tag Origin of Recapture	*Canyon*		*Campground*	*Canyon*	*Campground*	
Sample Size	334	5242	449	296	262	2886
Minimum	44	36	45	48.5	48.5	42
Maximum	84	105	87	93	90	98
Range	40	69	42	44.5	41.5	56
Median	68	68	68.5	69	70.75	70.5
Mean	**66.62**	**66.99**	**67.12**	**68.28**	**69.17**	**69.21**
95% CI Upper	67.46	67.22	67.91	69.16	70.17	69.51
95% CI Lower	65.79	66.75	66.33	67.40	68.17	68.92

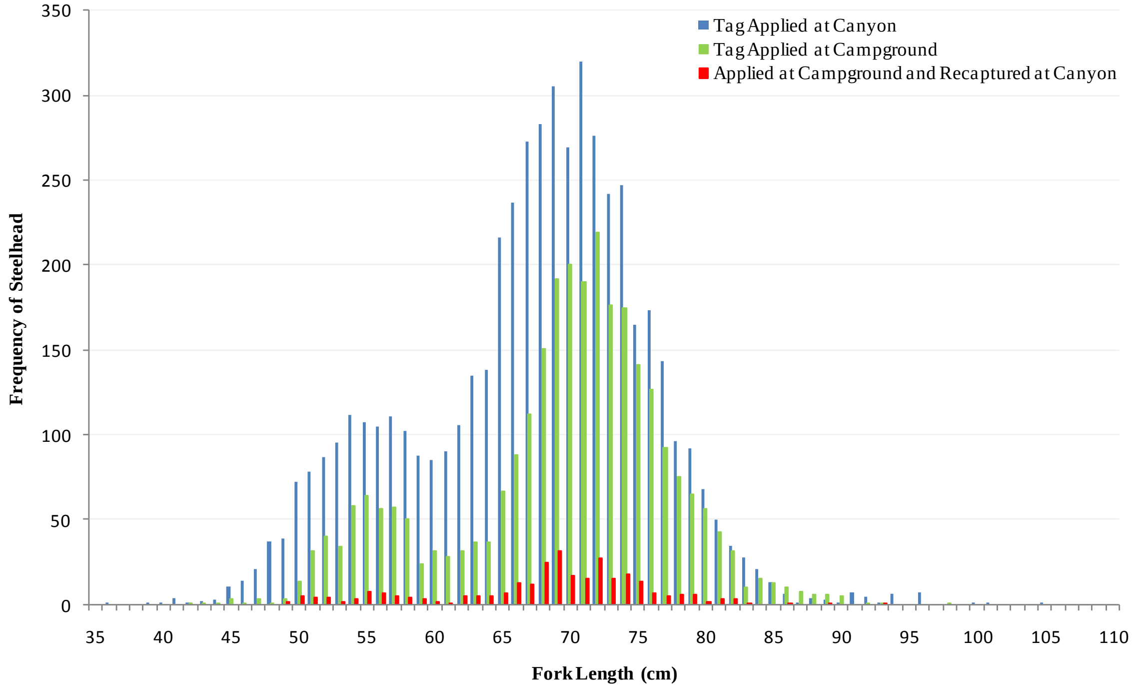


Figure 2. Histogram displaying distributions of fork lengths recorded for steelhead tagged at the campground, tagged at the canyon, and recaptures at the canyon of steelhead tagged at the campground.

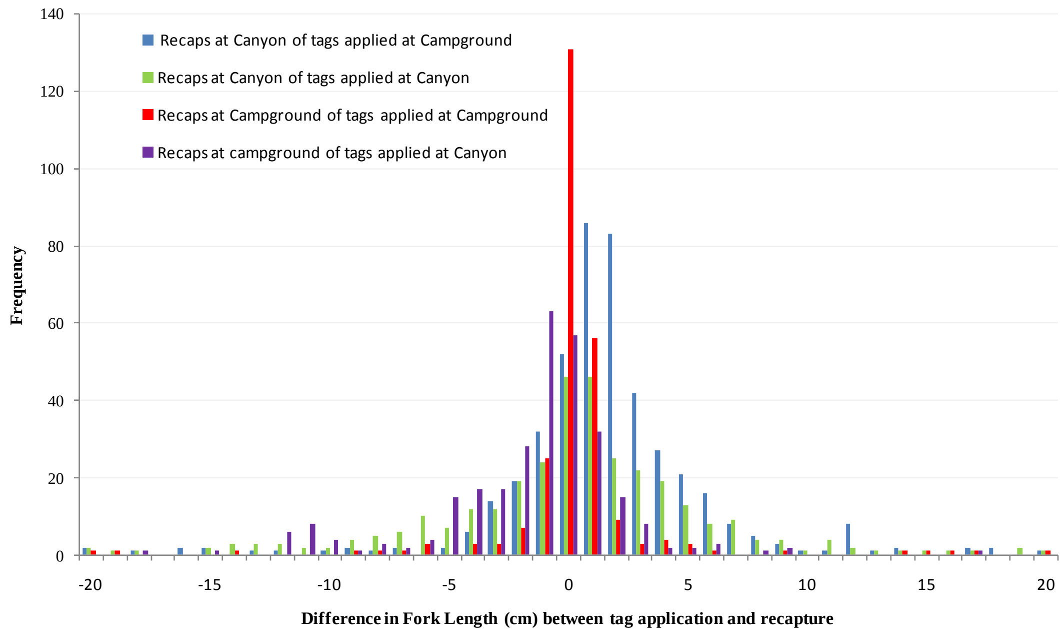


Figure 3. Histogram displaying differences between steelhead fork lengths recorded at tag application and recapture locations.

3.1.3 Fish Condition

The field assessment of fish condition during handling times, and the incorporation of true or false check boxes for specific fish health criteria on the field data forms and in the database has provided some useful results for the general health of steelhead handled at Moricetown in 2010 to evaluate the observable effects of beach seine and dip net sampling methods on fish condition. Fish condition criteria recorded in 2010 can be grouped into two broad categories: "natural condition criteria" (e.g. bite marks, cysts, fungus, lice; table 2) and "condition criteria related to fish handling" (scale loss, net marks, bleeding gills, torn tail, torn fin; table 3) though some criteria could fall into both categories (e.g. fungus, scale loss). Although no alarming rates of natural causes of degradation in steelhead health were observed in 2010, notably higher proportions of steelhead with cysts and fungus and notably fewer steelhead with bite marks and sea lice were observed at the campground than at the canyon (Table 2). Hypothetically, it is possible that seal bite marks may be associated with faster migration of steelhead from the coast and a potential bypass of the campground holding area; thus a higher occurrence of seal bites at the canyon. Conversely, cysts and fungus infections may result in slower migration of steelhead from the coast with fish searching out slower moving water; thus a higher occurrence of cysts and fungus at the beach seine. Some useful results related to the impacts of beach seining and dip netting on steelhead health were identified in 2010 (Table 3). Scale loss, believed to be primarily from sampling activities at Moricetown, was observed to be very common among steelhead sampled at both locations, but were more frequently reported for fish sampled at the campground by beach seine than at the canyon by dip net (Table 3). Net marks, which include marks received from gill nets prior to sampling at Moricetown, were observed to be higher at the dip net than the beach seine sampling, implying that additional net marks are due to the dip net sampling technique (Table 3). Not unexpectedly, dip net sampling also identified a relatively high incidence of fin damage for steelhead sampled at the canyon (Table 3). The well documented effects of the different sampling methods used in this mark-recapture study should provide the support to emphasize the need to consider further modifications of the sampling methods and continued collections of this data to document, monitor, and help minimize the impact of this study on steelhead health.

Table 2. Natural condition factors related to the health of steelhead at Moricetown Canyon in 2010.

Tag Status	Reacapture Location	Tagging Location	Sample Size	Bite Marks	Cyst	Fungus	Sea Lice
Applied		Campground	2887	0.3% (9)	3% (88)	0.3% (10)	0.2% (5)
Recaptured	Canyon	Campground	449	0% (0)	2.9% (13)	0.2% (1)	0% (0)
Recaptured	Campground	Campground	263	0.4% (1)	3% (8)	0.4% (1)	0% (0)
Applied		Canyon	5247	0.2% (13)	0.6% (30)	0.1% (3)	0.4% (23)
Recaptured	Canyon	Canyon	334	0.9% (3)	1.2% (4)	0% (0)	0.6% (2)
Recaptured	Campground	Canyon	296	0.3% (1)	0.7% (2)	0% (0)	0.3% (1)

Table 3. Steelhead condition factors related to fish handling during the tagging program conducted at Moricetown Canyon in 2010.

Tag Status	Reacapture Location	Tagging Location	Sample Size	Scale Loss	Net Marks	Bleeding Gill	Torn Tail	Torn Fin
Applied		Campground	2887	45.6% (1317)	8.9% (258)	0.4% (11)	2.2% (64)	0.7% (21)
Recaptured	Canyon	Campground	449	47% (211)	8.5% (38)	0% (0)	1.6% (7)	1.6% (7)
Recaptured	Campground	Campground	263	44.9% (118)	8.7% (23)	0% (0)	3% (8)	0.8% (2)
Applied		Canyon	5247	39.4% (2068)	25.7% (1349)	1.1% (60)	22% (1155)	9.4% (495)
Recaptured	Canyon	Canyon	334	38% (127)	25.7% (86)	0.6% (2)	24.9% (83)	9% (30)
Recaptured	Campground	Canyon	296	40.2% (119)	23.6% (70)	0% (0)	22.3% (66)	10.1% (30)

3.2 CUMULATIVE STEELHEAD CATCH

Indices of cumulative catch for estimating steelhead abundance have not been derived for the Moricetown sampling locations due to difficulties determining a suitable unit of effort (i.e. steelhead per net section, sets per day, dip netting efforts could not be derived) and incorporating appropriate corrections for setting locations (e.g. difficulties with a species selective fishery), influences of different densities of other species on efficiency, variable net lengths (e.g. variable net length tied on shore), and significant effects of flow conditions. This variability is demonstrated by the large range in overall annual catch over the 12 years of the study (Table 4). The total catch of steelhead at the campground in 2010 was 3510, in comparison to totals ranging from 164 to 1316 steelhead in previous years (Table 4). The total catch of steelhead at the canyon of 6323 in 2010 was also very high, in comparison to totals ranging from only 1010 to 2263 steelhead in previous years (Table 4). Although the ranking of the total catch at both the tag application and re-sample locations are similar, the inter-annual variability of cumulative catch does not appear to be relative to abundance since differences in annual cumulative catch at either site are not proportionate to each other (e.g. beach seine catch suggests abundance in 2003 to be 50% of abundance in 2009, while dip net suggests 80%). In addition, the lack of continuous sampling (i.e. 7 days per week), the occurrence of inconsistent sampling effort among years (e.g. sampling on occasional weekends), and the different end dates of sampling for each year further complicate inter-annual comparisons of the cumulative catch.

Based on the catch results from 1999 to 2010, inter-annual variability of catch efficiency, the timing of steelhead migration, and the delay of steelhead migration at Moricetown are summarized in the following sections.

Table 4. Steelhead sampled at the beach seine sites and dip net site during the steelhead tagging program conducted at Moricetown Canyon from 1999 to 2009.

	Campground Sites Tag Application[1]			Canyon Site Resampling		
Year	**# of steelhead**	**Ranking**	**% of Highest (i.e. 2010)**	**# of steelhead**	**Ranking**	**% of Highest (i.e. 2010)**
1999	164	12th	5.6%	1555	9th	24.6%
2000	225	10th	7.6%	1010	12th	16.0%
2001	322	8th	10.9%	1183	10th	18.7%
2002	846	3rd	28.7%	1933	4th	30.6%
2003	670	5th	22.7%	1864	5th	29.5%
2004	319	9th	10.8%	1615	8th	25.5%
2005	523	7th	17.7%	1697	7th	26.8%
2006	595	6th	20.2%	1777	6th	28.1%
2007	224	11th	7.6%	1101	11th	17.4%
2008	799	4th	25.7%	1988	3rd	31.4%
2009	1316	2nd	47.1%	2263	2nd	35.8%
2010	3510	1st	100 %	6323	1st	100%

Note [1] Number of steelhead includes all recaptures

3.2.1 Inter-Annual Variability of Catch Efficiency

Catch efficiency by both the beach seine and dip net methods have shown inter-annual variability since the start of the Moricetown steelhead tagging program due to the development of technical aspects of the sampling methods and the partially selective fishery for different species in previous years. In addition, abundance of other species in the system (e.g. some years with high abundance of coho or pink salmon), and targeted effort to various species at different times of the year, as well as environmental variables (e.g. water level) affect catch efficiency for individual species. The number of steelhead tagged at the campground locations for the different years divided by the corresponding Petersen estimates indicates the catch efficiency by beach seine to have ranged from 0.5 % (2000) to 7.2% (2010) of the total estimated return of steelhead to Moricetown Canyon (Table 2). Total catch at the canyon sites divided by the corresponding Petersen estimates indicates the catch efficiency by dip net to have ranged from 1.8 % (2000) to 15.4% (2003 and 2010) of the total estimated return (Table 2). The total number of recaptures at the canyon divided by the total number of steelhead marked at the campground locations is also displayed in Table 2, since it may be a useful for estimating abundance in-season if an adjustment for the delay of steelhead migration from the campground locations to the canyon can be derived (i.e. temporal stratification). Overall, no correlations between Petersen estimates and cumulative catch adjusted by catch efficiencies are obvious, thus cumulative catch of steelhead by beach seine or dip net still requires further investigation of other potential correlations of cumulative catch to abundance. It is worth noting that the estimated proportion of steelhead arriving at Moricetown and sampled by beach seine or dip net was considerable in 2010 (i.e. [M]+[C]-[R]/[N] = 21.4%, Table 5), and emphasizes the importance of minimizing the impacts of sampling on steelhead health if sampling is to continue at this intensity.

Table 5. Catch efficiencies related to Petersen steelhead abundance estimates at Moricetown Canyon.

Year of Study	Number of Steelhead (Ranking)			Petersen Estimate [N]	Catch Efficiency			Canyon Sampling End Date
	Marked at Beach Seine [M]	Examined at Canyon [C]	Recaptured at Canyon [R]		Beach Seine [M/N]	Canyon Dip Net [C/N]	Canyon Dip Net [R/M]	
1999	164	1555	8	**28,527**	0.6%	5.5%	4.9%	Oct. 25th
2000	225	734	3	**41,428**	0.5%	1.8%	1.3%	Oct. 18th
2001	322	1184	23	**15,948**	2.0%	7.4%	6.5%	Oct. 17th
2002	846	2068	68	**25,398**	3.3%	7.6%	7.7%	Sept. 30th
2003	670	1864	102	**12,150**	5.5%	15.3%	15.1%	Sept. 19th
2004	319	1615	32	**15,670**	2.0%	10.3%	10.0%	Sept. 13th
2005	523	1697	57	**15,341**	3.4%	11.1%	10.9%	Sept. 27th
2006	595	1777	69	**15,138**	3.9%	11.7%	11.6%	Sept. 26th
2007	224	1101	12	**19,073**	1.2%	5.8%	3.1%	Sept. 28th
2008	759	1988	54	**27,484**	2.8%	7.2%	7.1%	Oct. 9th
2009	1390	2297	127	**24,973**	5.6%	9.1%	7.7%	Oct.1st
2010	2946	6323	452	**41,140**	7.2%	15.4%	15.3%	Oct. 22nd

Note: Some minor corrections from previous reports included: inclusion of recaptures at canyon re-sample site in C, and exclusion of tags applied after the last day sampled at the Canyon for M. Green font indicates maximum values and red font minimum values for each column.

3.2.2 Timing of Steelhead Arrival at Moricetown

Sampling started on July 9th in 2010 and the beginning of steelhead arrival indicated by the earliest dates that steelhead were captured at the campground and at the canyon was July 22nd in 2010 for both locations. July 22nd was a relatively early date of the first arrival in comparison to the previous 11 years, when the earliest steelhead catch dates recorded were July 27th in 2008 at the campground and July 20th in 2004 at the canyon. A more definitive measure of when steelhead began arriving may be better represented by when more than 5 steelhead were captured; July 27th (2008 and 2010) at the canyon and July 27th (2010) compared to July 20th (2004) at the campground. Daily steelhead catch results by beach seine immediately downstream of Moricetown Canyon (i.e. campground) and by dip net at the Moricetown Canyon falls and fishway (i.e. canyon) have been presented for comparisons of run timing at the two locations (Figure 4) and to help assess the annual variability in the timing of steelhead arrival at Moricetown (Figure 5). Due to the intra-annual variability in catch efficiency and apparent variability between the proportions of campground to canyon sampling (*see* Table 5), the catch at the sites have not been pooled. The main surges of steelhead arriving at the campground sites appear to be highly variable beginning as early August 9th in 2010, and as late September 12th in 2006 (Figure 5). For all weeks except the week of September 19 to September 26, canyon steelhead catch exceeded beach seine steelhead catch. However, for every day in the week prior to the September 25th high water event in the Bulkley River, steelhead catch at the campground exceeded that of the canyon. It is unknown why this week is unique in terms of the comparatively high catch of steelhead at the beach seine site, and low catch of steelhead at the canyon site. In addition, although the proportions of steelhead caught after October 1st at the canyon have not accounted for more than 5.2% in the years sampled (i.e. 1999, Figure 5), the total catch at the campground has increased as much as 25.9% after October 1st in 2000 and was 21.7% in 2010. Based on the steelhead catch at the campground, the majority of the cumulative catch to the end of sampling (~95%) are estimated to have arrived at the Moricetown as early as September 18th in 2009, but as late as October 4th in 2010 and October 15th in 2000. Evidence of late surges in steelhead arrival in late September and early October (e.g. 2010, *see* Figure 4) clearly emphasize the importance of extending future sampling well into October if the objective is to obtain the most accurate total and not just the minimum abundance estimate.

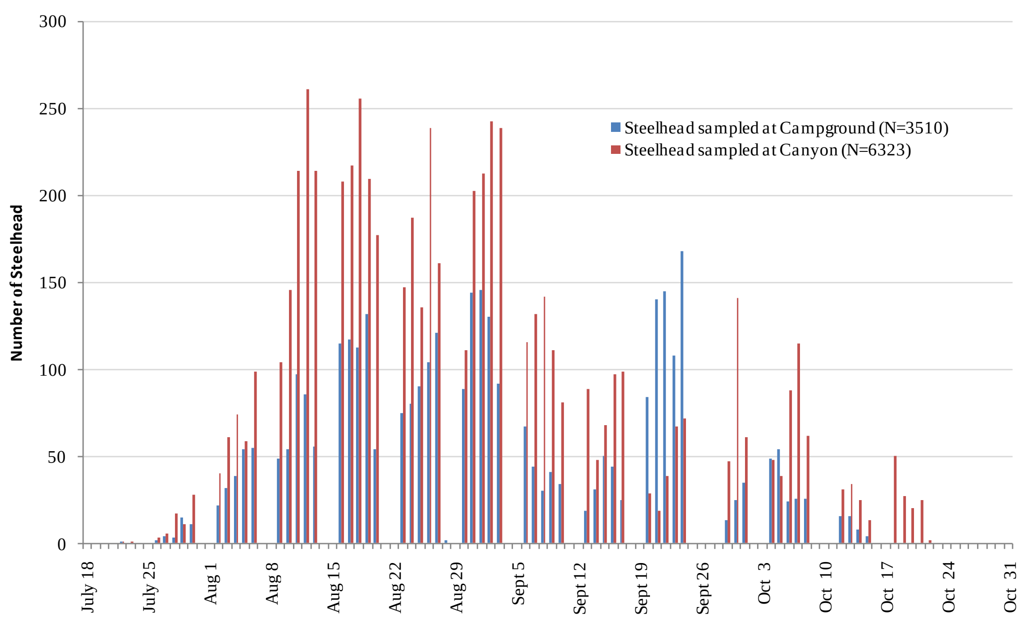


Figure 4. Distribution of steelhead catch at the campground and canyon location during the Moricetown steelhead mark and recapture study in 2010.

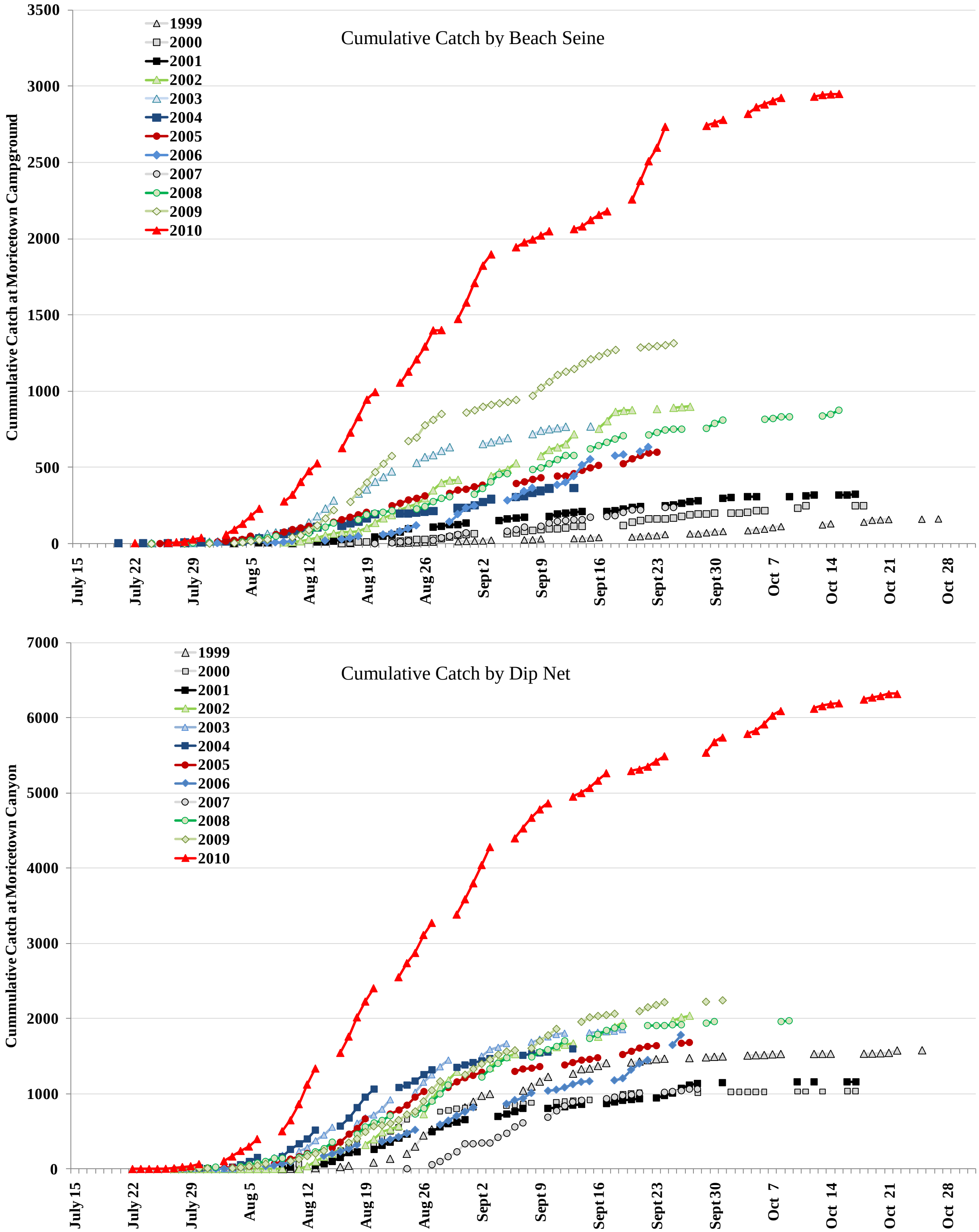


Figure 5. Cumulative catch of steelhead at Moricetown campground tag application sites 1 and 2 (top) and canyon resampling site 3 (bottom) from 1999 to 2010.

3.2.2.1 Associations of River Temperature and Water Levels with Steelhead Migration

From August 1st to November 12th in 2010, water temperature data loggers were placed in the Bulkley River downstream of the Moricetown Canyon by the B.C. Ministry of Environment. Minimum and maximum daily temperatures based on hourly recorded data have been presented in Figure 6. Fluctuations in water levels in the Bulkley River near Moricetown during the 2010 sampling period are presented in Figure 7 and display the flood event that commenced on September 25th and significantly reduced sampling intensity and catch efficiency from September 26th to 30th. No correlations of minimum and maximum water temperatures (Figure 6) or water levels (Figure 7) to the catch of steelhead at either the canyon or the campground (*see* Figure 4), that primarily peaked from August 8th to September 3rd in 2010 and then again at the campground in the third week of September prior to the flood, were identified.

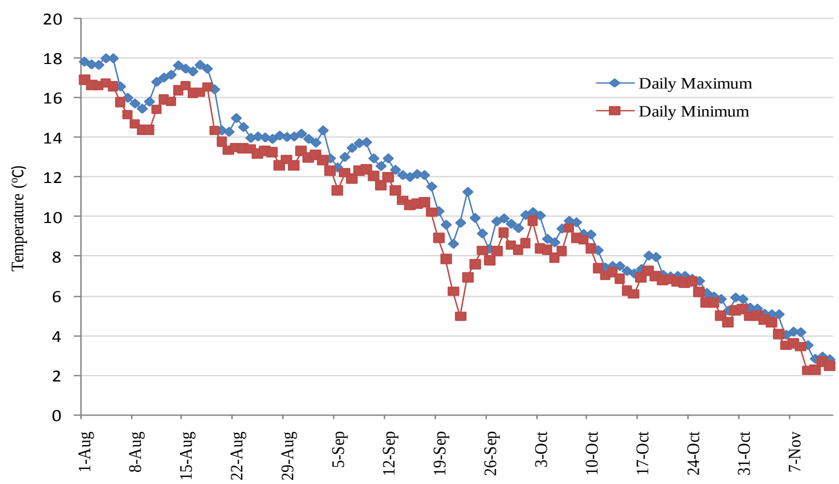


Figure 6. Summary of minimum and maximum water temperatures for the Bulkley River from August 1st to November 8th in 2010 (BCE Moricetown data logger, 2010).

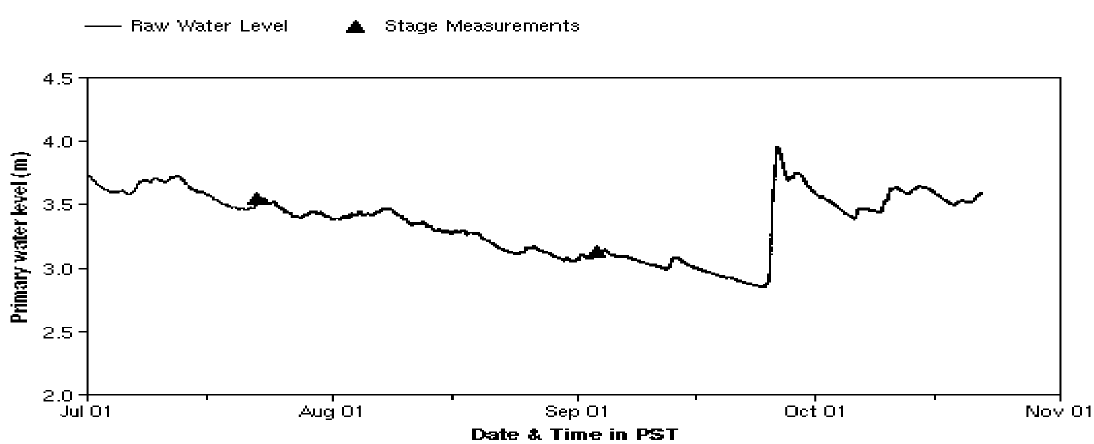


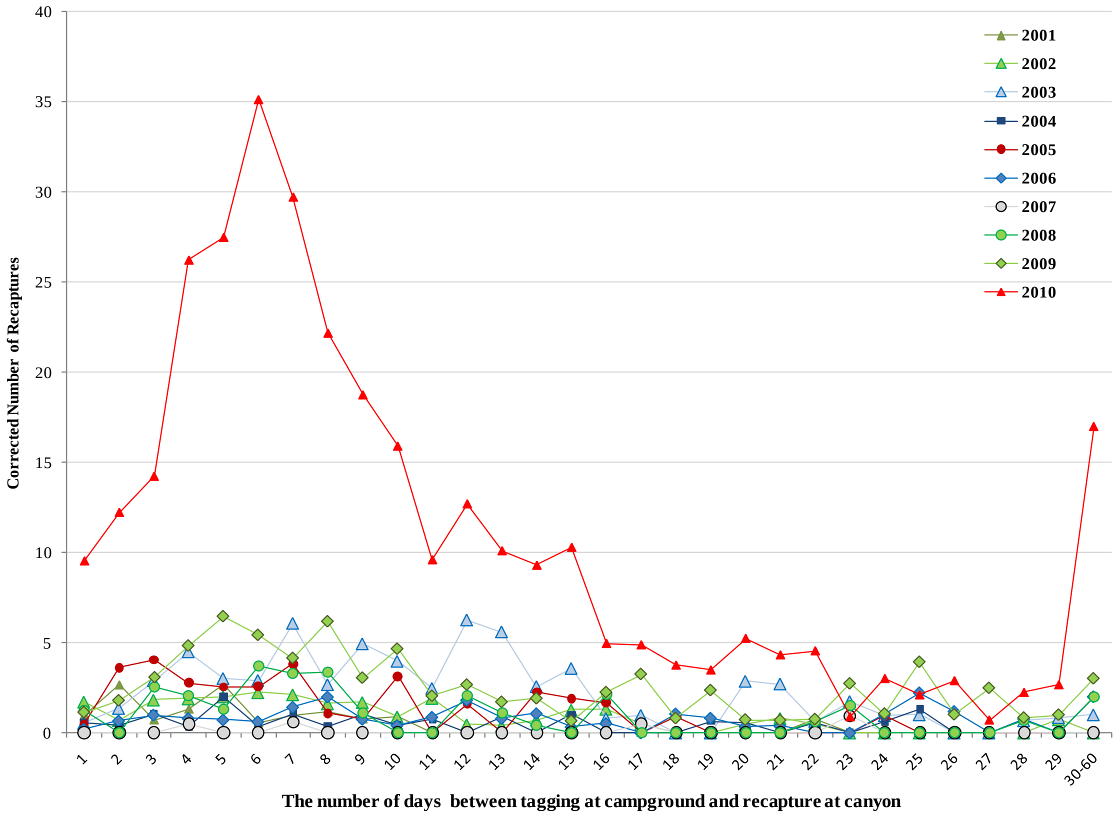
Figure 7. Real-time water levels of the Bulkley River from July 1st to October 22nd in 2010 from Environment Canada Hydrometric Station (08EE005) near Smithers, B.C.

3.2.3 Delay of Steelhead Migration at Moricetown Canyon

The tightly confined canyon, falls and fish way in Moricetown Canyon has locally been considered a bottleneck to all fish migration due to the observed congregation of migrating salmon and steelhead at the entrance to the canyon throughout the sport fishing season. A notable delay of steelhead migration from the Moricetown campground to the canyon has been supported by historical data for steelhead that were marked at the campground and recaptured at the canyon (Figure 8). The number of recaptures used to assess the delay of steelhead migration at Moricetown Canyon have been corrected (i.e. Corrected R) to account for the different sample sizes of marked steelhead (M) that were sampled for recovery at the canyon for the different lengths of delay (i.e. Corrected $R_i = R_i * M_i / M_{max}$, where *i* is the # of days delayed).

In 2010, a total of 452 recaptures had a median delay of 7.7 days between tagging and recapture in comparison to the pooled median of 7.9 days for all of the years combined (Table 6). Due to the very effective sampling conducted in 2010, a total of 19 steelhead recaptures that were tagged at the campground were actually recaptured twice at the canyon. In addition, 17 of the 452 (3.8 %) steelhead tagged at the campground were recaptured at the canyon more than 29 days later (30-55 days), in comparison to 1.8 % of the pool of recaptures from 2001 to 2010. Interestingly, the delay time of 6 of the 19 steelhead that were recaptured twice (i.e. 32%) were recorded for delays greater than 29 days which suggests that the majority of the steelhead with longer delays in migration from tag application to recapture at the canyon are repeat migrations or at least repeat attempts at the falls.

For comparison of time delays of steelhead migration from the campground to the canyon in 2010 to previous years, the median number of days for steelhead to be recaptured at the canyon has ranged from 4.4 days in 2001 to 12.8 days in 2006. The median of 7.7 days in 2010 has reduced the pooled median from 8.6 (i.e. 2001- 2009) to 7.9 days for 2001 to 2010 (Table 6). The means in table 3 are only presented for a general comparison to the medians and goodness of fit testing for normality, and are not considered appropriate for inter-annual comparisons as the distribution appears to be skewed and possibly multi-modal (Figure 8). Importantly, no significant differences between the medians was identified when comparing the years when more than 30 steelhead were recaptured ($\chi^2 = 11.388$, df=6, p = 0.0724), indicating that environmental variables (e.g. Bulkley River discharge) effecting the migration behaviour of steelhead from the campground to the canyon have not been detectable among the years sampled so far. Thus the data from 2001-2010 were pooled to calculate the expected distribution of delays in steelhead migration from the campground tagging location to the canyon sampling location (Table 6). The pooled results imply that half of the steelhead can be predicted to arrive at the campground 7.9 days prior to arriving at the base of the canyon falls. It will be important to incorporate and constantly test and update this temporal stratification into future mark recapture abundance estimates to account for early end dates of sampling and to acknowledge the uncertainties of the distribution (i.e. upstream or downstream of Moricetown) of overwintering steelhead in the Morice/Bulkley watershed.



Note: The number of recaptures used to assess the delay of steelhead migration at Moricetown Canyon have been corrected (i.e. Corrected R) to account for the different sample sizes of marked steelhead (M) that were sampled for recovery at the canyon for the different lengths of delay (i.e. Corrected $R_i = R_i * M_i / M_{max}$, where *i* is the # of days delayed).

Figure 8. Distribution of the corrected numbers of recaptured steelhead with different time delays when migrating from the campground/beach seine location to the canyon/dip net re-sampling location.

Table 6. Distribution of the time delay (days) and the median delay (red) for steelhead marked at the campground/beach seine location were recaptured at the canyon/dip net sampling location.

Delay (Days)	Adjusted Number of Steelhead Recaptured (R) *[1] 2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Pooled Total	Proportions of time delay from Campground to Canyon	Cumulative Proportion of tagged steelhead arriving at the Canyon
1	1.0	1.7	0.5	0.6	0.5	0.2	0.0	1.2	1.1	9.5	16.3	**0.027**	**0.027**
2	2.7	0.7	1.4	0.4	3.6	0.7	0.0	0.0	1.8	12.2	23.4	**0.038**	**0.065**
3	0.7	1.8	2.9	1.1	4.0	1.0	0.0	2.5	3.1	14.2	31.4	**0.051**	**0.116**
4	1.3	1.9	4.5	0.3	2.8	0.8	0.5	2.1	4.8	26.2	45.2	**0.074**	**0.190**
5	2.7	2.0	3.0	1.9	2.5	0.7	0.0	1.3	6.5	27.5	48.0	**0.078**	**0.268**
6	0.5	2.2	2.9	0.3	2.6	0.6	0.0	3.7	5.4	35.2	53.4	**0.087**	**0.356**
7	1.0	2.1	6.0	1.0	3.8	1.4	0.6	3.3	4.1	29.7	53.2	**0.087**	**0.442**
8	1.2	1.6	2.7	0.4	1.1	2.0	0.0	3.4	6.2	22.2	40.6	**0.066**	**0.508**
9	0.8	1.7	4.9	1.0	0.7	0.8	0.0	1.1	3.0	18.8	32.8	**0.053**	**0.562**
10	0.9	0.9	3.9	0.4	3.1	0.4	0.0	0.0	4.6	15.9	30.2	**0.049**	**0.611**
11	0.0	1.9	2.5	0.8	0.0	0.9	0.0	0.0	2.0	9.6	17.6	**0.029**	**0.640**
12	0.0	0.5	6.2	0.0	1.6	1.8	0.0	2.0	2.7	12.7	27.5	**0.045**	**0.685**
13	0.0	0.4	5.6	0.9	0.0	0.8	0.0	1.1	1.7	10.1	20.5	**0.033**	**0.718**
14	0.0	0.7	2.6	0.0	2.3	1.1	0.0	0.4	1.9	9.3	18.2	**0.030**	**0.748**
15	0.0	1.3	3.6	1.0	1.9	0.3	0.0	0.0	0.6	10.3	19.0	**0.031**	**0.779**
16	0.0	1.3	0.8	0.0	1.7	0.5	0.0	2.1	2.2	4.9	13.6	**0.022**	**0.801**
17	0.0	0.5	1.0	0.0	0.0	0.0	0.5	0.0	3.2	4.9	10.0	**0.016**	**0.817**
18	0.0	0.0	0.0	0.0	0.9	1.1	0.0	0.0	0.8	3.7	6.5	**0.011**	**0.828**
19	0.0	0.0	0.0	0.7	0.0	0.8	0.0	0.0	2.3	3.5	7.3	**0.012**	**0.840**
20	0.0	0.5	2.8	0.0	0.0	0.4	0.0	0.0	0.7	5.2	9.6	**0.016**	**0.856**
21	0.0	0.8	2.7	0.0	0.0	0.4	0.0	0.0	0.7	4.3	8.9	**0.014**	**0.870**
22	0.8	0.5	0.6	0.6	0.0	0.0	0.0	0.6	0.7	4.5	8.4	**0.014**	**0.884**
23	0.0	0.0	1.7	0.0	0.0	0.0	0.9	1.5	2.7	0.9	7.8	**0.013**	**0.896**
24	0.0	0.0	1.0	0.6	0.9	1.0	0.0	0.0	1.0	3.0	7.6	**0.012**	**0.909**
25	0.0	0.0	1.0	1.4	0.0	2.2	0.0	0.0	3.9	2.1	10.6	**0.017**	**0.926**
26	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	1.0	2.9	5.1	**0.008**	**0.934**
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.7	3.2	**0.005**	**0.939**
28	0.0	0.0	0.7	0.0	0.0	0.8	0.0	0.7	0.8	2.2	5.2	**0.008**	**0.948**
29	0.0	0.7	0.8	0.0	0.0	0.0	0.0	0.0	1.0	2.7	5.2	**0.009**	**0.956**
>29	0.0	0.0	1.0	0.0	2.0	2.0	0.0	2.0	3.0	17.0	27.0	**0.044**	**1.000**
	13.4	25.6	67.2	13.3	36.0	23.8	2.5	29.0	76.3	326.0	**613.1**	**Adjusted Total Recaptures*[1]**	
	5.9	9.3	11.8	11.3	9.4	15.3		10.7	12.5	10.4	**10.9**	**Means**	
	4.4	7.2	10.4	8.6	6.5	12.8		7.1	9.3	7.7	**7.9**	**Medians**	
	21	*65*	*101*	*32*	*57*	*69*	*7*	*54*	*107*	*452*	***965***	***Actual sample size***	

*[1] Number of recaptures are corrected for due to the lack of sampling on consecutive days throughout the study and because the tag application and canyon sampling ended on approximately the same dates of each year. The number of recaptures (R) for each length of delay (i.e. 1-29 days) are corrected down by multiplying each R by a correction factor (i.e. minimum number of marked steelhead sampled for any given time delay of each year/number of marked steelhead sampled for each lag time of the same year) to account for the different number of tagged steelhead that were sampled for the different time lags in the same year.

3.3 MORICETOWN STEELHEAD ABUNDANCE ESTIMATES

Based on the available data, steelhead abundance estimates for Moricetown have historically been derived using a pooled Petersen estimate due to relatively low catches. As the program has developed over the years, in conjunction with favourable sampling conditions, recently higher catches have allowed stratified estimates such as Schaeffer and Maximum Likelihood Darroch methods to be considered. The presentation of steelhead abundance estimates for Moricetown is made under the standard assumptions concerning many population estimates, which are known to be violated to some degree. These estimates should likely be termed as an abundance index until the assumptions are tested and biases have been corrected. Key assumptions specific to this study design that require consideration for defendable inter-annual comparisons of abundance indices include that:

- the sampling time incorporates the entire migration time of steelhead through Moricetown Canyon,
- marked fish do not lose their marks (note: caudal punches insure no tag loss for Petersen estimates, and may provide a correction factor for stratified estimates in years with high numbers of recaptures),
- random samples of marked or unmarked fish are obtained (e.g. ensure sampling is not size selective, temporally biased),
- marked fish mix randomly with unmarked fish (e.g. assume that marked fish do not use the fishway more than unmarked fish),
- the ratio of mortalities for marked versus unmarked steelhead is consistent from year to year for stratified estimates (i.e. sampling is not more harmful to tagged fish in some years than other years),
- the ratio of fallback for marked and unmarked steelhead is consistent from year to year for stratified estimates (i.e. sampling does not impact migration of tagged fish differently in some years than other years), and
- mortality and fall back rates are consistent from year to year if estimating abundance upstream of Moricetown (e.g. sonic studies have already suggested some inter-annual variability of fallback), or annual fallback is measured annually.

Almost all mark recapture studies violate at least some of these assumptions to some degree, and this is a definite complication with the Moricetown steelhead tagging project as well. Fortunately, some estimators of abundance (e.g. pooled Petersen) are generally considered robust (Krebs 1982). Nevertheless, keeping the above assumptions in mind, the following sections summarize:

- inter-annual variability of abundance for steelhead arriving at Moricetown based on the historically presented Petersen estimate and stratified Schaeffer and Maximum Likelihood Darroch estimates,
- necessary corrections for fallback, emigration and tagging mortality , and
- a comparison of Moricetown Petersen estimates to the Tyee Steelhead Abundance Index.

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3.3.1 Petersen Estimates

Historically, pooled Petersen estimates have been used to estimate steelhead returns to Moricetown Canyon due to the common acquisition of only small numbers of recaptures and variable periods of sampling. A precautionary note when comparing Moricetown steelhead abundance estimates is to acknowledge the very small numbers of recaptures that occurred in 1999, 2000, and 2007 which resulted in estimates with more than 40% error for those years. In 2010, the Petersen estimate for steelhead arriving at the Moricetown campground was 41 140 (95% C.I. = 38 058 – 44 934) and was relatively high in comparison to the lowest abundance estimate since 1999 of 12 150 (95% C.I.: 10 388 - 14 908) in 2003. It is worth noting that sampling in 2003 had a relatively early end date (i.e. September 19th) and may have excluded a significant proportion of the return as indicated by the later surges in steelhead migration that have been commonly observed in late September and early October (e.g. 2010, *see* Figure 4). The Petersen estimate for 2001 of 15 948 may be a more useful comparison to future estimates indicating relatively low abundance for in-season comparisons to years with longer sampling periods (i.e. sampling to mid October), but the 95% confidence interval for that year is quite broad (i.e. 10 902 to 24,040). Excluding the abundance estimates from 1999 and 2000 that relied on very few recaptures and had greater than 50% error, the steelhead abundance estimate for Moricetown in 2010 is the highest estimate on record with a reasonably tight 95% confidence interval (i.e. <10% error).

Table 7. Petersen abundance estimates calculated for steelhead arriving at Moricetown Canyon.

Year of Study	Number of Steelhead			Petersen Estimate	95% Confidence Interval		Canyon Sampling End Date
	Marked (M)	Examined (C)	Recaptured (R)		Lower	Upper	
1999	164	1555	8	**28,527**	16,250	58,350	Oct. 25th
2000	225	734	3	**41,428**	18,876	103,819	Oct. 18th
2001	322	1184	23	**15,948**	10,920	24,040	Oct. 17th
2002	846	2068	68	**25,398**	20,890	33,481	Sept. 30th
2003	670	1864	102	**12,150**	10,388	14,908	Sept. 19th
2004	319	1615	32	**15,670**	11,425	23,126	Sept. 13th
2005	523	1697	57	**15,341**	12,459	20,753	Sept. 27th
2006	595	1777	69	**15,138**	12,511	19,767	Sept. 26th
2007	224	1101	12	**19,073**	11,621	32,258	Sept. 28th
2008	759	1988	54	**27,484**	22,097	37,856	Oct. 9th
2009	1390	2297	127	**24,973**	21,578	30,112	Oct.1st
2010	2946	6323	452	**41,140**	38,058	44,934	Oct. 22nd

Note: Some minor corrections from previous reports included: inclusion of recaptures at canyon re-sample site, and exclusion of tags applied after the last day sampled at the Canyon.

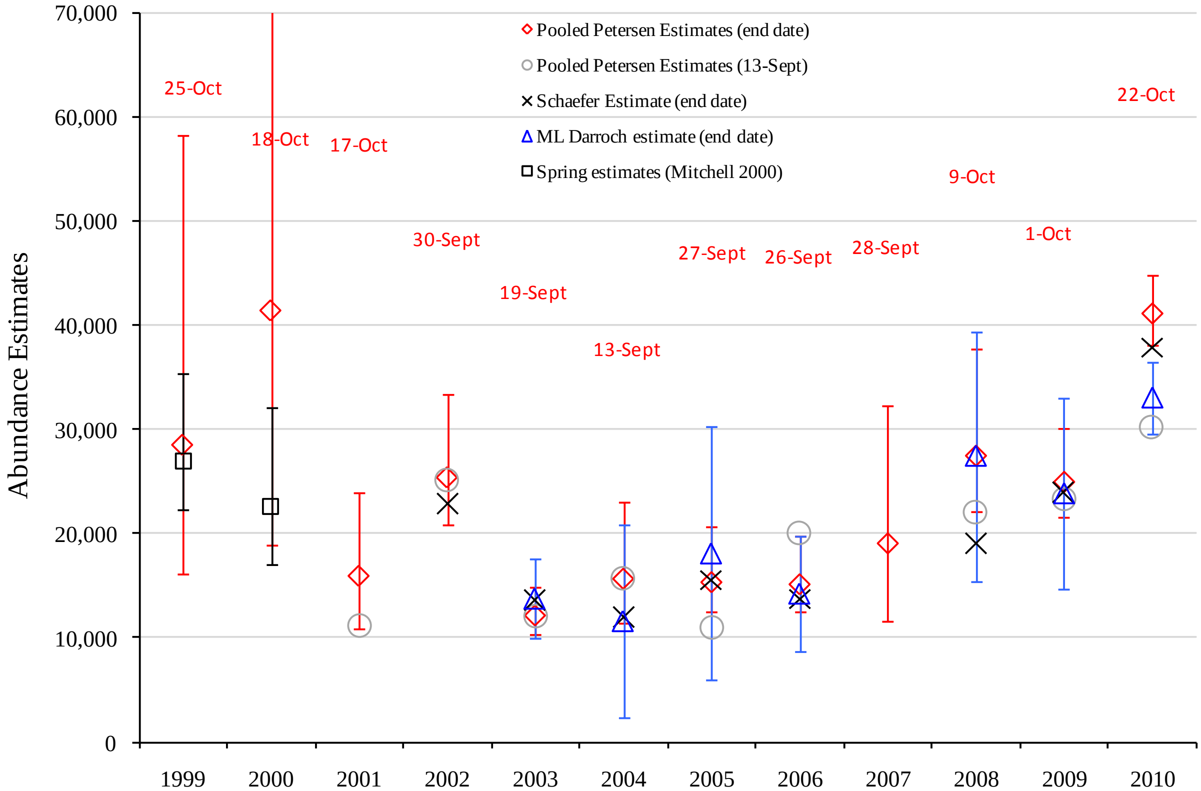
3.3.2 Stratified Abundance Estimates

From 2003 to 2010, a stratified population analysis tool (SPAS)(Arnason *et al* 1996) using a Schaefer estimate (Schaefer 1951) and a Maximum Likelihood Darroch estimate (ML Darroch) with arbitrary pooling to reduce the redundancy of temporal strata (Darroch 1961, Chapman and Junge 1956, Plante 1990) have been used to incorporate temporal stratification into the estimate and account for heterogeneity of catchability among the designated release groups (Appendix 4). For 2010, both capture (i.e. tags applied) and recapture strata (i.e. canyon sample) were grouped by 7 day intervals (i.e. week) and strata were pooled for Schaefer and ML Darroch estimates: weeks 1-3, 4 to 12, 13-14 for capture and 1-3,4 to 6, 7-14 for recapture strata. A complete summary of end of season abundance estimates for steelhead comparing pooled Petersen (Table 7), Schaeffer and ML Darroch results are presented in table 8 and figure 9. The late end to sampling (i.e. Oct. 22nd) and the large sample size acquired in 2010 (i.e. 2946 tagged, 6323 sampled, and 452 recaptures) has provided a clearer view of the potential biases in the various abundance estimate methods. Unlike previous years, the improved accuracy of the estimates in 2010 has resulted in a notably smaller estimate of 33 047 using ML Darroch, than 41 140 from the pooled Petersen estimate and 38 064 from the Schaefer estimate (Table 8, *see* Appendix 4). Unfortunately, the end of sampling for different years has been based on both budget constraints or sometimes the initial declines in steelhead arrival at the tag application site, thus these estimates may not be appropriate for ranking the inter-annual estimates of abundance. The development of a different abundance estimate is also under construction for the Moricetown Mark-Recapture Program to incorporate a Bayesian model to estimate abundance and run timing including hierarchical modeling of the capture probabilities and spline smoothing of the daily run size to assist with future in-season estimates (Schwarz 2011).

Table 8. Annual Comparisons of Steelhead Abundance Estimates using pooled Petersen, and stratified Schaefer and Darroch Maximum Likelihood (ML Darroch) Methods.

Study	Petersen Estimate*[1]	Schaefer Estimate	ML Darroch Estimate	95% Confidence Interval		Canyon Sampling End Date
				Lower	Upper	
Moricetown tagging 1999	**28,527**					Oct. 25th
Angling estimate spring 2000	**27,005**					N.A.
Moricetown tagging 2000	**41,428**					Oct. 18th
Sport fish estimate fall 2000	**22,627**					N.A.
Moricetown tagging 2001	**15,948**					Oct. 17th
Moricetown tagging 2002	**25,398**	**22,883**				Sept. 30th
Moricetown tagging 2003	**12,150**	**13,589**	**13,800**	9,928	17,673	Sept. 19th
Moricetown tagging 2004	**15,670**	**12,033**	**11,647**	2,398	20,897	Sept. 13th
Moricetown tagging 2005	**15,341**	**15,567**	**18,126**	5,969	30,284	Sept. 27th
Moricetown tagging 2006	**15,138**	**13,734**	**14,283**	8,795	19,771	Sept. 26th
Moricetown tagging 2007	**19,073**					Sept. 28th
Moricetown tagging 2008	**27,484**	**19,039**	**27,474**	15,487	39,461	Oct. 9th
Moricetown tagging 2009	**24,973**	**23,986**	**23,986**	14,639	33,136	Oct.1st
Moricetown tagging 2010	**41,140**	**38,064**	**33,047**	29,599	36,495	Oct. 22nd

*[1] for details on the Petersen estimates see Section 2.3 for methods and Table 7 for data summary and confidence intervals.



Note: Error bars indicate 95% confidence intervals with Poisson (<50 recaptures) or Normal approximation.

Figure 9. Estimates of the number of Bulkley/Morice steelhead arriving at Moricetown Canyon from 1999 to 2010.

3.3.3 Corrections for Fallback and Mortality Based on Acoustic Telemetry

In order to estimate steelhead abundance upstream of Moricetown Canyon, a correction to the abundance estimates for steelhead arriving at the campground is required to account for the fallback and mortality of steelhead that arrive at the campground, but do not reach the re-sampling location. The Bulkley River sonic tagging studies have estimated the fallback of steelhead handled at the Moricetown campground (i.e. tagged steelhead not available for recapture) to approximately 34% in 2009 (Welch *et al.* 2009, 2010, Peard and Beere 2010). Accounting for the potential difference between fallback and mortality of tagged steelhead and untagged steelhead is a key factor for any abundance estimates, however there is currently no information available for the fallback or mortality of untagged steelhead from Moricetown Canyon. In addition, it is unknown if the behaviour of steelhead tagged with anchor tags and caudal punches differs from those tagged additionally with a sonic tag used in the sonic tagging studies. Based on the variability of fallback and unknown difference of mortality between tagged steelhead and untagged steelhead between the two years assessed, a range of corrections for the pooled Petersen estimates are presented in table 9, making the assumptions of a maximum expected difference in fallback and mortality (e.g. 40% of tagged steelhead will never reach the re-sampling location) through a range considering smaller differences in fallback that assumes bias and inter-annual variability (i.e. 20%, and 10% corrections to the abundance estimate). Based on these correction factors, the corrected pooled Petersen estimates for steelhead upstream of Moricetown canyon as of October 22nd in 2010 are from 24 684 (i.e. 40% fallback) to 37 026 (i.e. 10% fallback) (Table 9). To put this estimate into perspective, the lowest range of estimates on record for steelhead migrating upstream of Moricetown Falls has been as low as 7 297 to 10,935 as of September 19th in 2003 and as high as 16 505 to 24 736 as of October 9th in 2008 (Table 9).

Table 9. Corrected pooled-Petersen Abundance Estimates with examples of adjustments to convert estimates of steelhead arriving at Moricetown campground to estimates of steelhead migrating upstream of Moricetown Canyon as of the end of sampling.

		Petersen Abundance Estimates			
Year	**End of sampling**	**No Correction**	***10% Fallback***	***20% Fallback***	***40% Fallback***
2001	Oct. 17th	15,948	*14,353*	*12,758*	*9,589*
2002	Sept. 30th	25,398	*22,858*	*20,318*	*15,251*
2003	Sept. 19th	12,150	*10,935*	*9,720*	*7,297*
2004	Sept. 13th	15,670	*14,103*	*12,536*	*9,422*
2005	Sept. 27th	15,341	*13,807*	*12,273*	*9,216*
2006	Sept. 26th	15,138	*13,624*	*12,110*	*9,083*
2007	Sept. 28th	19,073	*17,166*	*15,258*	*11,478*
2008	Oct. 9th	27,484	*24,736*	*21,987*	*16,505*
2009	Oct.1st	24,046	*21,641*	*19,237*	*14,435*
2010	Oct. 22nd	41,140	*37,026*	*32,912*	*24,684*
Range	***Variable end dates***	**12,150 – 41,140**	***10,935 – 37,026***	***9,720 – 32,912***	***7,297 – 24,684***

3.3.4 Comparison of Petersen Estimates to Tyee Test Fishery Index

The cumulative index for the mixed steelhead stock abundance at Tyee in the lower Skeena from 1999 to 2010 (Fisheries and Oceans Canada 2010) are presented (Figure 10) and compared to the Moricetown steelhead abundance estimates (Figures 11 & 12). This comparison is primarily an attempt to assess the potential for errors and the uncertainties related to steelhead abundance when sampling seasons at Tyee or Moricetown end early. Although the mix of steelhead stocks and sub-stocks returning to the Bulkley and Morice watersheds are not suspected to represent the majority of steelhead that pass through the Tyee test fishery at the mouth of the Skeena River, it still appears useful to make this comparison to help assess the length of sampling required to incorporate the majority of steelhead returning each year and potentially detect differences in run timing of different stocks. From this comparison, it appears that the Tyee steelhead index and the abundance estimates at Moricetown have similar inter-annual rankings of abundance when comparing the status at the earliest end dates at each location (i.e. Aug. 23rd for Tyee and Sept. 13th for Moricetown, Figures 11 & 12), but then become less associated at the end of sampling. Variable lengths of sampling at the two locations and for different years appear to be the primary cause for this difference (e.g. Figure 10). Based on the available information it appears that the sampling period for summer run steelhead abundance should more consistently extend to at least mid to late September for the Tyee test fishery and approximately three weeks later (i.e. early to mid October) for the Moricetown Tagging project in order for these abundance estimates to consistently represent the annual returns of summer-run steelhead.

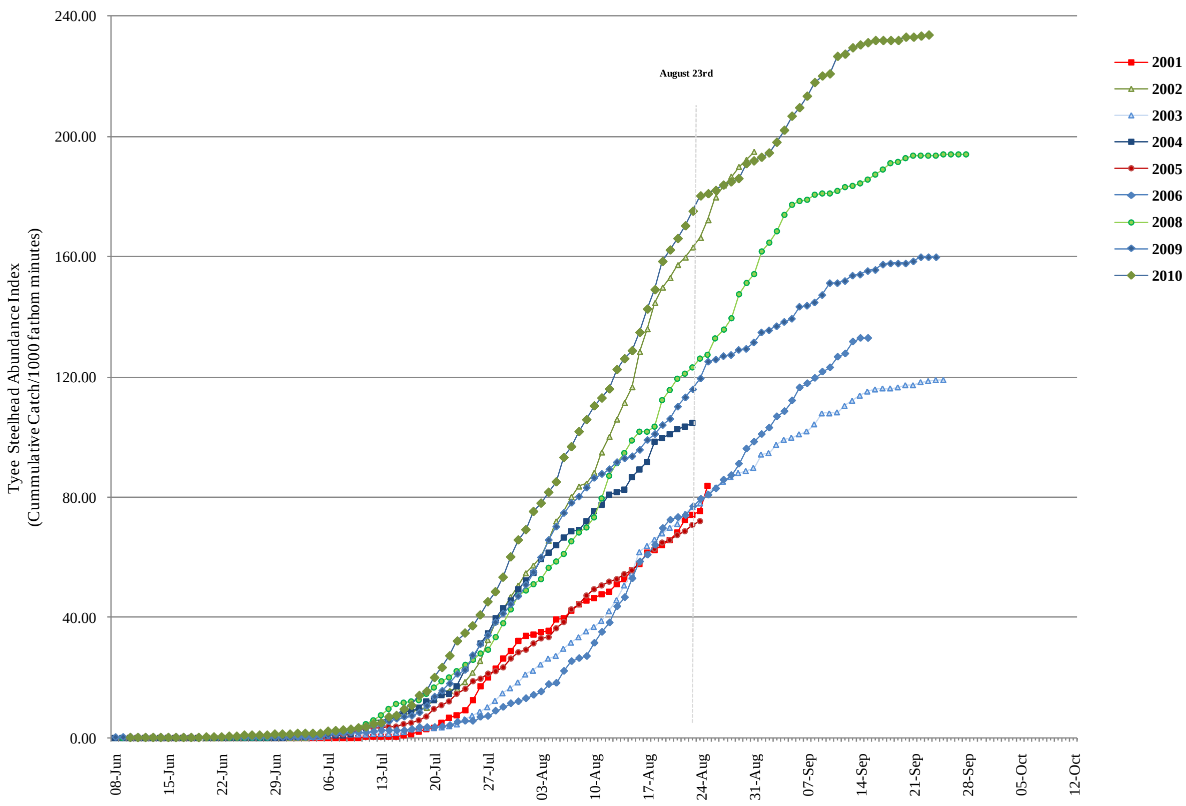


Figure 10. Intra-annual progression of the Tyee Steelhead Abundance Index for 2001 to 2010.

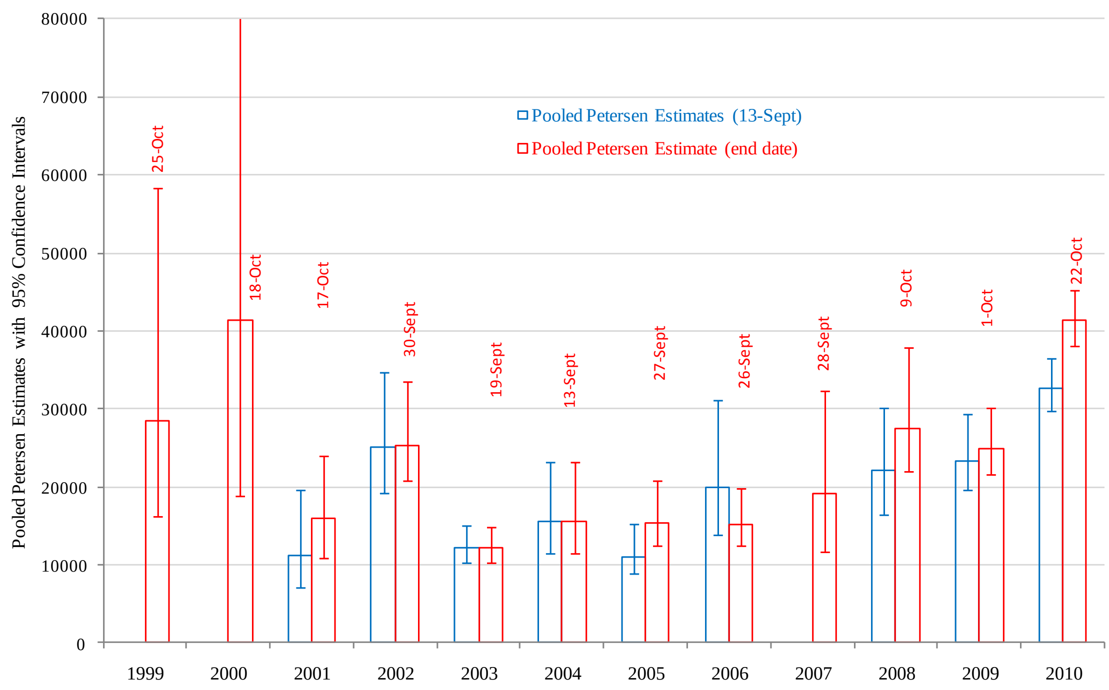


Figure 11. Pooled Petersen estimates of the number of Bulkley/Morice steelhead arriving at Moricetown Canyon 1999 to 2010.

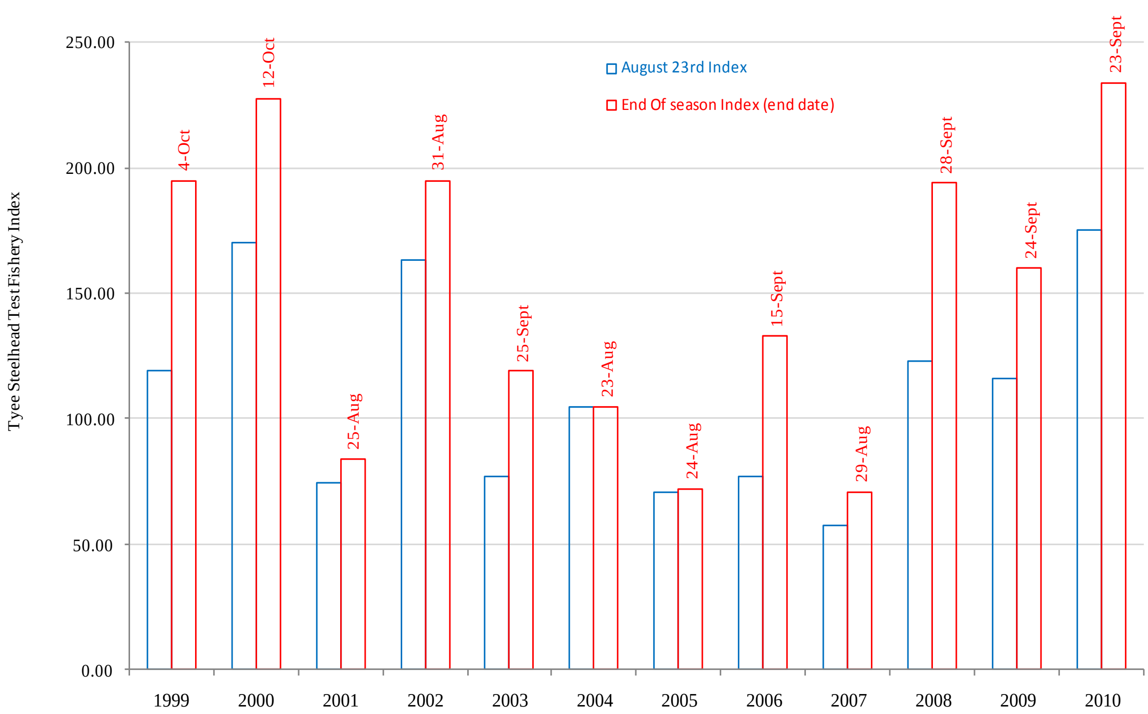


Figure 12. Tyee Test Fishery Skeena Steelhead Abundance Index from 1999 to 2010.

4.0 RECOMMENDATIONS

The steelhead tagging program at Moricetown is the most extensive steelhead tagging program in the Skeena watershed, and has the potential to provide critical information on steelhead stock status vital to the management for this world-renowned aquatic resource. If the Wet'suwet'en Fisheries steelhead tagging project is proposed to be utilized as a long term stock assessment program, applications for annual base funding to help subsidize the steelhead portion of this program will be critical toward the refinement of the study design, improving the presentation and efficiencies of the overall tagging program, and fostering co-management of this fisheries resource. In addition, it would be advantageous for Wet'suwet'en Fisheries, BC Ministry of Environment, Fisheries and Oceans Canada, and other interested parties to conduct a pre-season workshop to ensure that funding and feasibility are integrated into the project design with defined objectives. The potential for this program to obtain useful annual steelhead abundance estimates for ongoing management of this highly valued freshwater resource emphasizes the importance of refining the study design. To rank the priority for the following recommendations it may be important to determine the value and estimate the number of years of data that would be desired for future assessments of the collected data with regards to correlations of Bulkley/Morice river steelhead returns to the Tyee Test Fishery cumulative index, harvest activities and steelhead life history characteristics (e.g. iteroparity, fall estimates for spring spawning species).

With the increasing catch efficiencies of fish sampling at Moricetown since 2007, it may now be useful to implement a suitable abundance prediction model (e.g. Schwarz and Bonner 2011) that will incorporate temporal stratification, account for heterogeneity of catchability of the release groups, and provide admissible in-season abundance estimates of steelhead arriving at Moricetown. Especially if this project is proposed to continue for more than just a few years, a number of potential modifications to the program have been identified with the intent to reduce the effect of fish handling on steelhead condition and improve the aesthetics, operation, and data results. Detailed recommendations were provided in previous reports, and only additional or high priority recommendations are mentioned here. A more comprehensive list of previous recommendations is provided in SKR (2010). The general purposes for the following recommendations are to:

- develop an appropriate sampling schedule that integrates practical employment opportunities, work load, budget constraints and the complications of the time delay of steelhead from the tag application to the re-sample locations,
- adjust sampling effort to better ensure that abundance estimates will have levels of accuracy and precision that can assist with the management of steelhead,
- limit the potential for impacts on fish by minimizing and improving catch, fish handling, and tag application methods, and
- modify field data forms and database to simplify data entry and related quality assurance, improve data quality, and potentially develop suitable reports.

The following sections summarize the recommendations for potential improvements to the *Sampling Schedule*, *Sampling Methodologies*, and the design of *Data Records*.

4.1 Sampling Schedule

The starting date for sampling has consistently been in early July and appears to have encompassed the initial arrival of steelhead at Moricetown canyon. Based on the results from the initial 12 years of this study, it is likely possible to delay the initiation of sampling to three weeks after the first steelhead is captured in the Tyee Test fishery if this tagging program is only focused on steelhead in future years. A suitable end date for future years of sampling appears to be the second or third week of October, but this could be shortened for the occasional year when early and precise estimates achieve predefined targets and management objectives. Acquisition of at least a sub-sample of abundance estimates with sample periods extending to October 15th or later will continue to be valuable in helping recognize the biases of abundance estimates at various end dates of sampling. For the purpose of reducing bias for in-season abundance estimates and improving its precision, the following suggestions related to the sampling schedule should be considered:

- sampling 7 days per week would provide the best results even if the effort per day is strategically decreased (e.g. two crews working 4 days on/4 days off with 10 hour days) for the entire study period,
- increase beach sampling intensity from August 7th to 21st in an attempt to improve precision of abundance indices throughout the study and to acquire better precision earlier in the season as reliable indicator of low or high abundance years (e.g. potentially two crews working simultaneously at slightly different, and steelhead preferred, locations), and
- avoid increasing sampling effort when arrivals of steelhead are high, but conduct weekend sampling (i.e. continuous) if funding is available.

It may also be useful, for management purposes, to begin establishing an emergency fund to ensure that, when in-season indices are low, sampling effort can be increased and continued into October in an attempt to acquire as accurate and precise estimations of the lower abundance years as possible.

4.2 Sampling Methodology

The sampling methodologies developed throughout this project have been effective, but in conjunction with past recommendations (SKR 2010) the following suggestions are either reiterated for emphasis or newly provided for the beach seine and dip net operations with the intents to improve aesthetics, reduce the effects of handling on fish condition, and to possibly help establish a measurable unit of sampling effort that may be useful toward establishing catch per unit effort (CPUE). The following suggestions for any modifications to the existing scientific experimental design of the Moricetown Tagging Program should be clearly presented to Wet'suwet'en Fisheries and FOC for discussion and refinement prior to implementation.

Beach Seine Sampling

The catch efficiency of beach seine sampling has been improving in conjunction with field crew experience, but training will remain critical with staff turnover each year. It may be helpful for cumulative index calculations if the initial setting of each crew or for the settings at 0800 hours to 1800 hours (next setting if overturned) are made to target steelhead in conjunction with sampling seven days per week. Catch from these designated sets should be clearly identifiable in the data sheets, as these catches may also serve as an in-season CPUE indicator. The impact of beach seining on steelhead condition may be reduced if fish are less exposed to air in the holding area, crews continue to handle steelhead first, and constant reminders are given to remove gloves prior to handling any species, as well as to support the fish in their natural swimming position during confinement, handling and release.

Some suggestions for potential improvements to sampling at the campground include:

- design and construction of suitable and adjustable fish collection/holding area for the beach seine catch when large numbers of fish are being handled,
- design and trial of horizontal fish finders to detect locations of species holding areas and abundance to help determine the best routes for setting the seine net and potentially the optimum frequency of sampling,
- determine and define target numbers of tags to apply for different stratum to potentially avoid unnecessary intensities of sampling,
- design and prepare equipment for optional sampling methods or locations suitable for tag application during high water events to reduce the risk of creating significant gaps in the data, and
- hold a pre-season preparation meeting with all employees to review the objectives, sampling methodologies, fish condition topics, and for input on any proposed design change.

Dip Net Sampling

Dip net sampling has been efficient and effective since the initiation of the study, but refresher and initiation training meetings should be provided at the start of each year and especially as staff are replaced. The primary concern related to dip net activities has been with regard to the long handling time required to catch, transport to the tag application site, transfer of fish from net to net, and release the fish. Notable impacts of handling have been observed based on a greater frequency of steelhead with net marks, torn fins, and slower recoveries after release than appear to occur on steelhead released after beach seine capture and tag application. There have not been any easily implemented ideas for reducing the stress imposed on fish at the re-sample location, but some suggestions to be considered include the following:

- establish secure and adjustable holding containers at three dip net sampling sites to allow faster and less stressful transfer of fish from nylon mesh dip nets to a conveniently located holding tank,
- design the holding tanks to allow gentler release of fish from the dip nets into the holding tanks as possible and easily remove untargeted species,
- design the holding tanks to allow more gentle transfer of fish to the mark and release location, possibly with carrying devices designed to easily insert, remove and transport with up to 4 fish,
- design a fish carrying device made with a smoother coating or material with less flex to reduce entanglement and loss of scales and protective mucous coating,
- consider construction of a floating platform or specialized skiff on the river left side of the fishway for the mark and release to standardize the impacts of fish release at different river levels and reduce the stress on fish that appears to occur during lower river levels,
- add fish release methods to the training session to reduce the stress and enhance the recovery of released fish,
- consider installation of a protected holding area at the release location to allow monitoring of fish in poor condition and reduce the fallback of releases over the falls or into the fishway,
- hold a pre-season preparation meeting with all employees to review the objectives, sampling methodologies, fish condition topics, and for input on any proposed design changes,
- calibrate the tape measure in the tagging trough to ensure more accurate recording for fork length,
- reduce handling time by measuring the fork length of all recapture steelhead, and only a sub-sample of previously untagged steelhead, and
- modify the motivation for dip net crews being based on tag application to something such as number of days with the highest steelhead catch.

Tag application

Tag application methods appear to have been successful, but more practical consideration of colour and number sequences distributed from year to year and among species has become crucial when so many tags are applied. Some suggestions for helping to standardize the tag application methodology include the following:

- ensure that sufficient tags are on hand (and easily accessible) at the beginning of the field season to last for the duration of the field season (based on the highest number of tags applied in previous years), with some extras available should steelhead catch be high,
- continue the application of upper caudal punch to allow monitoring of fallback and recapture of fish sampled at the canyon re-sampling location, but omit application of dorsal tags at the canyon unless upstream sampling is to be conducted and a higher number of applied tags is desired, and
- ensure a different colour tag is applied at the dip net from the beach seine to provide the option of later comparisons of survival and fall back between sampling locations.

4.3 DATA MANAGEMENT

Some valuable field data potentially related to the time delays of steelhead moving from the tag location to the canyon re-sampling location has not been or has been inconsistently collected. Some suggestions for modifications to the Moricetown fisheries database and field datasheets that may be useful or help improve field entries and data entry include:

- daily weather and water conditions should be moved from the detailed data sheets to the daily summary cover sheet,
- date format should be presented (i.e. year/mm/dd) on each form and an indicator of the day of the week (i.e. M/T/W/TH/F/SA/SU) could be added as a check method for dates recorded
- an additional field should be added to the detailed data sheet to clarify between "caudal punch present" and "caudal punch applied",
- the daily summary sheet should include a table with fields for species, pages, total captured, total harvested, tags/caudal punches applied, beach seine recaptures, and other recaptures to assist with in-season estimates,
- the beach seine daily summary page should be reviewed and updated to any modifications to the sampling methodology and data requirements, and
- the MSAccess data entry form could be modified to duplicate the appearance of the field data sheet (i.e. 25 records per page) with a daily summary form added to omit duplications of data for individual records, the addition of autofills for next "tag number", "tag colour", "applied caudal punch" and "fisherman", and the addition of roll down menus for suitable fields (e.g. "fisherman", "tag colour", etc.).

List of References

Arnason, A.N., C.W. Kirby, C.J. Schwarz, and J.R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Can. Tech. Rep. Fish. Aquat. Sci. 2106: vi+37p.

Chapman, D.G. and C.O. Junge 1956. The estimation of the size of a stratified population. Ann. Math. Statist. 27: 375-389.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. *Biometrika* 48:241-260.

Fisheries and Oceans Canada, 2010. (http://www.pac.dfo-mpo.gc.ca/northcoast/webdocs/Tyee%20Test/QDailyIndices.htm)

Krebs, C.J. 1999. Ecological Methodology. 2nd ed. Addison – Wesley, New York.

Mitchell, S. 2000. A Petersen Mark-Recapture Estimate of the Steelhead Population of the Bulkley/Morice River Systems Upstream of Moricetown Canyon. Unpublished report prepared for the Steelhead Society of British Columbia, Bulkley Valley Branch and Fisheries Renewal BC.

Mitchell, S. 2001. A Petersen Mark-Recapture Estimate of the Steelhead Population of the Bulkley/Morice River Systems Upstream of Moricetown Canyon During Autumn 2000, Including Synthesis with 1998 and 1999 Results. Unpublished report prepared for the Steelhead Society of British Columbia, Bulkley Valley Branch and Fisheries Renewal BC.

Peard, D. And M. Beere 2010. *Personal communications*. In house review of sonic telemetry results by Welch et al. (2009, 2010).

Plante, N. 1990. *Estimation de la taille d'une population animale à l'aide d'un modèle de capture-recapture avec stratification.* M.Sc. thesis, Université Laval, Quebec.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Bd. Can. No. 191.

Schaefer, M. B. 1951. Estimation of the size of animal populations by marking experiments. *U.S. Fish Wildl. Serv. Fish. Bull.* 69:191-203.

SKR Consultants Ltd. 2010. 2009 Steelhead Tagging Project at Moricetown Canyon by Wet'suwet'en Fisheries. Data Analysis and Recommendations. Unpublished report prepared for the Pacific Salmon Foundation Vancouver, BC and the Ministry of Environment, Smithers, BC.

Schwarz, C.J. and S.J. Bonner. 2011. A spline-based mark-recapture model applied to estimating the number of steelhead within the Bulkley River passing the Moricetown Canyon in 2001-2010. Unpublished report prepared for the British Columbia Ministry of Environment.

Welch, D.W., M.J. Jacobs, H. Lydersen, A.D. Porter, L. Neega, and Y. Muirhead. 2010. Acoustic Telemetry Measurements of Survival and Movements of Adult Steelhead (*Oncorhynchus mykiss*) within the Bulkley River, 2009. Kintama Research Corporation, Final Report submitted to the B.C. Ministry of the Environment.

Welch, D.W., M.J. Jacobs, H. Lydersen, A.D. Porter, S. Williams., and Y. Muirhead, 2009. Acoustic Telemetry Measurements of Survival and Movements of Adult Steelhead (*Oncorhynchus mykiss*) within the Skeena and Bulkley Rivers, 2008. Kintama Research Corporation, Final Report submitted to the B.C. Ministry of the Environment.

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Appendix 1. Steelhead data obtained at campground sites by beach seining.

Appendix 2. Steelhead data obtained at canyon site by dip net

Appendix 3. Summary of data for steelhead recaptures obtained during the 2010 Moricetown tagging program.

Appendix 4. Summary of mark-recapture data and results for the Schaeffer and Maximum Likelihood Darroch estimates for steelhead abundance in 2010.