Bulkley/Morice Steelhead Assessment, 2000

A PETERSEN CAPTURE-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

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Executive Summary

The Bulkley and Morice rivers are significant contributors to the Skeena River. both in terms of discharge and use by steelhead. The steelhead of the Bulkley/Morice system are highly significant to anglers, First Nations. local communities and to the integral functioning of the ecosystem. Management efforts in allocating use of these fish and instituting regulations have been based largely on two indexes of steelhead abundance –the Tyee Test Fishery and results from the annual Steelhead Harvest Analysis. Both indexes provide valuable information of long-term trends in steelhead abundance in the Skeena and Bulkley/Morice systems, but cannot be used to provide absolute population estimates without some form of calibration. Recognizing all of these factors, and the critical need for accurate and current data on the steelhead in the Bulkley/Morice systems in order to manage users of these rivers, the Bulkley Valley Branch of the Steelhead Society of British Columbia has been the driving force behind attempts to derive accurate steelhead population estimates of the Bulkley/Morice systems above Moricetown in 1998, 1999, and 2000. The 1998 program was fraught with political difficulties and resulted in being cancelled prior to completion. but 1999 and 2000 both resulted in successful completion of capture-recapture programs allowing Petersen estimates of the population sizes to be determined.

Tag application to an estimated 1,211 steelhead was conducted by the Wet'suwet'en Fisheries between early August and late October 2000, via three separate fisheries – a seine, dip net and fish wheel. Tag recovery was conducted by volunteer anglers throughout the length of the river system between early October and the end of December, 2000; this resulted in a total catch of 945 fish, 41 of which were tagged. In order to accurately estimate the number of steelhead within the area of interest, these values were corrected for drop-back (emigration; 4.2%), multiple recaptures (6.2%), and tag loss (1.5-2.4%). After such corrections, the resulting Petersen estimate of the number of steelhead upstream of the Moricetown Canyon in autumn, 2000 is approximately 22.630 with (Poisson) 95% confidence intervals of 19,200 to 32,135 fish. This estimate is similar to the 1999 estimate but lower than 1998. The identification of the sex of the fish remains problematic, similar to 1999, with males likely misidentified as females. Fork length measurements are very consistent between fisheries.

An assessment of the Tyee Test Index and the Steelhead Harvest Analysis compared with the 1998-2000 Petersen estimates of the Bulkley/Morice, and with eight years of Toboggan Creek data, showed discrepancies and low correlation. It appears that the two indexes are reasonably well correlated with each other, but do not correlate with population estimates. The implication of this is that absolute abundance of steelhead in the Bulkley River cannot be reliably estimated from these indexes. However, the small sample size involved must be a consideration in any conclusions drawn from these analyses.

A number of assumptions underlie the Petersen capture-recapture methodology and must be met or approximated for a valid population estimate to be calculated. The

first is that the population is "closed" (i.e.. there are no introductions or losses to affect the estimate). For the Bulkley River steelhead. births/recruitment do not occur during the period of study, immigration is estimated to be minimal, and emigration (drop-back) is corrected for. The large number of tags applied also lends a degree of robustness to violation of the closure assumption. Thus, while closure may not be rigorously met (and rarely is in capture-recapture studies), for these fish in this system it is at least closely approximated.

A second important assumption is equal catchability of all fish. The use of different capture methodologies (seine, dip net and fish wheel during application; angling during recovery) minimizes bias due to previous capture history and helps to ensure this assumption is met. As well, the distribution of tagging effort to the steelhead run is shown to be representative with respect to final destination (i.e., all "stocks" are equally likely to be tagged) and time through the canyon (i.e., "early" run equally likely to be tagged as "late" run; equal probability of tagging throughout the day). The tagged fish appear to mix randomly with the untagged fish, and equal mortality between tagged and untagged fish is tested (and found to be equal) on a tributary of the Bulkley – Toboggan Creek. It is concluded from these analyses that the assumption of equal catchability of all fish is met, or at least closely approximated, and that there are no obvious biases present affecting catchability that would significantly influence the estimate of total steelhead upstream of Moricetown Canyon.

Tag loss and non-reporting of tags may also affect the population estimate. In this study assumed tag loss is corrected for, and the magnitude of the bias associated with unreported tags is shown to be small. Therefore, it is unlikely that these factors significantly influence the population estimate.

In conclusion, the 2000 estimate of the Bulkley/Morice steelhead population appears to be a valid and reliable estimate of the true population. Based on 1999 and 2000 results, the recent steelhead population appears to be on the order of 22,000-27,000 fish. The existing methodology of tag application and recovery is not without its problems, but it is fundamentally sound and is a valuable and important method of providing accurate and up-to-date information on the steelhead population of the Bulkley/Morice systems. Such information is critical to allow appropriate management. Recommendations to improve precision and assess biases further, include:

- Continuation of this program every 3-5 years
- Improved identification of sex of fish
- Use of a different secondary mark
- Analysis of seine and dip net selectivity using existing Coho data
- A comprehensive compilation/critical analysis of steelhead estimation procedures in use in Bulkley and Skeena systems
- Comprehensive compilation/critical analysis of all existing information on steelhead in Bulkley/Skeena systems
- Critical assessment of the use of Toboggan Creek as an indicator stream for the much larger Bulkley/Morice systems.

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INTRODUCTION

1.1 Background

The Bulkley River (including the Morice) is a highly significant steelhead (*Oncorhynchus mykiss*) angling river within British Columbia; this is evident by its designation as a Classified Water in 1990 (Anonymous, 1998), and the estimated angling pressure it receives (Morten, 1999, but see also Mitchell, 2001). The steelhead within the system are also important to the First Nations (Wet'suwet'en and Giksan) as a food source and cultural icon, and to local communities as an attraction producing economic benefit by luring non-local anglers to the area (see Morten and Parken, 1998; Morten, 1999; Mitchell, 2001 for estimates of non-local angling use). Additionally, from a non-anthropocentric perspective, there is the biological/ecological role that the steelhead play within the aquatic system – acting as prey at one level and predator at another. Yet despite the importance of steelhead in this system to anglers, communities, First Nations, and the integral functioning of the aquatic system, there have been very few studies aimed at quantifying how many steelhead are actually present in the Bulkley/Morice system.

Traditionally, agency/government emphasis has been placed on the Tyee Test Fishery as an estimator of steelhead abundance in the Skeena drainage. The Tyee Test Fishery has been in operation since 1955 and is conducted by setting a 366 m long by 6 m deep nylon gillnet (mesh size 9 cm to 20 cm) in a 0.8 km wide channel running parallel to the northern shoreline of the river at Tyee (Anonymous, 2000). Drifts are exactly one hour long and usually three sets are made in a day, but sometimes only two are possible. In the last ten years the test fishery has run between July 1 and August 25 (1996) to October 7 (1998) (Anonymous, 2000). The goal is to estimate the number of sockeye salmon (*O. nerka*) past this point by developing an index, and then calibrating this with the known number of sockeye through the Babine counting fence. This calibration is based on the previous three years of Babine fence counts, and is thus continually updated. As incidental catch in this fishery steelhead are also captured and thus a similar index developed. Tyee Index values for steelhead from 1990 to 2000 are presented in Figure 1. However, there is no second, absolute, steelhead count allowing this index to be calibrated as there is with the sockeye, and the relationship between the Tyee Test Index catch and the true steelhead abundance has been an issue throughout the existence of the fishery (Hooten, 1999). This lack of a second, accurate, count means that the index of steelhead abundance cannot be transformed into terms of absolute abundance. As White et al. (1982 p. 32) state "*The use of indexes in science is to be discouraged because indexes lack the basic factors required for making inferences about parameters based on data. Indexes are useful only when they have been calibrated with the parameter of interest.*" Such calibration has not been adequately performed/documented to place much reliance on the Tyee Test Fishery with respect to steelhead <u>except as an indicator of trends over time</u>. The fact that it has been consistently performed annually over the last 45 years suggests that the information may accurately reflect trends of abundance.

The Tyee Test Fishery has been used to estimate steelhead abundance by multiplying the Index value by a factor of 245 (Hooten, 1999); this implies that there are 245 steelhead escaping the net for every one captured. This current multiplier of 245 fish per index point appears to be used largely due to lack of a better guesstimate. The development of this value is not well documented to allow analysis of how it was derived. In addition, profound regulation changes in 1991-1992 also likely affected any multiplier in use in the 1980s and carried over into the 1990's. The commercial interception of steelhead was high prior to 1992-93 when the Department of Fisheries and Oceans (DFO) began to reduce interception of steelhead to a targeted 50% of pre-1990 levels on the approach to the Skeena and Nass rivers. At the same time the Provincial government introduced strict rules enforcing the release of wild steelhead caught by sport anglers (Smith, 2000; Smith et al., 2000). These management decisions, and the implementation of them, has resulted in a larger number of steelhead escaping to the Skeena and Bulkley river systems, making any non-revised multiplier likely in error. Despite all of these issues with the Tyee Test Index, this method has been considered by Provincial Fisheries staff to be adequate for management purposes (R. White, cited in Mitchell, 2000a).

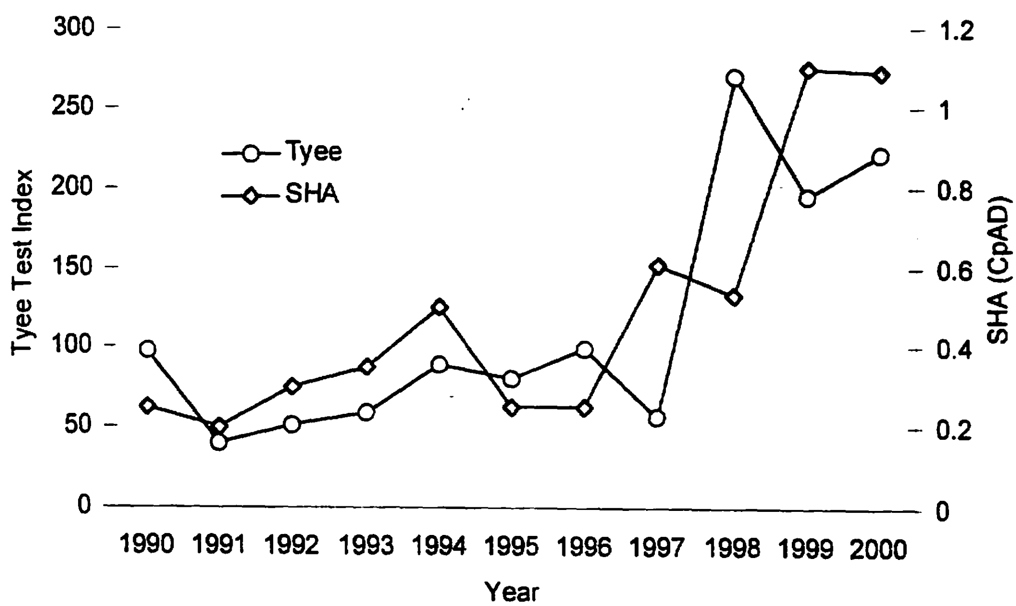


Figure 1: Trends of Tyee Test Index and Steelhead Harvest Analysis (Catch per Angler Day; CpAD) between 1990 and 2000. Data from DFO website, MELP SHA, and Smith et al. (2000).

A second source of data used by the Ministry of Environment. Lands and Parks (MELP) for estimating relative abundance of steelhead has been another index. the Steelhead Harvest Analysis (SHA). Since 1967, the provincial government has sent out questionnaires to a random sample of anglers who had angled for steelhead the previous fiscal year (Billings, 1989). The questionnaires are sent to approximately 60% of anglers who had purchased a license (Smith et al., 2000) and the response is variable per year, but generally is in the range of 43-58%, though has ranged from 29% to 58% over the last 33 years (G. Scolton, Ministry of Environment, Lands and Parks. personal communication). The questionnaires collects data on the number of days fished, residency of the angler, location (river) fished, and number of wild and hatchery steelhead captured. From this data an estimate of Catch per Angler day (CpAD) may be derived. Similar to the Tyee Test Fishery, the SHA provides a valuable index of steelhead abundance due to its high degree of consistency over time. However, without some form of calibration of absolute steelhead numbers, abundance may not be estimated from it with any validity (note Table 10 in Mitchell 2000a which attempted this is in error). Steelhead Harvest Analysis Catch per Angler Day data for the Bulkley River from 1990 to 2000 are presented in Figure 1. The SHA has been criticized as being biased and of low precision (DeGisi, 1999), though the presentation of his results are not convincing of this. In contrast, the SHA has also been reported to provide a reliable index of the mean trends in wild adult steelhead abundance (Smith et al., 2000). Accepting that even should significant bias exist in the data collection, consistent collection over the 33 years of the SHA existence would imply consistent bias, and thus the index may still be useful. As Krebs (1989; p.59) points out – "*If the bias is such as to be consistent over time, your biased estimates may be reliable indicators of changes in a population.*" Therefore, it is included here for comparison with the Petersen derived population estimates.

While the Tyee Test Index is considered adequate for management purposes by Government managers, the accuracy of estimates based upon this and decisions made using the SHA are questionable due to the lack of calibration. The increasing demand for fishing opportunity by the commercial sector, and the escalating intensity of catch and release sportfisheries, as well as First Nations requirements, result in increasing fishing pressure on salmonid stocks. The use of accurate and up-to-date information is essential (particularly considering the significant fishery changes in the early-mid 1990's) to properly manage people in order to ensure steelhead population stability/viability while meeting the demands of society. For these reasons, since 1998 the Bulkley Valley Branch of the Steelhead Society of British Columbia (SSBC) has promoted and been the driving force in attempting to derive more accurate estimates of the number of steelhead in the Bulkley/Morice system using more sophisticated methodology; that is, capture-recapture techniques.

In 1998, 1999 and 2000 the Wet'suwet'en Fisheries, in conjunction with the Department of Fisheries and Oceans, have been applying tags to steelhead in addition to the regular Coho salmon (*O. kisutch*) tagging program in Moricetown Canyon. This steelhead tagging program, combined with a recapture phase, allows an estimate of the number of steelhead in the Bulkley system upstream of Moricetown Canyon. Due to difficulties and agency concerns, the 1998 recapture phase was cancelled (see Mitchell

2000a for review), but a total of 36.000 fish were estimated in that year using a different methodology (Mitchell and Wadley, 1999). The 1999 applied tags were not recaptured until Spring of 2000, due to political and weather prohibitions, and the resultant Petersen estimate for Autumn 1999 was approximately 27,000 steelhead in the Bulkley/Morice system above Moricetown (Mitchell, 2000a). In Autumn 2000, the program was again conducted, with tags applied in three different fisheries at Moricetown, and a recapture phase conducted by volunteer anglers during the Autumn months of 2000. This report documents this 2000 program and compares results with previous years estimates.

1.2 Rationale and Objectives

Recognizing that, *a*) the Bulkley River is a highly significant steelhead system to anglers, local communities, and First Nations, *b*) steelhead are an integral component to the natural functioning of the Bulkley River, *c*) the use of uncalibrated indexes does not provide valid abundance estimates, and *d*) accurate estimates of the steelhead population within the system are critical to allocation of use and protection of the Bulkley steelhead stock for the future, the need for accurate and up-to-date population estimates is evident. Accurate estimates would also provide a solid baseline (i.e., calibration) for which future comparisons and trends may be evaluated. Thus, the 2000 steelhead mark-recapture program was conducted with the objectives of:

To derive an estimate of the population size of steelhead upstream of Moricetown Canyon in the Bulkley/Morice system. This estimate may then be compared with estimates from the last two years and compared with the Steelhead Harvest Analysis and Tyee Test Fishery information.

To evaluate the value/applicability of the Tyee Test information and Steelhead Harvest Analysis information, with respect to estimating abundance in the Bulkley River.

To provide information on ancillary aspects of steelhead movement and behaviour on which there has been a great deal of speculation. Specifically, associated factors for which this project, and previous work, was expected to provide information were:

- Rate of drop back of tagged fish below the canyon
- Sampling biases between the seine fishery and dip-net fishery
- Similarity of (or differences in) distribution of tagged and untagged fish after tagging
- The final destination of steelhead relative to their timing of movement through the Canyon.

To encourage working relations between First Nations, communities and Government. First Nations and community groups are demanding larger roles in the management of natural resources; fostering these working relationships will be important in ensuring integrated management of these resources in the future.

2.0 STUDY AREA

Originating in a high lake system (i.e., above 850 m) which includes Bulkley, Maxan, Nanika, Kidprice, Atna and Morice lakes, the Bulkley/Morice drains an area of approximately 12,173 square kilometers (Morten, 1999). These river systems extend from the confluence of the Bulkley and Skeena Rivers at Hazelton (Lat. 127°40', Long. 55°15') upstream approximately 218 kilometers to the outflow of Morice Lake (Lat. 127°25', Long 54°75') (Figure 2). This drainage flows through the Boreal Interior, Subalpine Southern Cordilleran, and Southern Cordilleran Ecoclimatic Regions of the Cordilleran Ecoprovince (Anonymous, 1989). Biogeoclimatically this large area is diverse with Interior-Cedar Hemlock and Sub-Boreal Spruce zones covering most of the study area, at least at valley bottom level, changing to Englemann Spruce –Subalpine Fir at higher elevations (Banner et al., 1993). Coastal Western Hemlock and Mountain Hemlock zones also form small components of the study area. The soils are mapped as Humo-Ferric Podzols and Luvisols throughout the drainage (Lord and Valentine, 1981). These soils are associated will well drained areas (Podzols) or poorly drained sites due to accumulation of clay horizons (Luvisols; Valentine and Lavkulitch, 1981). The climate is relatively mild in the area (the following is from the Smithers Airport Climate Station; Anonymous, 1991a) with a mean annual temperature between 1961 and 1990 of 3.8°C, and mean daily temperatures ranging from –9.0°C (January) to 14.9°C (July). Mean annual precipitation amounts to 337.4 mm/year as rainfall and 216.4 cm/year as snowfall. There are an average of 1,164 degree days greater than 5°C. It is important to note that the preceding is based on only a single station at Smithers. The climate varies between this point and the upper reaches of the Morice, so these values should not be taken as representative, but only as a rough guide of the climate in the Bulkley/Morice area. Unfortunately there are only two climate stations in the study area (Smithers and Quick), so finer discrimination of climate is not possible.

The drainage areas accounts for nearly one-quarter of the Skeena River discharge above Terrace (Annual mean discharge 911 m^3/s, range 702-1,230 m^3/s at Usk Station No. 08EF001; this and following discharge data from Anonymous, 1991b). The Bulkley River (Annual mean discharge 134 m^3/s, range 100-188 m^3/s at Quick station No. 08EE004) is the largest tributary to the Skeena River, and is itself composed largely of flow from the Morice River (Annual mean discharge 74.4 m^3/s, range 58.1-92.1 m^3/s Houston Station No. 08ED002) which joins it downstream of Houston (Figure 2). The Quick stream-flow station is reported here as the geographically more appropriate Hazelton station has very limited outdated data (i.e., years of operation 1928-1941). However, calculated flows at Hagwilget (near Hazelton) are provided in Figure 3 (based on Northwest Hydraulics Consultants, Ltd., 2000) and the Mean Annual Flow at this point is calculated as 203.3 m^3/s (Kingston and Associates Ltd., 2000) which represents approximately 22% of the total Skeena mean annual discharge at Usk. Of course, below Terrace are additional incoming rivers (e.g., Zymoetz, Kalum. Ecstall, etc.) which greatly increase the discharge of the Skeena River.

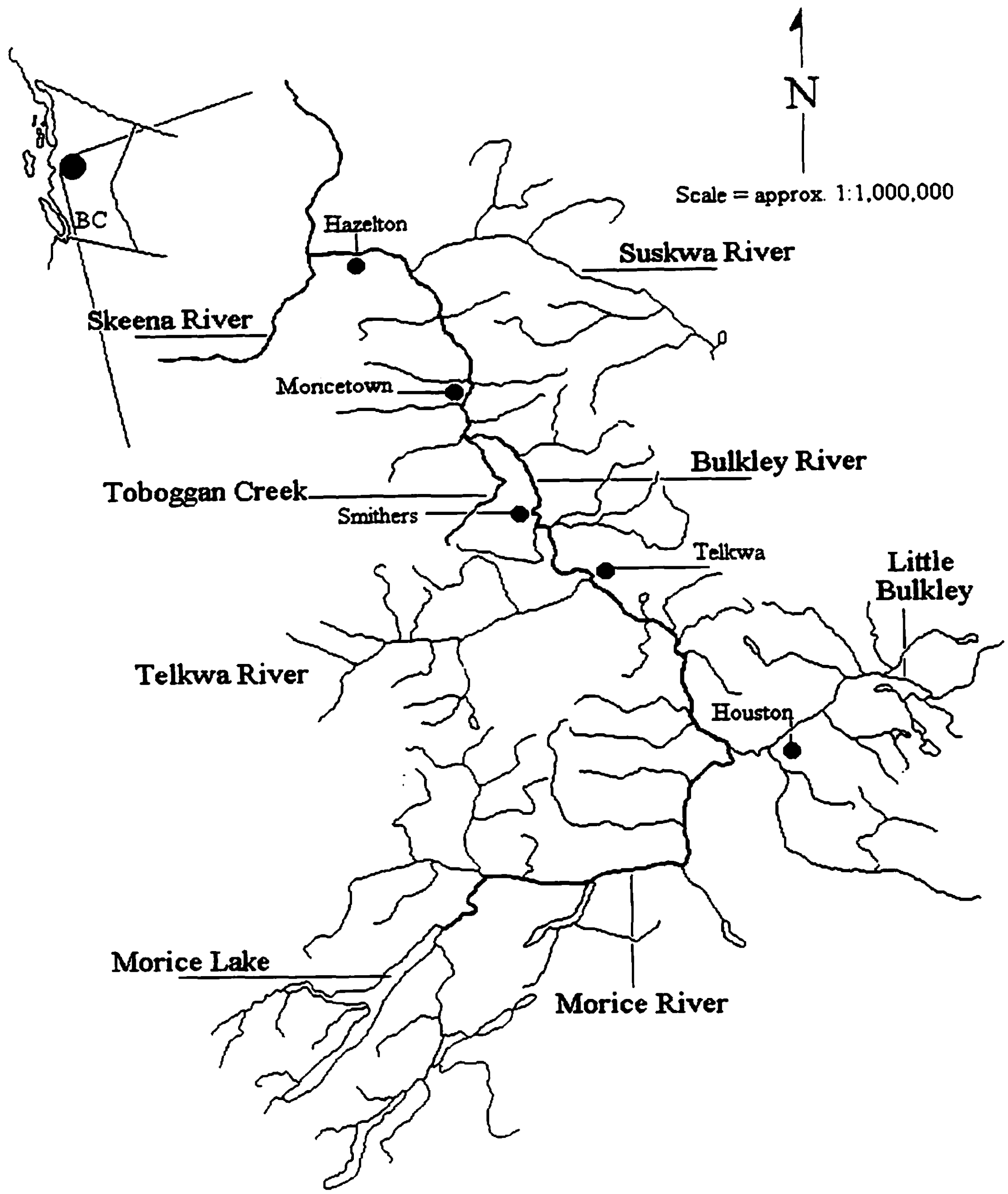
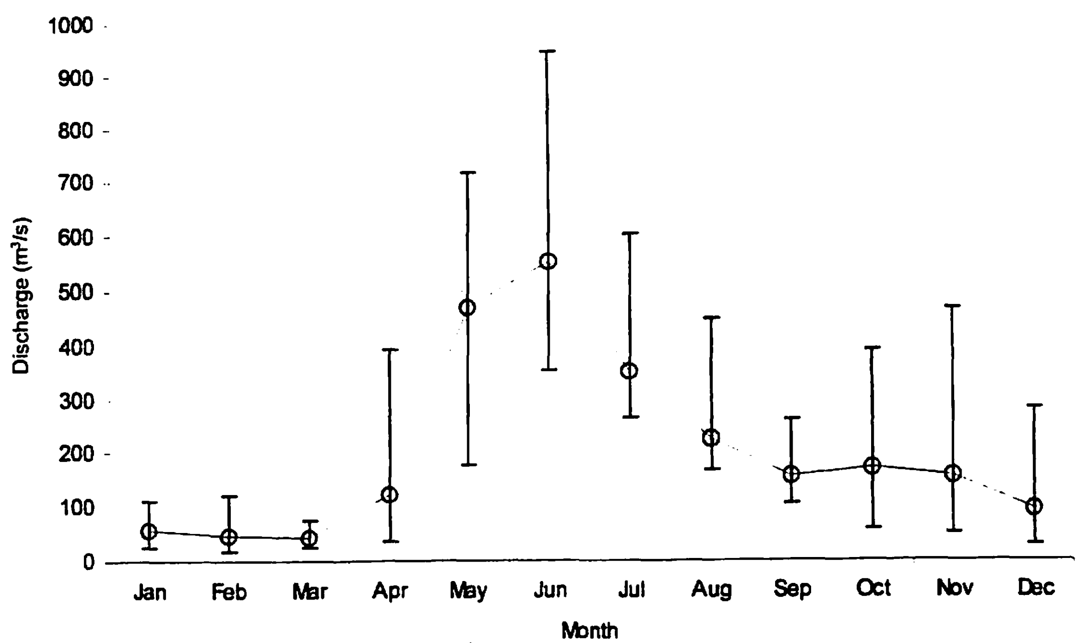


Figure 2: Study area of the 1999-2000 Bulkley/Morice steelhead assessment

Figure 3: Annual hydrograph of the Bulkley River at the Hagwilget wastewater treatment



facility. Points are mean estimated flows from Northwest Hydraulic Consultants Ltd. (2000). Error bars are minimum and maximum flows derived by using (drainage basin at Hagwilget / drainage basin at Quick) $^{0.9}$ as a multiplication factor of maximum and minimum flows at Quick station. Relationship determined in Northwest Hydraulics Consultants, Ltd. (2000).

The study area comprises a large number of tributaries in addition to the mainstem rivers. Some of the more important ones with respect to steelhead include Gosnell, Owen, Lamprey, Canyon and Toboggan Creeks, and the Telkwa River watershed. These tributaries are subject to degradation from a number of sources such as sedimentation due to upslope activities, poor culverts blocking fish passage, forestry activity, transportation corridors, agricultural uses, etc.(for examples see Mitchell 1997; Gibson, 1997; Mitchell et al., 1998). Toboggan Creek is a highly significant tributary from an enumeration perspective as there has been a fish counting fence on it estimating populations of Coho salmon (starting in 1989) and steelhead since 1993 (Mitchell, 1999a). This provides a valuable record of eight years of steelhead tagging behaviour with which to compare the results from the larger Bulkley.

The Bulkley/Morice drainage encompasses two of the primary steelhead producing streams of the Skeena River watershed – the Bulkley and Morice Rivers. Together these rivers are considered to be the destination of 33% (Koski et al., 1995) to

45% (Labelle et al., 1995) of the steelhead entering the Skeena River. Koski et al. (1995), using radio telemetry, report an approximate distribution of 75-80% of Bulkley/Morice bound fish to the Bulkley, and the remainder to the Morice. In addition to steelhead, all species of Pacific salmon (*Oncorhynchus*) are present in the system and resident fish species include rainbow (*O. mykiss*), cutthroat (*O. clarki clarki*) and bull trout (*Salvelinus confluentus*), Dolly Varden char (*S. malma*), kokanee (*O. nerka*), Mountain whitefish (*Prosopium williamsoni*), Pacific lamprey (*Lampetra* sp) and sculpins (*Cottus* sp.). Scott and Crossman (1973) list at least 22 fish species with distributions in the Bulkley River system.

There are five principal communities distributed along the Bulkley River; Hazelton, Moricetown, Smithers, Telkwa, and Houston though there is residency and land use (e.g., agriculture, pasture, etc) along its entire length where the terrain permits. Highway 16 follows the river over much of its course, and this together with secondary roads allows many access points for angling. There are also many areas for boat launching.

3.0 MATERIALS AND METHODS

3.1 Tagging and Recapture Procedure

3.1.1 Application (Autumn, 2000)

The Wet'suwet'en Fisheries conducted the 2000 Coho and steelhead tagging program from August 9 to October 18, 2000. In contrast to the 1999 application program, this year weekends were worked as well. The tagging program consisted of two crews during the week and one on the weekends using different capture methods – a beach seine crew below the canyon and a dip-net crew within the canyon. Marking of steelhead was carried out by applying a numbered spaghetti tag at the base of the dorsal fin with a secondary mark applied by a punch to the upper (seine fishery) or lower (dip-net fishery) lobe of the caudal fin. Some of the recaptured fish had the original tag removed and replaced with a second numbered tag.

Beach seining was carried out in the pool immediately below Moricetown Canyon using a 64 m x 11m seine with 5 cm diagonal mesh set from a jet boat. The net was set in a semi-circle to capture the fish and drawn to the beach to sort, tag and release captured species. Non target species (pink salmon, Dolly Varden, whitefish and bull trout) were released. Coho and steelhead were handled in the water for tagging, secondary mark application and measurement, and released after data was recorded.

Two crews were utilized in the dip-net fishery to tag and release Coho and steelhead both within Moricetown Canyon and in the fish way area at the head of the canyon. Each crew was comprised of two fishermen, a runner, a tagger and a data recorder. Steelhead were dip netted and transported immediately to the tagging location, measured, tagged and punched, and released upstream of the fish ways immediately after tagging. Capture and tagging took place daily between approximately 0600 to 2300 hours.

3.1.2 Recovery (Autumn, 2000)

The river was divided into fourteen reaches (Figure 4; Appendix 1) consistent with the 1998 and 1999 programs. Approximately seventy anglers and guides were selected to provide assistance in the recapture phase of the project; of these 40 (57%) had also participated in the Spring 1999 project, and 24 of the 70 (34%) had also assisted in the Spring 2000 angling recapture effort. All participants were instructed on methods and requirements, the goals and methodology of the project, and provided data books, instructions, and measuring tapes. Fishing was carried out between approximately October 4 (although 25 records prior to this are included in the analysis) to December 31, 2000. Anglers were encouraged to beach fish as quickly as possible, keeping them in the water while examining them closely for tags, secondary marks, predator, hook or net scars and measuring them before releasing them back to the river. The dorsal surface of the fish was examined for tag scars as well as the tail examined for punch marks or scars. Any fish that were hooked deeply or bleeding were recorded as such and the line was cut leaving the hook *in-situ* to avoid further injury by attempting to remove it. Fork length was measured (mm), sex of the fish identified, and condition at release recorded. Data cards were collected bi-weekly or submitted by guides at the end of season. No effort was made to control timing or location of angler effort during the early phase of the recovery component, but as data came in efforts were focussed to ensure coverage on more remote/under-fished reaches. This was to done to approximate representative coverage of all reaches.

3.2 Statistical Analysis

3.2.1 Population Estimate

The steelhead population estimate for 2000 was made using the modified Petersen estimator (from Krebs, 1989):

$$N' = (M * (C+1)) / (R + 1)$$

Where N' = Estimated population size at time of tagging
M = Number of individuals marked in first sample
C = Total number of individuals captured in second sample
R = Number of individuals in second sample that are marked

This estimator is slightly different from that used in the 1999 project in that this formula is appropriate when sampling with replacement and is nearly unbiased when the number of recaptures is greater than six (Krebs, 1989). The population estimates using either method are very similar. The Poisson approach was used to calculate 95% confidence intervals for the estimate (see Krebs, 1989). The comparison of population estimates between years is based on 95% confidence intervals; if the value for one year falls outside the confidence intervals of the other, they are deemed different.

3.2.2 Assessment of Precision and Tests of Bias

Evaluation of the precision and bias required a variety of statistical approaches/tests and these are documented as encountered in the text. For all tests $\alpha = 0.05$ and the null hypothesis is rejected if $p<0.05$.

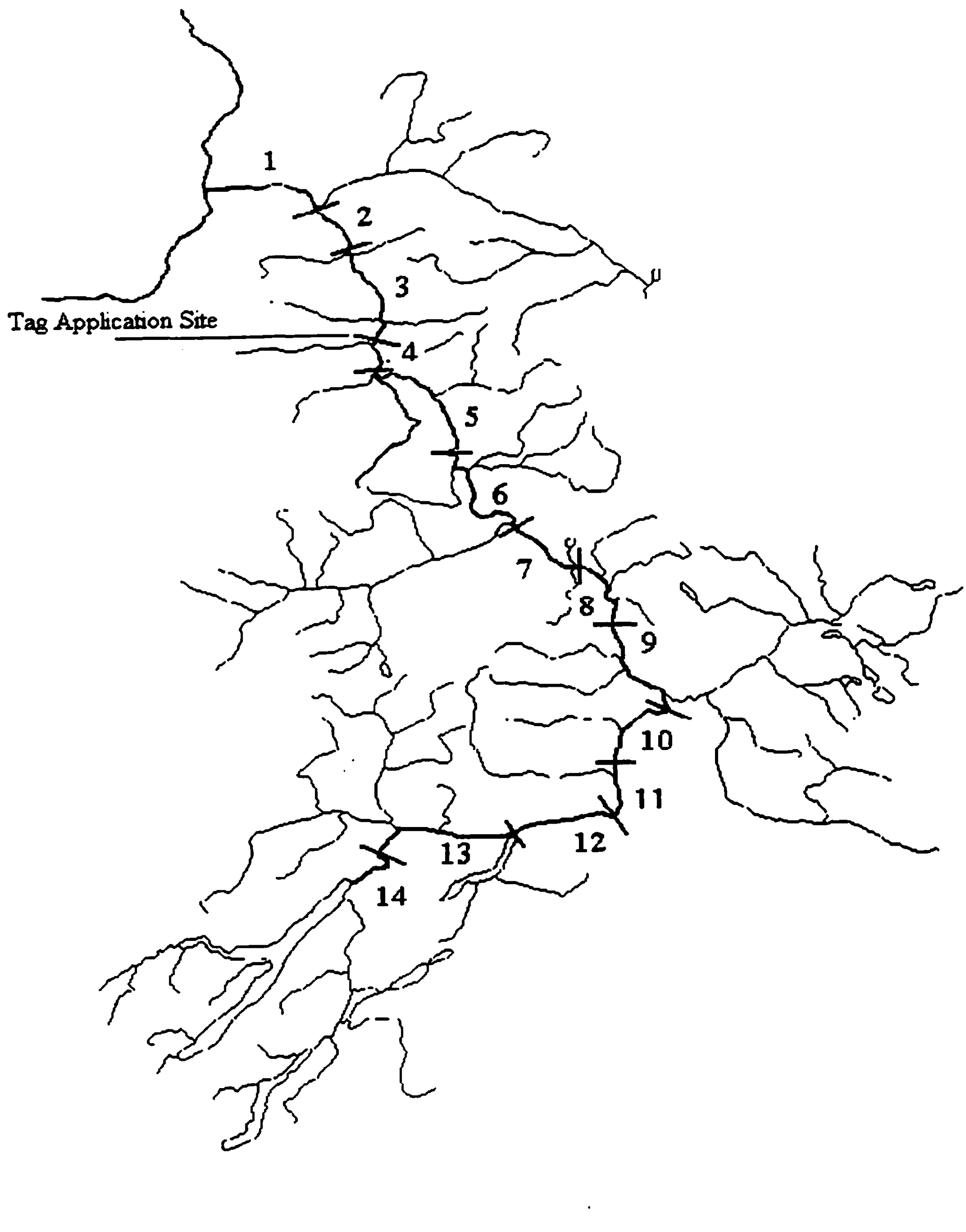


Figure 4: Breakdown of reaches of 2000 Bulkley/Morice steelhead assessment for recovery component.

4.0 RESULTS AND DISCUSSION

4.1 Population Size and Characteristics

4.1.1 Population Size

"An approximately correct estimate with low precision is always better than a highly precise incorrect estimate" (Paulik, 1963, cited in Otis et al., 1978).

Between August 9 and October 18, 2000, an estimated total of 1,211 steelhead were tagged (i.e., M=1,211) by the Wet'suwet'en Fisheries at Moricetown Canyon, with 992 of these being tagged in the dip net fishery, 208 in the seine fishery, and 11 in the fish wheel. Angling effort to recapture these tagged fish began on approximately October 4 and continued until December 31. A total of 945 steelhead were captured in this recapture fishery. Of these, 52 were tagged, with 43 of these tags originating in the Moricetown fishery and nine originating elsewhere (i.e., tag of a different color or from previous years or sources). Of these 43 recaptured fish with brown tags, two did not have their tag numbers recorded by the angler; thus, there are 41 positively identified steelhead recaptures, and two probables. The subsequent population estimates are conducted using estimated recaptures (R) of only the 41 positive recaptures. Of these 41 positively identified tagged fish, seven were tagged in the seine fishery and 34 in the dip nets.

A number of corrections to the values C and R used in the Petersen estimator need to be applied to accurately reflect the true number of steelhead captured, measured and recaptured. These corrections include excluding fish outside the area of interest and those caught more than once, and accounting for those which lost tags. The estimate of the steelhead population presented here is for the Bulkley/Morice rivers upstream of Moricetown Canyon, and therefore, only those angled fish caught upstream of Moricetown are included in the calculations. Sixty fish were angled below Moricetown, and these are subtracted from the 945 total angled fish to leave 885 angling captured fish (this is C in the uncorrected population estimate). No tagged fish were captured downstream of Moricetown in 2000, therefore, a "drop back" rate of steelhead below the canyon cannot be estimated. However, a drop back rate of 4.2% from 1999 (Mitchell, 2000a) is used to account for fish that may have moved downstream of the Canyon (see also Section 4.3.1b). The capture of individual fish more than once will inflate R and C, and thus this needs to be accounted for. None of the 41 angled tagged fish were caught more than once for a multiple recapture rate of 0% (as opposed to the estimated 10.3% in the 1999/2000 project; Mitchell, 2000a). In order to account for multiple recaptures, a weighted mean estimate of recaptures between the two years (68 recaptures in 1999-2000 with multiple recapture rate = 10.3% and 41 positive recaptures in Autumn, 2000 with recapture rate = 0%) of 6.2% is used to correct C (the number of individuals captured in the second sample). Finally, it may be expected that some fish lose their tags (i.e., they are pulled out due to excessive abrasion against objects, or not securely applied) and this potential loss of tags will affect the estimate of the population by reducing (R) and thus must be accounted for. A tag loss estimate of 1.5% (from the 1999/2000 project) is used to correct the number of recaptures (see also Section 4.3.4). Only one lost tag of 945 fish handled was noted in the Autumn 2000 recovery program, but due to the large number of anglers involved in the program this year it is uncertain how carefully all fish were checked caudally for punches or tagging scar (though see Section 4.3.4). Population estimates are presented in Table 1; these include both uncorrected and corrected estimates using the above described corrections.

TABLE 1: POPULATION ESTIMATES OF BULKLEY/MORICE RIVER STEELHEAD UPSTREAM OF MORICETOWN CANYON, AUTUMN, 2000.

	Uncorrected	Corrected
M	1211	1161[a]
C	885	831[b]
R	41	42[c]
N'	**25,545**	**22,627**
95% Confidence Interval	19.164-35.801	17.200-32.135

[a] = Corrected for drop back (4.2%)
[b] = Corrected for multiple recaptures (6.2%)
[c] = Corrected for tag loss (nominally 1.5%; actually 2.4%; see Section 3.3.4)

The population estimates for uncorrected and corrected data range between 22.627 and 25,545, a difference of 2,918 fish (i.e., the range of estimates are within 13% of each other). The confidence intervals range between 25% (lower interval) and 42% (upper interval) of the estimate. These ranges suggest that the estimates are relatively precise (i.e., 25% is considered appropriate for management studies; Krebs, 1989) and are similar to the precision of the 1999/2000 assessment. However, it should be noted that the estimator used (sampling with replacement) and confidence interval calculations (Poisson) are different in Autumn 2000 than those used in 1999/2000 (see Mitchell, 2000a). These minor differences notwithstanding, the Bulkley steelhead population in 2000 was similar to 1999 (i.e., the 1999 estimate falls within 95% confidence interval of the 2000 estimate) but less than the 1998 estimate (Figure 5). It is worth emphasizing that the 1998 estimates are based on an incomplete mark-recapture program and therefore must be interpreted cautiously in comparing with other years.

4.1.2 Comparison of Capture-Recapture Estimates with Indexes and Other Procedures

Comparison of the 2000 Petersen estimate of the Bulkley/Morice steelhead population with other, indirect, sources reveals some inconsistencies. Prior to the SSBC efforts beginning in 1998 to determine an accurate estimate of steelhead in the Bulkley River, the population in the river was unknown, and management was conducted largely based on the SHA and Tyee Test Fishery. As discussed in the Introduction, the SHA attempts to estimate the total capture effort and total number of fish caught relative to other years, while the Tyee Test Index is used to indicate trends over time (the extent of the usefulness of an index). Smith et al. (2000) found that Catch per Angler Day (CpAD) derived from the SHA was a generally reliable indicator of regional or geographic trends of wild adult steelhead abundance, and they further found that CpAD correlated (r=0.70) with results of the Tyee Test Fishery (see also Figure 1). Thus, the two indexes are relatively consistent, but I will reiterate White et al (1982; p.32) the "*Indices are only useful when they have been calibrated with the parameter of interest*" (steelhead abundance in this case). Therefore, it is of interest to attempt to correlate the Petersen estimates with the Tyee and SHA indexes, in an effort to calibrate them. Such a calibration will only be a coarse determination due to errors in estimation and the sampling of only a small proportion of a very large population.

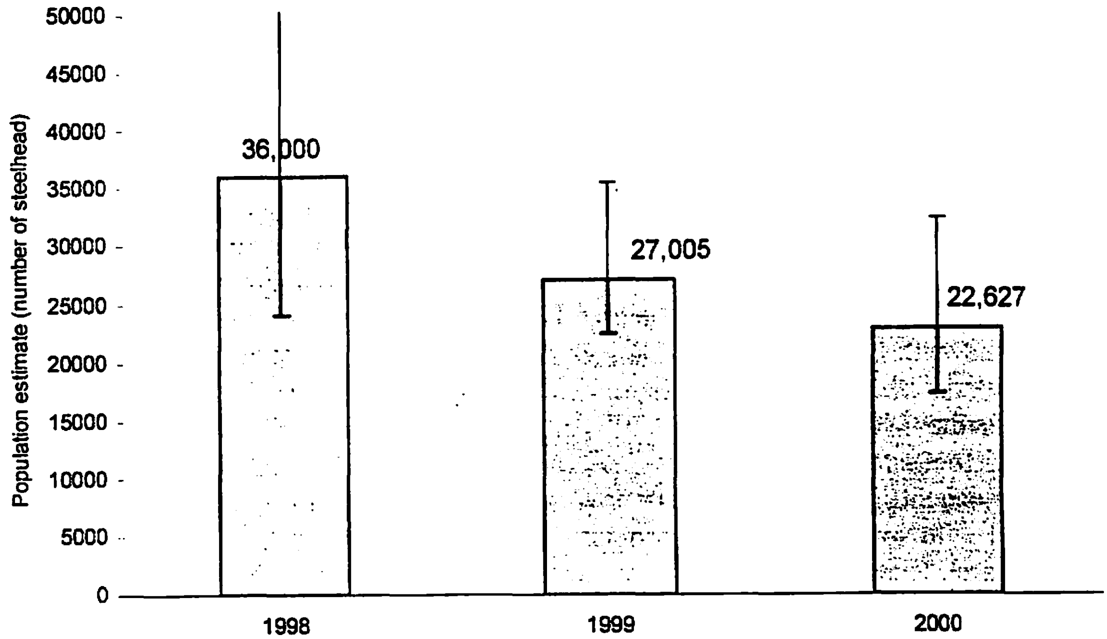


Figure 5: Estimated steelhead population in Bulkley/Morice rivers, 1998-2000. Data from Mitchell (2000a) and this study. Error bars are 95% confidence intervals (for 1998 upper interval = 71,800 fish).

In attempting to calibrate the Tyee Test Index with the estimated populations in the Bulkley between Autumn 1998 and Autumn 2000, the years 1998 and 1999 provided close agreement (133 to 135 fish per point, respectively) but Autumn 2000 indicated substantially lower fish per point (97.7) in such an index. Due to this discrepancy, it was thought that an assessment of longer term data would be appropriate. Toboggan Creek provides eight years of population estimates data to compare with the Tyee Test Fishery for concordance, but first its relationship with the abundance of steelhead in the Bulkley needs to be established. In Spring, 1999, twelve of approximately 2,000 (0.6%) Moricetown tagged fish were found at the Toboggan Creek fence, and in Spring 2000 nine of 1,630 (0.55%) Moricetown tagged fish were present in this stream (Mitchell, 1999a; 1999b; 2000b). The 2000 Moricetown application component in Toboggan Creek for Spring 2001 is not available at the time of report preparation. Based on these estimates, and since marked and unmarked fish appear to mix randomly (Mitchell, 2000a and Section 4.3.3c), it appears that the Toboggan stock accounts for approximately 0.5-1.0% of the entire Bulkley steelhead population. Previous studies also indicate that Toboggan Creek accounts for between 0% (Beere, 1991) and 1.07% (Lough, 1992; 1993) of the entire Bulkley/Morice run, providing good agreement between studies. The correlation between Toboggan Creek and the Bulkley River steelhead populations may be further validated/assessed via the count of Moricetown tagged fish through the fence in the Spring of 2001. As a prediction, if 0.6% of Moricetown tags end up in Toboggan Creek, the 2001 Spring Toboggan recovery should encounter 12 or 13 Moricetown tags.

The use of Toboggan Creek may be considered a near independent assessment of the Bulkley/Morice Petersen estimates for 1998 and 1999 as the only shared data is the estimate of M. The close agreement between estimates (i.e., 1998 estimate of 36,000 fish based on the Bulkley assessment, 35,700 by expanding Toboggan Creek by 100 times; 1999 estimate of 27,005 fish based on Bulkley assessment, 28,600 by expanding Toboggan Creek estimate) provides a certain degree of confidence that Toboggan Creek is representative of the Bulkley River. Using this logic, the results from Toboggan Creek should correlate well with the Tyee Test Index if the Tyee Fishery is indicative of abundance in the Bulkley River. These data, and their correlation, are provided in Table 2. It is clear that there is no correlation between the Tyee Test Index and the estimated steelhead population of Toboggan Creek. This implies that the Tyee Test fishery is not well correlated with the Bulkley steelhead population either. That the SHA data is also not correlated with the Toboggan Creek estimates suggests that a relationship (at least a linear relationship) between CpAD and estimated population size is not apparent. Of course, it must be recognized that these are very small samples with which to be attempting to determine correlation. However, Sokal and Rohlf (1973) indicate that for a sample size of eight, correlation coefficients of less than 0.71 are not statistically significant; this lends some weight to the determination that there is no correlation between the indexes and actual population estimates. As a check on this analysis, the correlation of the SHA with the Tyee Test Index is 0.513 – still not significant based on n=8, but approaching the value reported by Smith et al. (2000). Thus, it appears that Toboggan Creek represents approximately 1% of the Bulkley run, but the population of this small system cannot be reliably estimated from the two indexes. If this small system cannot be well estimated by these, than it remains doubtful whether the much larger (and perhaps more variable) Bulkley/Morice system can be estimated from these.

A Petersen steelhead population estimate for the Bulkley/Morice rivers using only the seine and dip-net Moricetown fisheries, in which tags are applied in one and recaptures conducted in the other, has been proposed. The initial attraction of this approach is obvious; it is much less labor intensive and would provide an in-season population estimate which management could then use immediately. Indeed, such a project was conducted on the 1999 tagging data (SKR Consultants Ltd., 2000), and they derived a population estimate similar to the larger scale study reported by Mitchell (2000a). However, their precision was considerably less (i.e., ± 43%-52%) and there are fundamental problems with this approach. Primarily, this in-season approach cannot be expected to even approach meeting the assumption of closure for the Petersen estimate as large amounts of immigration are occurring while the project is ongoing. It is also not possible to test for random mixing of tagged and untagged fish. As well, the resulting small sample size, when compared with the angling recaptures, inflates the confidence intervals and decreases the power of testing for biases. In the Autumn 2000 tagging operation 19 fish were tagged and recaptured in the dip net, 8 in the seine, 13 tagged in the dip net and recaptured in the seine, and 2 tagged in the seine and recaptured in the dip net. Thus only 2 of 42 fish were captured moving in the appropriate direction (from seine upstream to dip net) to even approximate the assumption of random mixing. In 1999 only 8 of 55 tag recaptured fish were encountered moving from the seine to the dip-net (SKR Consultants Ltd., 2000). Twenty seven of the 42 fish (64%) in 2000 and 31 of 55 fish (56%) in 1999 were tagged and recaptured in the same gear which has potential biases associated with it (see Section 4.3.3a). As a rough estimate, if M for 2000 is taken as 1,211 fish, C_{DipNet} = 992 and R_{DipNet} = 21 for the dip net fishery, and C_{Seine} = 208 and R_{Seine} = 21 fish for the seine fishery, the calculated Petersen estimates using these techniques are N_{DipNet} = 54,660 and N_{seine} = 11,505. This is a very wide range of estimates depending upon how the data is used. For these reasons - violations of assumptions, inability to test assumptions, small samples, and inconsistent results depending on how they data is used - the use of an in-canyon, in-season estimate cannot be justified for use in estimating steelhead populations in the Bulkley River.

Table 2: Tyee Test Index (TTI), Steelhead Harvest Analysis (SHA in CpAD) data and Toboggan Creek population estimates (number of steelhead), 1993-2000. Note: TTI and SHA are values from year prior to that listed as these are measures made in Autumn while Toboggan Creek count is conducted the following Spring. Correlation coefficients (ρ) are very low indicating no correlation between measures.

Year	TTI[1]	Toboggan Creek[2]	SHA[3]
1993	52.04	435	0.30
1994	59.61	237	0.35
1995	89.08	330	0.5
1996	80.16	120	0.25
1997	99.14	543	0.25
1998	56.05	381	0.61
1999	269.64	357	0.53
2000	195.01	286	1.10
ρ	0.003		-0.107

[1] = from DFO website (Anonymous, 2000)
[2] = from Mitchell (1999a; 1999b, 2000b)
[3] = from MELP SHA and Smith et al. (2000)

4.1.3 Fork Length and Sex Ratio

Fork lengths of the steelhead sampled are presented by capture method and reported sex in Table 3 and Figure 6. These results include the 60 fish captured downstream of Moricetown, in contrast to the population estimate which excluded these animals. Condition of the angled fish are summarized in Table 4.

Table 3: Fork lengths (mm) of sampled steelhead by capture method and sex for application and recovery samples. Number of male and female not equal to total *n* as sex not recorded for all fish.

	Tag Application							
	Seine (n=208)			**DipNet (n=992)**			**Fish Wheel (n=11)**	
	Male	Female	Sexes combined	Male	Female	Sexes combined	Male	Female
Mean	754.40	693.58	710.92	697.83	692.03	693.54	--	707.27
Std. Dev.	80.66	79.52	84.27	85.78	78.92	80.75	--	104.22
Median	760	702.5	720	710	700	700	--	710
Minimum	530	470	470	380	290	290	--	510
Maximum	925	920	925	950	960	960	--	900
n	59	148	207	256	730	986	0	11
Sex ratio (F:M)		2.50:1			2.84:1			

	Angling Recovery					
	Tagged (n=43)			**Untagged (n=893)**		
	Male	Female	Sexes combined	Male	Female	Sexes combined
Mean	746.0	694.0	713.5	730.71	721.99	725.85
Std. Dev.	65.77	75.15	75.36	102.22	74.34	87.87
Median	750	710	717.5	750	730	735
Minimum	630	540	540	305	300	305
Maximum	900	820	900	1040	900	1040
N	15	25	40	395	495	890
Sex ratio (F:M)		1.53:1			1.25:1	

Similar to the 1999/2000 study, the sex ratio of females to males in the application fishery appears elevated in Autumn 2000 (see also Section 4.2.2). The steelhead moving through in August to October are very difficult to accurately sex as the secondary sex characteristics (e.g., color and type) have not yet developed. In addition, the Coho and steelhead are handled and processed in the application fisheries with a goal of rapid movement of the fish in order to minimize stress to the animal, thus the workers are trying to handle a large number of different animals as quickly as possible which does not allow extensive time for sex identification. Due to this elevated sex ratio suggesting probable error in sex identification, the measured fork lengths by sex are provided in Table 3 but no further analysis using stratification by sex of the application fisheries is conducted. The reported lengths by sex for tag application in Table 3 are not to be taken to be accurate and the reader is discouraged from using these estimates in future work. Fork lengths of the combined sexes, however, are accurate and may be used with confidence (see Section 4.2.3).

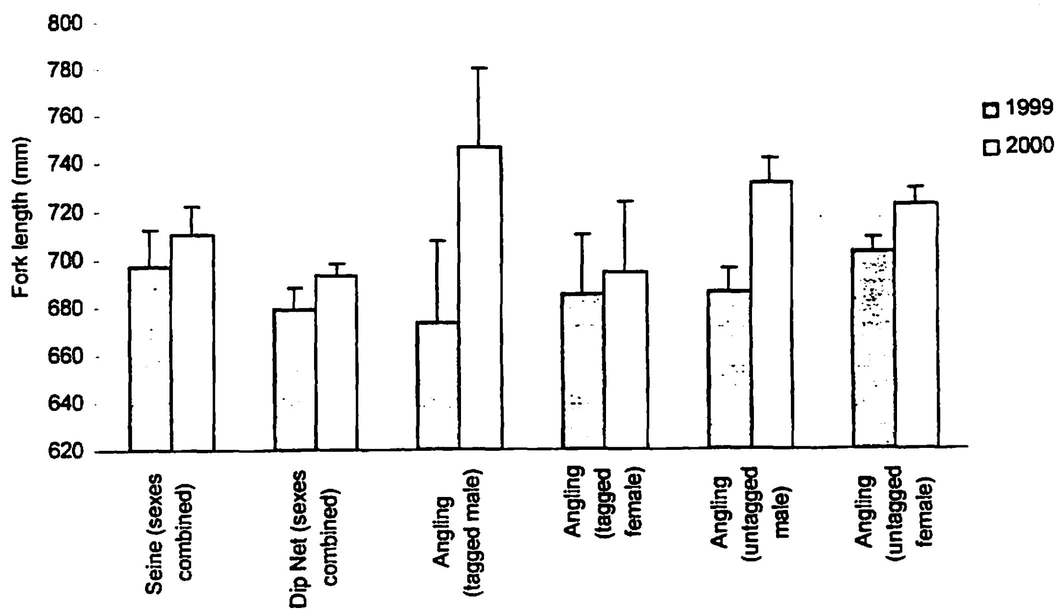


Figure 6: Mean fork length, with 95% confidence intervals, for the various fisheries between 1999 and 2000. Note. Seine and dip-net fish have sexes combined due to imprecise sexing.

TABLE 4: CONDITION OF THE AUTUMN, 2000 ANGLED FISH IN BULKLEY/MORICE SYSTEM. PERCENTAGE OF TOTAL CAUGHT IS OF TOTAL FISH CAPTURED WHILE PERCENTAGE OF REPORTED IS OF TOTAL WITH COMMENTS RECORDED. ALSO INCLUDED ARE PERCENTAGE BY CATEGORY FOR SPRING 2000 ANGLED FISH (FROM MITCHELL 2000A).

Condition	Number	% of total reported (n=764)	% of total caught	
			AUTUMN 2000 (N=945)	Spring 2000 (n=1334)
Bleeding	1	0.13	0.1	1.5
Damaged tail	10	1.31	1.06	1.4
Head scars/wounds	10	1.31	1.06	Not used
Hook scars/marks	68	8.9	7.19	3.6
Net marks	26	3.4	2.75	4.0
Miscellaneous scarring[1]	40	5.23	4.23	6.6

[1] = In Spring 2000 Miscellaneous include. head scars/wounds

Excluding sex stratification in the application fisheries, it may be seen that the mean fork length between the seine, dip net and fish wheel all fall within 17 mm of each other and the medians within 20 mm. This suggests that the 2000 fisheries tagged very similar mean size fishes, though the frequency of occurrence of the various size ranges varied significantly between the seine and dip net (see Section 4.3.2). The angling recovery showed the frequency of occurrence of fork lengths (in 10 mm increments) was different for untagged females from untagged males (χ^2 = 132.9, df = 53, χ^2_{crit} = 70.9, $p<0.001$), and tagged females (χ^2 = 61.3, df = 44, χ^2_{crit} = 60.48, $0.025<p<0.05$). All other groups (i.e., tagged and untagged males, and tagged females) were similar (chi-square tests, $p>0.25$ for all tests). Of interest, in 1999/2000, the fork length frequency of untagged females were significantly different from the untagged males, but similar to all others. This is consistent with the results from 2000, though in 2000 the untagged females were additionally found to be different from tagged females (they were the same in 1999). However, the statistical significance of this latter test is low ($0.025<p<0.05$), therefore conclusions cannot be safely drawn of the distribution of fork lengths between untagged and tagged females. It does appear however, that the distribution of fork length captured by angling is different between untagged females and males.

These Autumn 2000 results for the angling recovery across all categories show a range in mean size from the category with smallest mean size (tagged females) to the largest (tagged males) of 52 mm, and range of medians within 40 mm. Comparable measurements from the Spring 2000 indicate a range in mean size between fisheries of 57 mm and in median size of 90 mm. Thus, from a practical point of view, these fishing methodologies are capturing approximately the same size of fish with respect to mean size (within ~50 mm [5 cm] of each other) and median size (within 40-90 mm [4-9 cm] of each other). Due to the large sample sizes associated with the dip net application fishery, and also with the untagged component of the angling recapture, trivial statistical difference are easily found. However, these differences must be assessed at a practical level. For example, untagged females are significantly shorter than untagged males (a difference in mean fork length of 8.72 mm) but not tagged males (difference in means of 24.0 mm). This difference despite a shorter discrepancy in length is due solely to the much larger sample size ($n_{untagged}$ males = 395; n_{tagged} males = 15). Thus statistics should be applied sparingly among samples of such grossly differing sample sizes. The fork lengths results may be best viewed descriptively only, with limited or no inferential work done on them.

The condition reported for the angling released fish was similar between the 1999 and 2000 capture-recapture programs (Table 4). One difference was in the classification; in Spring 2000 the condition was divided into five categories while in Autumn 2000 there were six. The Spring category of Miscellaneous scarring was broken into Miscellaneous and Head scars/wounds in the Autumn sampling.

4.2 Precision of Measurements

In describing the steelhead population in terms of numbers, fork length and sex ratios, it is important to have some assessment of the accuracy of these estimates. However, since "*Accuracy is defined as "exact conforming to truth" or "freedom from error or defect". This ideal is unattainable in sampling studies and inductive inference; therefore, we rely on the concepts of bias and precision as aids in making good inductive inference*" (White et al., 1982; p. 18). The following is intended to provide the reader with an indication of the precision (i.e., bounds within which, if the experiment were repeated, results are likely to fall) of these estimated parameters.

4.2.1 Estimation of M, C, and R for Population Estimate

Precise estimates of the number of individuals marked in the first sample (M), total number of individuals captured in the second sample (C), and the number of marked individuals (R) captured in the second sample are essential to provide a valid and meaningful population estimate of the Bulkley/Morice steelhead. In determining the precision of M, problems arise in that multiple fish were marked, recaptured and some fish had original tags removed and replacement tags attached. Therefore, the estimate of M is not simply a count of known tags out. However, some feeling of the precision of the estimate may be developed. Prior to the QA/QC procedures on the tagging data conducted by SKR Consultants Ltd, I developed an estimate of M on the uncleaned data. The M estimate from this data was 1,217; the difference between this estimate and the second one developed after QC is only six fish (i.e., ~0.5% of the estimate of 1,211 fish). This suggests that based on the records of the Wet'suwet'en Fisheries, the estimate of the total number of marked fish at large is likely very precise, with an error of ± 1% or less. Gross errors in record keeping would, of course, make this estimate much less precise or valid. However, there is no reason to suspect that this has occurred, and thus the estimate of M for this study is accepted as a highly precise estimate of the true number of steelhead tagged by the Wet'suwet'en Fisheries.

The precision of C and R estimates are dependant upon the return information from the anglers in the program. It is well known that tag returns based on volunteer effort in capture-recapture studies are extremely variable and dependent upon the incentive to the angler (Paulik, 1961; Seber, 1973; Ricker, 1975). One important aspect in this study over other projects where tag returns by anglers/commercial fishermen is passive, is that this project entailed active pursuit of returns. The project coordinator made every effort to locate and retrieve the records of all anglers involved in this program. It is estimated that five of the anglers (5 of 70; ~7%) could not be accessed (G. Wadley, project coordinator, personal communication) but this active pursuit of the records ensured high returns of catch information, thus improving the precision of C and R estimates. There are two other potential sources of error affecting the accuracy of these estimates 1) differential probability of reporting catch by presence/absence of tagged fish, and 2) misreporting of catch. An angler may perceive his information as being of greater importance if he has caught a tagged fish, while if he has not he perceives that his records are of lesser significance. Anglers may also exaggerate their catch (i.e.. some fishermen lie) in order to enhance prestige (O'Neill and Whately, 1984; Pollock et al, 1994). This project attempted to minimize the type of bias by using a sub sample of the population of all Bulkley anglers; this sub sample of 70 selected angler had to have shown interest in the project and be accomplished steelhead anglers. As indicated in Section 3.1.2 many had participated in the previous two years projects and so were familiar with procedures and had demonstrated dedication. All of this will decrease inaccuracies in reported catch by ensuring anglers are conscientious and informed. I cannot rigorously quantify the precision of the estimates of R and C with available data but resort to the value of the large sample size as protection against systematic bias.

From the previous discussion it may be seen that the precision of the estimates going into the Petersen formula are relatively high (For assessment of bias. the other component aiding in making good inductive inference, see Section 4.3). The forgoing have not been rigorous tests but do provide confidence that the values being used to estimate the Bulkley steelhead population are reasonable and unlikely to be highly in error.

4.2.2 Identification of Sex and Estimation of Sex Ratios

The elevated sex ratio reported in the application fisheries in both 1999 and 2000 suggests that there may be a systematic bias within these fisheries in identifying males as females. In 2000, within the Moricetown fisheries, (i.e., between the seine and the dip net fisheries), there were 40 fish tagged in one fishery and recaptured in that fishery or the complementary one. Of these 40, seven (17.5%) were inconsistently sexed between the fisheries. Staff of one fishery identified these fish as one sex while personnel of the other fishery, or within the same fishery, identified it as the opposite. In the 1999 project the rate of inconsistent sexing between observers within the Moricetown fisheries was 32% (24 of 75 repeat handling of an individual fish). A comparison of the sex identification of the recaptured fish between the application fisheries at Moricetown and the angling fishery indicates that 14 of the 41 (34.1%) fish were inconsistently sexed between the fisheries in 2000. In 1999, the inconsistent sexing between the application and recovery fisheries was 48%. It thus appears that there is considerable inter-observer variability in sexing these fish, though it also appears to have decreased between the two years.

The elevated estimates of female to male sex ratios from the application fisheries are likely due to mistaken identification of males as females. The angling identification provides more reasonable estimates of sex ratios and show great consistency between years (1.29:1 in 1999, 1.26:1 in 2000), though even these estimates appear slightly high relative to eight years of fence counts on Toboggan Creek where the sex ratio has had a mean value of 0.82 F:M (SD = 0.19) (Mitchell, 2000b). Considerable variation in sex ratios has been demonstrated for a wide range of steelhead populations between southern BC and California (i.e., 1.2 to 3.2 F:M) but sex ratios of 1:1 are strongly indicated in general (Withler, 1966). A statistical comparison (Chi-square test followed by Tukey-type multiple comparison on proportions; pgs 395-402 in Zar, 1984) of the estimated proportions of females in the population between the seine, dip net and angling fisheries indicates that the seine and dip net estimates are similar ($0.2<p<0.5$), and both are significantly different ($p<0.001$) from the angling fishery.

The outcome of this analysis on sex identification is that the angling data appears to produce reasonable estimates of proportions of sex within the population (though Withler (1966) suggests angling may preferentially take females), while the Moricetown application data appears unrealistically high and is significantly different from that which is being defined as appropriate (i.e., the angling data). Therefore, as with 1999/2000, sex stratification is done only on the recapture data, and analysis of the application data does not stratify by sex.

4.2.3 Fork Length Estimates

Comparison of the measured fork length of 40 steelhead captured and recaptured within the seine and dip net fisheries result in a mean difference between observers when measuring the same fish of 17.5 ± 28.03 mm (±SD; n=40). The equivalent analysis between the application fishery and angling recapture fishery in both 1999 and 2000 result in mean differences of 17.23 ± 29.88 mm (n=70) in 1999 and 25.52 ± 28.39 mm (n=38) in 2000 (note that the 1999 value given here is different from Mitchell (2000a) as in this case the absolute differences were used). All comparisons of corresponding measurements of individual fish by two observers are statistically different (i.e., between seine and dip-net fisheries, 2000; between Moricetown application and angling recovery, 1999 and 2000; paired sample t-test, $p<0.005$). These results suggest that there is a statistically significant difference in measured fork lengths between observers in the different fisheries. However, it is important to recognize the distinction between statistical and practical significance. The mean differences reported here represent differences of less than ± 4% on the measurement of a 700 mm fish. For a field measurement of a writhing, slippery fish this is an excellent concordance in measurement despite the statistical difference. Therefore, the precision of fork length measurements between all fisheries is taken to be equal and to be within ± 5% or less of true length.

In summary, the precision of the various parameters used for this steelhead analysis is, for the most part, high. The precision of M is approximately ± 1%, and fork length ± 5%. Precision of C and R cannot be calculated, but the large sample size provides a certain robustness to the estimates. Finally, the sex identification and calculated sex ratios are likely of low precision in the application fishery, but relatively precise in the recovery fishery.

4.3 Meeting of Assumptions

The validity of the Petersen capture-recapture methodology rests on several assumptions and much of the analysis reported here is an attempt to evaluate how well these assumptions are being met. These underlying assumptions are (compiled from Seber, 1973; Ricker, 1975, Otis et al., 1978; White et al., 1982; Krebs, 1989; Pollock et al., 1990):

The population is closed
All animals have the same chance of being caught in the first sample
All animals have the same chance of being caught in the second sample
3a) All animals have "equal catchability"
3b) The marked fish suffer the same natural mortality as the unmarked
3c) The marked fish become randomly mixed with the unmarked <u>or</u> the distribution of fishing effort in subsequent sampling is proportional to the number of fish present in different parts of the body of water.
Animals do not lose marks between the two sampling periods
All marks/tags are correctly identified and reported on discovery in the second sample.

<u>4.3.1 The Population is Closed</u>

The assumption of population closure in capture-recapture studies implies that there are no changes in the number of individuals within the population between marking and recapture. Specifically, it requires no additions to the population via birth, recruitment or immigration, and no losses from the population due to emigration or deaths (Otis et al., 1978; Pollock et al., 1990; Kendall, 1999). The applicability of these assumptions to a natural population of steelhead is discussed below.

4.3.1a Additions

The biology of the steelhead supports the meeting of the components of this assumption of no births or recruitment. The steelhead is a Spring spawner with egg incubation through approximately late-May and June, and fry swim up around late-July and August (based on Toboggan Creek runs and MacPhail and Lindsey, 1970). These fry and maturing juveniles then reside in the stream for from one to four years (Withler, 1966); in Toboggan Creek primarily three to four years (Mitchell, 1999a; 1999b; 2000b) prior to emigration to the ocean. This life history prevents births from occurring during the time of this sampling and juveniles from recruiting into the adult population in the Bulkley River during the period of study. The adult steelhead in a given year may be considered a single cohort (though they, in fact, come from a variety of birth-years) without recruitment. This assumption, however, does reinforce one important point. The steelhead population estimates reported here are adult population only; number and abundance of other phases of the life history of the fish (e.g., fry and juveniles) is unknown in the Bulkley River.

The addition of adult steelhead to the population between periods of tagging and recapture is a potential violation of closure. Immigration leads to an increase in the number of unmarked fish, thus inflating (C/R) in the recovery sample and so leading to a positive bias in N' (i.e., an overestimate of the population). To assess whether immigration was likely to be a problem in this study, the timing of tag application and recovery sampling were examined and is illustrated in Figure 7. If it is assumed that the application fisheries at Moricetown sample approximately proportional to the abundance of fish passing through the canyon (see Section 4.3.2), then 95% of the population passing through the canyon had been marked by the time intensive recovery sampling began (October 4). Based on the pattern of distribution of fish passing through the canyon in the first two weeks of October (Oct. 4-Oct 18; median = 3 steelhead per day), and extrapolating this to the end of October, it is estimated approximately (3 steelhead per day * 12 days) 36 fish may have immigrated into the study area after tagging was completed. This would be a 2.9% difference in M compared with if tagging had been occurring as they passed through. This immigration is not corrected for in the population estimate as it is speculative, though if it occurs the order-of-magnitude is probably correct, and such a small change is not likely to affect the C/R factor significantly. Pollock et al. (1990) suggest that the assumption of closure may be weakened and state that if immigration does occur the Petersen estimator is a valid estimate of the population size at the time of the second (i.e., recapture) sample. Immigration is likely to be of much greater concern when its magnitude is much greater or the numbers of marked and recaptured animals much less.

4.3.1b Losses

Emigration, the movement of animals out of the study area, in this study can only occur via downstream through Moricetown Canyon; all of the watershed upstream of the canyon is within the area of interest and so the steelhead are contained. Emigration of animals may be minimized by sampling as near to the time of mark application as possible (Seber, 1973; Kendall, 1999), in the case of the Bulkley steelhead, while simultaneously trying to avoid significant immigration. In 2000 the recovery fishery began before the applications were complete, though was not intensive until after completion of applications. The 'drop-back' of fish from upstream of Moricetown through the canyon to downstream (a form of emigration) has long been a source of speculation. The programs in 1999 and 2000 have provided some estimates on this drop back rate and also its duration (i.e., whether it is emigration or the fish promptly re-ascend). In 1999, 14 of the 1,528 (0.9%) dip net tagged fish were subsequently caught in the seine fishery, while in 2000 this occurred to 15 of 992 (1.5%) fish. These may be viewed as 'immediate drop-back' and their fate, whether emigrants or re-ascending is unknown. However, in 1999, the angling recovery occurred in the Spring months (March and April) more than four months after tagging. Three tagged fish of a total of 71 tagged recaptures (4.2%) were caught below Moricetown suggesting that roughly this percentage of fish may be emigrating. However, the very small sample size must be considered in this evaluation; if the drop back/emigration rate is 4.2% then the 2000 recovery angling should have recaptured approximately (41 * 0.042) 1 to 2 tagged fish below Moricetown. None were captured in the 2000 angling. The results of the last two years work on drop back are suggestive of some degree of emigration. but the degree of it is by no means certain. However, by not detecting it easily, it is probable that emigration forms only a small proportion of the total population. Recognizing that emigration (purpose or accidental) likely occurs, the population estimate N is corrected for it using the 4.2% estimate from 1999.

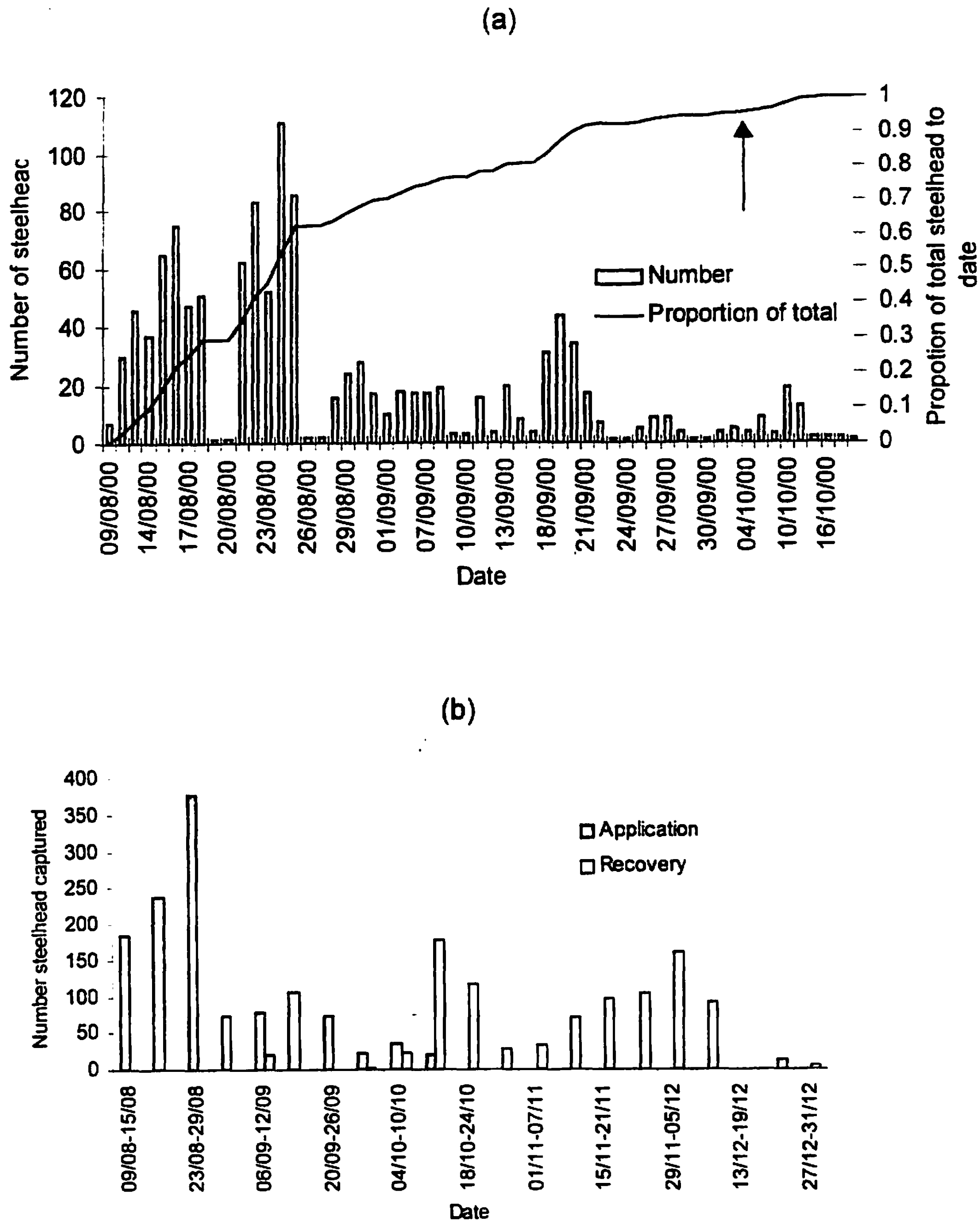


Figure 7: (a) Number and proportion of steelhead sampled by application fisheries in Moricetown canyon, Autumn, 2000. Arrow indicates approximate starting date of recovery sampling. (b) Number of steelhead captured per week for application and recovery fisheries.

Losses due to deaths may bias the population estimate. However, if the deaths are equal between the marked and unmarked fish, the estimate remains unbiased (see section 4.3.3b for discussion of this). Some of the steelhead in the population are likely to have died in the period between August and December. The Bulkley River sees very heavy angling pressure during the Classified Waters period of September and October (see Morten and Parken, 1998; Morten, 1999; Mitchell, 2001) and the number of steelhead captured in this study which had evidence of having been previously angled is relatively high (7%-9% of fish captured bore previous hook marks; Table 4). Repeated stressing of a fish by angling may lead ultimately to its death. In addition there are direct causes of death such as poaching, predators, disease, parasites, and physical exhaustion from the migration. Thus, it would be naïve to assume that no deaths occurred during the 21 weeks of the study. Meeting the assumption, then, becomes a matter of determining if deaths are proportional for tagged and untagged fish. Unfortunately, this is very difficult to test directly (Krebs, 1989), and cannot be done with the data collected in this study (but see Section 4.3.3b). However, the steelhead estimation projects over the last three years have all included very large sample sizes (M>1,100) and one advantage to this is that it results in robustness to assumptions. As an example, if an arbitrary 10% mortality rate is assigned to the steelhead, the number of tagged steelhead which die (1,211 * 0.1) is 121 fish and the number of untagged fish is ((22,627-1,211) * 0.1) 2,142 when mortality is equal. Now, suppose that this estimate is in error and mortality of tagged fish is actually 150 individuals, while untagged remains the same. The 150 deaths is 12.4% of the tagged population, which is qualitatively similar to the estimates 10% of the untagged group. Thus large samples are not highly sensitive to errors of mortality rates; that is, a large error may occur but the proportions remain similar. The true mortality rate of the two groups is unknowable, but the large sample allows a certain freedom in error, so that even should the absolute number of tagged and untagged fish dying alter substantially, the proportion is little affected. A large, systematic mortality factor would be required to alter the proportion of deaths in one group relative to the other. Thus, while the equality of the mortality cannot be directly tested, the large number of fish tagged provides robustness, allowing an increase in confidence that this assumption is not violated

In summary, the assumption of population closure is likely not strictly met, and in fact rarely is in capture-recapture studies (Otis et al., 1978; White et al., 1982). These authors just cited further recommend that closure be assessed largely on a biological basis rather than a rigorous statistical perspective. With respect to the Bulkley River steelhead there are no births or recruitment to the adult population, and immigration during the period of study is likely to be minimal due to segregation of tag application and recovery. Emigration is estimated to form a small component of the total population and the derived population estimate is corrected for this. Finally, deaths probably occur over the sampling period but the large number of tags applied lend a certain amount of robustness to the assumption of equal proportional mortality between tagged and untagged fish.

4.3.2 All animals have the same chance of being caught in the first sample

If there is systematic variation (i.e., bias) of the capture of animals in the first sample, the more catchable individuals will be caught and tagged. This implies that if the same capture methodology is used in the recapture phase, that tagged fish will be more catchable than the untagged in the second sample (Seber, 1973), decreasing the C/R ratio and thus leading to an underestimate of N'. Ideally, the first sample would be a simple random sample taken from the entire population, but in reality this is not possible and the sampling is widely recognized as biased in some form (citations in Otis et al., 1978; White et al., 1982). This subject of equal catchability is more fully explored in Section 4.3.3a.

In order to evaluate how closely the 2000 Moricetown application fisheries met this assumption of equal probability of capture. the abundance of tagged versus untagged fish subsequently captured was compared spatially (between reaches) and temporally (by week of tag application and time of day of tag application). The concept underlying this analysis is that if sampling is unbiased with respect to timing of tag application (i.e.. all components of the run are equally available to tagging), the relative numbers of tagged and untagged fish in the recovery sample should be equal throughout the river (indicating that all of the run was tagged representatively). Equivalently, if sampling is unbiased with respect to week of the season and time of day, the relative number of tagged fish recovered should be similar to the relative number of tagged fish not recovered for that week or time of day. Departure from similarity provides evidence that the fish were not tagged without bias.

The distribution of tagged recaptured fish, by week of tag application is presented in Figure 8 for both 1999 and 2000. In both years it is apparent that there is spatial effect to the run with the fish travelling to the further reaches (i.e., upper Morice) moving through the Canyon earlier than those remaining lower down. This figure also indicates that tagging appears to have encompassed fish bound for all portions of the river, and thus, is evidence that spatially, all fish had approximately equal probability of tagging. That is, there is no obvious reach component missed by the tagging operation.

Analysis of spatial distribution, using chi square analysis of the recaptures by reach. indicate that the distribution of tagged and untagged fish is equal through the 14 reaches of the river ($\chi^2 = 13.56$, df = 13, $\chi^2_{crit} = 22.362$, $0.25<p<0.5$; Table 5) supporting the assumption of equal tag application to the entire run. A similar chi square analysis on the frequency of tagged recaptures versus tagged non-recaptures by week for the 11 weeks of tag application also suggests that the tagged recaptures are not different from the tagged non-recaptures ($\chi^2 = 7.00$, df = 10, $\chi^2_{crit} = 18.307$, $0.5<p<0.75$). When frequency of tagged recaptures is compared with tagged non-recaptures by time of day of tag application (Table 6). there is also a non-significant difference ($\chi^2 = 14.355$, df = 16, $\chi^2_{crit} = 26.296$, $0.25<p<0.5$). These results suggest that tagging over the season was unbiased (i.e., representative) and in agreement with the 1999/2000 program.

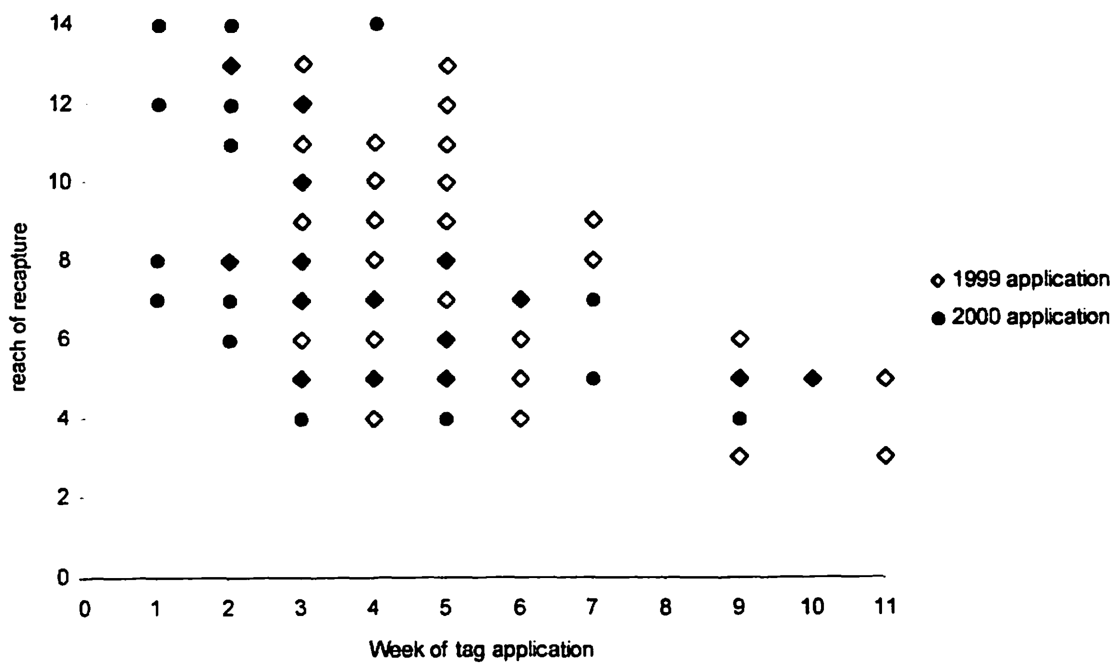


Figure 8: Final destination (reach) of recaptured fish tagged at Moricetown Canyon for 1999 and 2000 tagging projects.

In addition to assessment of bias due to the timing of tag application, the bias (i.e., sampling selectivity) of the seine and dip net are also of concern. The assumption is that they sample equally both sexes and all sizes of the population passing through the canyon. Due to the sex identification problems discussed earlier, bias of sex cannot be determined, but the high precision of the fork length measurements between these fisheries, and with the angling recovery, lends itself to assessment of the representativeness of capture by size. A chi square analysis (using subdivided contingency tables, p 62-70, Zar, 1984) of the seine, dip net and angling fisheries, using numbers of steelhead captured per 10 mm increment of fork length, indicates all three fisheries are significantly different ($p<0.001$) from one another with respect to frequency of fish capture by size. This suggests that the three fisheries are selectively sampling different sized fish. These results are similar to those of Spring 2000. Length frequency histograms are presented in Figure 9 comparing each fishery with the others. These findings of variability by fishing method are neither surprising nor unusual. In fisheries catchability usually varies with the size of the fish (Seber, 1973) and though common will usually not be a serious problem as the bias introduced is low (Ricker, 1975).

The results of this analysis suggest that in the tag application sample, equal probability of capture likely applies spatially and temporally but may break down with size of the fish. Based on Seber (1973) and Ricker (1975) it is unlikely that these violations are significant (see also Section 4.3.3a for further support).

Table 5: Number of tagged and untagged fish captured per reach in recovery sampling (see Figure 4 for illustrations of reaches). 12 fish did not have reaches recorded. thus N=933 rather than 945.

Reach	Tagged	Untagged	Total	Reach composition as % of total
1	0	4	4	0.43
2	0	27	27	2.90
3	0	29	29	3.11
4	3	49	52	5.57
5	10	260	270	28.94
6	3	113	116	12.43
7	9	152	161	17.26
8	6	58	64	6.86
9	0	45	45	4.82
10	1	23	24	2.57
11	1	15	16	1.71
12	3	41	44	4.71
13	2	15	17	1.82
14	3	61	64	6.86
Totals	41	892	933	

Table 6: Number of angling recaptured and non-recaptured steelhead in recovery fishery stratified by week of the season and hour of the day. Total may not equal 41 (R). or 1.211 (M) due to the time of every fish not being recorded.

Week of application	Recaptured	Non-recaptured	Total	Cumulative proportion of tags applied over weeks
1	7	178	185	0.15
2	11	309	320	0.42
3	9	284	293	0.66
4	3	70	73	0.72
5	4	75	79	0.79
6	1	106	107	0.87
7	2	72	74	0.93
8	0	24	24	0.95
9	3	32	35	0,98
10	1	18	19	1.0
11	0	1	1	1.0
Totals	41	1169	1210[1]	

[1] = One fish without week of capture recorded.

Hour of application	Recaptured	Non-recaptured	Total	Hourly composition as % of total
0600 – 0659	0	19	19	1.59
0700 - 0759	3	72	75	6.26
0800 – 0859	2	84	86	7.18
0900 – 0959	2	66	68	5.68
1000 - 1059	3	56	59	4.92
1100 – 1159	3	94	97	8.10
1200 – 1259	2	137	139	11.60
1300 – 1359	4	84	88	7.35
1400 – 1459	1	92	93	7.76
1500 – 1559	5	88	93	7.76
1600 – 1659	1	118	119	9.93
1700 – 1759	1	71	72	6.01
1800 – 1859	4	100	104	8.68
1900 - 1959	5	66	71	5.93
2000 – 2059	1	11	12	1.00
2100 – 2159	0	1	1	0.08
2200 - 2259	0	2	2	0.17
Totals	37	1161	1198	

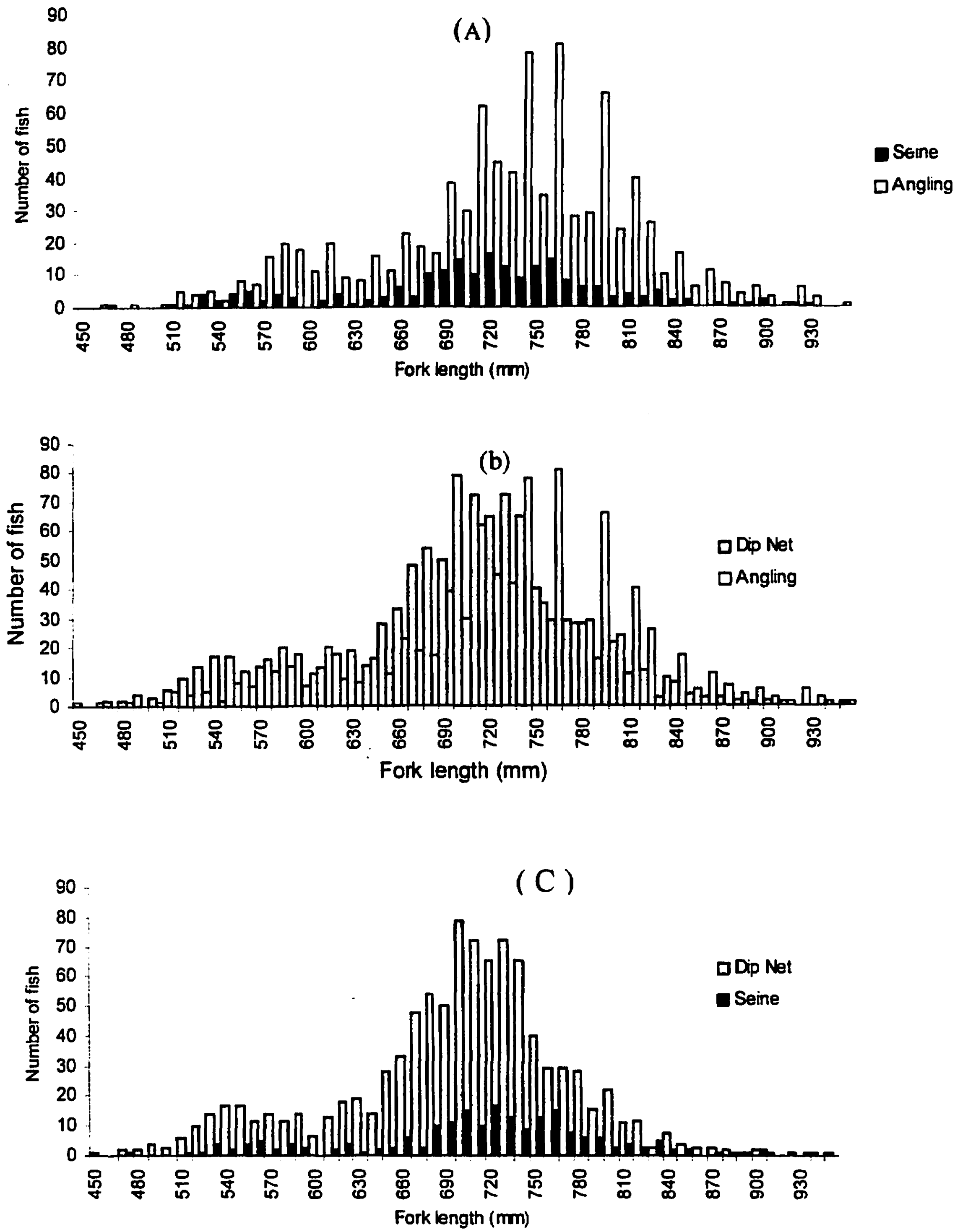


Figure 9: Comparative length frequency histograms of the captures made during the 2000 capture-recapture program in the (a) seine and angling fisheries, (b) dip-net and angling fisheries, and (c) dip-net and seine fisheries.

4.3.3 All animals have the same chance of being caught in the second sample

The assumption that all fish have an equal probability of capture in the second sample (i.e., recovery sample) may most easily be treated as three subsections: *a*) All animals have equal catchability, *b*) The marked fish suffer the same natural mortality as the unmarked, and *c*) The marked fish become randomly mixed with the unmarked.

4.3.3a All animals have equal catchability

The susceptibility of a fish to capture (i.e., its "catchability") may not be equal to the susceptibility of other fish in the population. This difference may be due to (from Krebs. 1989; Pollock et al., 1990):

- Heterogeneity: The probability of capture in any sample is a property of the animal and may vary over all of the animals in the population. That is, behavior of all animals is not the same and due to behavior (e.g., territoriality, dominance, learning, etc.) the probability of capture is not equal across all animals.
- Trap response: The probability of capture in any sample depends on the animals prior history of capture (e.g., development of "trap-happy" or "trap-shy" behaviors).
- Trap position: Unequal opportunity to be caught because of trap position

The first two causes are the primary concerns in this steelhead assessment.

Heterogeneity, if it exists, produces animals with high capture probabilities being more likely to be captured in the first and second samples. This results in an underestimate of C/R, due to an inflated value of R, which in turn negatively biases N' causing an underestimate of the total population (Otis et al., 1978; White et al., 1982; Pollock et al., 1990). However, the use of different capture methodologies between application and recovery, each possessing its own bias, will minimize the effect of this heterogeneity of behavior by the animal as it is unlikely the same bias will be present in the two gear types used (Seber, 1973; Ricker, 1975; Pollock et al., 1990). Thus, while in this analysis, it is not possible to directly test for catchability (a two-sample capture-recapture program does not provide sufficient trapping periods to test for catchability using statistical methods; Krebs, 1989), the use of different application and recovery methods likely minimize any systematic bias leading to heterogeneity of capture. As a rough estimate of this, if the angling recovery is sampling the same proportion of the seine and dip net fisheries (i.e., one fishery does not predispose the fish to capture by angling) then the proportion of tagged to untagged caught by angling per application fishery should be equal. Angling recovered 7 of 208 (3.36%) seine tagged fish while capturing 34 of 992 (3.42%) dip net tagged fish. A test of proportions (z=0.042, z_{crit}=1.96, p~0.50, pgs 395-396 in Zar, 1984) indicates that these estimated proportions are similar lending support to the concept that the angling recoveries are sampling the tagged fish without bias due to previous capture.

The issue of trap response affecting catchability is also minimized by the use of different capture methodologies. However, a comment must be made here that the steelhead in the river were under intense angling pressure while the recovery fishery was ongoing and thus there may be concern that this will affect catchability via aversion to gear or attraction to it. However, if the recreational anglers are catching the same proportion of tagged to untagged fish as the recovery fishery, then the tagged and untagged components are essentially being treated in the same manner by the angling community at large. If so, the ongoing recreational fishery, despite using the same gear as the recovery fishery, should not affect catchability of one group over the other. The Trout Creek creel survey (data from G. Wadley, personal communication) reports 7 of 203 captured fish (3.6%) were tagged and this value is not statistically different from the angling tagged to untagged ratio (i.e., R/(C-R)) estimate presented here (4.8%; $z = 0.72$, $z_{crit}=1.96$, $p \sim 0.22$; Zar, 1984). This suggests that the prior angling history probably does not affect the catchability of the fish in the recovery component of this program.

Finally, the question of bias introduced by trap position must be addressed. It is important that all fish have equal chance of capture due to placement of sampling gear (i.e., anglers providing equal effort throughout river). This is unlikely to have been the case due to the use of volunteer anglers who fished where they chose. However, the large sample of anglers, drawn from communities throughout the study area and the directed effort in the latter period of the season to cover missed or under-fished areas, suggests that coverage may have approximated equal effort through the study area. Ultimately, due to an inability to directly test assumptions of equal catchability, the meeting of the assumptions must be judged based on these inferences presented. Fortunately, closed population capture-recapture models provide estimates that are robust to variation in capture probabilities (Kendall, 1999), thereby allowing the judge a certain degree of freedom.

4.3.3b The marked fish suffer the same natural mortality as the unmarked

Unequal mortality between tagged and untagged fish (e.g., caused by the tagging process or interference from the tag) will result in the number of recoveries (R) being too small and the resulting population estimate N' being positively biased or too great (Ricker, 1975). Providing the mortality between the tagged and untagged animals is equal, the assumption of no deaths (in Closure) may be met (Seber, 1973; Krebs, 1989). As an estimate of whether mortality is likely to be equal between tagged and untagged fish in the Bulkley/Morice capture-recapture program, data from the tagging program at Toboggan Creek, which utilizes similar tagging procedures, is presented. The advantage to the Toboggan Creek system is that the number of dead tagged fish is known relatively well from operation of the fence and regular stream walks. The number of live, tagged fish is also known as the total number tagged minus dead tagged. Live untagged may be estimated as the population estimate minus the dead untagged found. These data from 1997 to 2000 are presented in Table 7. The proportion of untagged fish noted dead (0.033) in Toboggan Creek is similar to that of the tagged fish (0.021) over these four years ($z=1.272$, $Z_{crit} = 1.96$, $p=0.10$). Information from an independent source (Sustut River, 1994), indicating a tagged mortality of 0.0157 (Saimoto, 1995) suggests that the

Toboggan Creek results are reasonable over a broader extent than locally. This similarity between moralities of tagged and untagged, while not conclusive, lends support to the assumption of equal mortality being met (at least approximately).

Table 7: Estimated numbers of mortalities in Toboggan Creek capture-recapture programs, 1997-2000. Based on carcasses at fence and encountered during stream walks. Data from Mitchell and Wadley (1999) and Mitchell (2000b).

	Est. # untagged fish[1]	Untagged dead	# tagged fish	Tagged dead
1997	500	10	43	1
1998	226	6	155	4
1999	201	14	156	4
2000	212	8	74	0
Sum	1139	38	428	9
Prop. dead	0.0333		0.021	

[1] = estimated # of untagged fish = Population estimate – Number of tagged fish

4.3.3c The marked fish become randomly mixed with the unmarked

For a tagging experiment to be representative, either the marked fish or the total effort must be randomly distributed over the population being sampled (Ricker, 1975). Random distribution of tagged fish is equivalent to equal mixing of tagged with untagged, so that at every location a tagged and untagged fish have respective probabilities of capture equivalent to every other location on the river. The analysis reported in Section 4.3.2 of the number of tagged and untagged fish per reach of the river (see also Table 5) strongly support this assumption of equal mixing by tagged and untagged animals.

4.3.4 Animals do not lose marks between the two sampling periods

Loss of marks by the animal results in an underestimate of R which results in an overestimate of C/R and so a positive bias in N' (Seber, 1973; Pollock et al., 1990). A short duration between tag application and recovery efforts will help to minimize this problem (Otis et al., 1978) as there is less time for each animal to lose its mark. Tag loss remains, however, an issue to be addressed in this study. Previous studies suggest a range of tag loss rates. English and Link (1999) suggest that spaghetti tag loss is less than 5%. Lough (1995) found a 0% tag loss of steelhead between Autumn and Spring sampling on the Morice River, and Parken and Atagi (1998) report one of 18 steelhead (5.6%) losing their [Floy] tag in the Cranberry River. Seven years of tagging data (1994-1996, 1998-2000) from Toboggan Creek (O'Neill, 1995, 1996, unpublished data;

Mitchell, 1999a; 1999b, 2000b) show a range of tag loss from 0 to 18.75% over short term periods (< 3 months). The Cranberry River result and the high estimate for Toboggan Creek are both based on very small sample sizes (18 and 32 tagged fish, respectively) and so, under these conditions, the loss of even a single tag will be highly influential. Parken and Atagi (1998) also cite studies (Begich, 1992; 1997) conducted in Alaska which showed a range of from 3% to 11% tag loss over one to four months. Clearly, tag loss is variable among systems, years, and sampling methodology.

As part of the Bulkley/Morice project in 2000 the fish had been caudal punched during tag application in order to assess tag loss. With the large number of anglers participating in the recovery fishery, it is uncertain how carefully the caudal fin of each fish was checked. However, by taking a sub-sample of known reliable fishermen (supplied by the project coordinator) and examining their records for tag loss it is possible to determine if there is a large error in estimated loss of tags. Of four fishermen that captured 301 of the total untagged fish, only one fish (0.3% of the 301) was noted as having a caudal punch and no tag. If the true tag loss was significant (i.e., greater than the assumed loss rate of 1.5 to 2.4% - see below) than a larger number of punch-no tag fish (i.e., approximately 3 fish for every percent of tag loss) would have been reported by these reliable anglers. Thus, while the tag loss rate is unknown for certain, indications are that it is very low. The Petersen estimate in Autumn 2000 was based on a nominal tag loss of 1.5%, which implies that if 41 tagged fish were recovered, the true number of tagged fish should have been (41*1.015) 41.615 fish. The addition of one fish as a correction is actually reflecting a tag loss of 2.4%, and so tag loss is actually estimated at slightly greater than 1.5%.

4.3.5 All marks/tags are correctly identified and reported on discovery in the second sample.

Recovery programs, particularly those that depend upon volunteer effort, are prone to non-response error, where tags or the records of them are not turned in resulting in incomplete reporting (Paulik, 1961; Ricker, 1975). In this event R will be too small and N' will again be overestimated (Seber, 1973). As discussed previously, non-response in this case is likely to be a small component due to the active pursuit of the anglers, and the relatively small number of them actually engaged in the project. This cannot be quantified rigorously but again due to large sample sizes and control of anglers, it is qualitatively not expected to exert a great influence. Rajwani and Schwarz (1997) evaluated the effect of missed tags by observers and report that the bias leading to an inflated N' is very high when few tags are involved but decreases rapidly with increasing number of tags. They recommend at least 25 tags returned in order to minimize this bias. Based on their figures, and an estimated miss rate of noting tags of 0 and 10%, the positive bias introduced is approximately 8% to 12% on the Petersen estimator if uncorrected, it is approximately 0% to 6% if corrected. Due to the large number of tags recaptured (i.e., >25), the very low miss rate (as discussed in the previous section), and corrections made for missed tags, it is unlikely that a positive bias has been introduced through this assumption.

5.0 Conclusion

The Autumn, 2000 steelhead population estimate for the Bulkley/Morice systems of 22,630 fish (95% confidence interval 19,200-32,135 fish) appears to be an unbiased estimate of the true population of the system, at least to the extent that there are no obvious violations of the assumptions required to produce an unbiased estimate. As such, the results from this program (and the 1999/2000 program for which apparent bias was also absent) should be viewed as probably the most accurate steelhead estimates yet derived in these systems. The estimates from 1998-2000 correlate well with the much smaller Toboggan Creek runs (forming ~1% of the Bulkley/Morice run) providing consistency among estimates. The Tyee Test Index, however, did not correlate with the Toboggan Creek data. This raises significant questions regarding the deviation of Bulkley/Morice steelhead estimates from those values projected from the Tyee Index. This implies that the use of the Tyee data, while excellent for trends and possibly estimation of the total Skeena run (though use of the factor 245 may no longer be justified due to significant regulatory and escapement changes over time), cannot be justified in attempts to estimate the number of steelhead in the Bulkley/Morice. A similar conclusion is derived from attempted correlation of the Catch per Angler Day estimates of the Steelhead Harvest Analysis with Toboggan Creek data. These results suggest that these indexes may be very valuable for temporal trends, and possibly at large geographic scales, but cannot reliably estimate abundance of steelhead in the smaller systems. A caveat, however, is that these analyses are based on small sample sizes; continued population estimates in Toboggan Creek and the Bulkley/Morice will allow more refined testing of these indexes in the future.

Conducting large scale capture-recapture programs is expensive and so a simpler in-canyon estimate based on the seine and dip-net fisheries is an attractive alternative. However, the use of these two Moricetown fisheries to derive an in-season, in-canyon estimate cannot be justified due to violations of assumptions and low robustness. Developing accurate and useful population estimates on a system as large as the Bulkley/Morice requires large scale and intensive sampling of the sort conducted in the last three years. Attempted shortcuts will only result in unusable, or worse – misleading - data.

The SSBC steelhead projects in 1999 and 2000 provided valuable information on ancillary aspects of the steelhead, in addition to population size. Rate of drop back below the canyon was the subject of heated speculation prior to these projects; there now exists at least an estimate from which informed discussion may take place. The selectivity of the gear types used by the Wet'suwet'en Fisheries was also unknown prior to these projects; it is now documented as being statistically different between gear types (though whether this is of practical significance is questionable). The proportion of the Bulkley steelhead stock which used Toboggan Creek was thought to be low, work from 1998 to 2000 has corroborated these earlier estimates.

The projects over the last three years have also suggested future directions for improving the knowledge of steelhead in the Bulkley/Morice systems. Recognizing that sampling of this intensity is labor intensive as well as expensive, annual assessments may not be feasible for the future. Large scale population estimates such as these need to be done every 3-5 years however, in order to ensure established relationships still hold, to continue to test the validity of the more prevalent indexes, and to continue monitoring the population with a level of accuracy/precision that allows informed management. In the interim, however, there exists a lower cost need which would greatly increase efficiency and effectiveness of steelhead management in the Bulkley/Morice systems. Within government, university, consultant and public libraries there exists an immense body of information on Bulkley/Morice steelhead, habitat and management, but the documentation is diffusely spread throughout the province. There is a need to compile, review and assess this information. By collating and summarizing all of this existing information, recent and future information can then be placed in context of the past, and more importantly, such an effort will provide all available information in a single document to the public as well as government managers. The benefit of this is in allowing "true" co-management as everyone will be working from a common knowledge base.

Finally, and one of the most important lessons from these three years of projects, has been a demonstration of the ability of non-government organizations to take the lead and conduct high-quality fisheries science. This is extremely important due to the lack of government resources to carry out the required work. It is essential that, if community groups and First Nations are going to take on larger roles in resource management, the integrity and quality of their work be unimpeachable. The SSBC and Wet'suwet'en Fisheries have shown that this is possible and thus are qualified to play significant roles along with the Ministry of Environment, Lands and Parks, in the management of the steelhead of the Bulkley and Morice rivers.

6.0 Recommendations

The 2000 Bulkley/Morice mark-recapture project was very successful in meeting its objectives. However, several aspects may be improved in future years. These include:

1. Mark-recapture programs similar to this one should be conducted every three to five years to provide accurate population estimates with which to compare/calibrate indices and other indirect estimation procedures. As well, repeated programs like this will provide further ancillary information on drop-back from Moricetown Canyon. sampling biases by gear, variations in sizes of fish between years, etc.

2. Training of tagging crews on the identification of the sex of the fish for these difficult to sex migrants. This will not only improve accuracy of identification but provide greater consistency in how observers classify the fish. There was apparent improvement between 1999 and 2000 but identification remains biased toward females.

3. The use of a different secondary mark than the caudal punch should be considered. A punch of the anal or either of the ventral fins may be more noticeable to observers as these fins appear to get less damaged than the caudal fin. This would increase the probability of detecting fish which had lost their tags.

4. A DNA analysis of existing tissue samples from the Tyee Test Fishery may provide further information on the proportion of the Skeena run which has the Bulkley/Morice as a destination. This information may help to evaluate the conflicting estimates and provide evidence of the true Skeena River run component from the Bulkley/Morice systems.

5. An analysis of the Coho salmon size distributions between the seine and dip-net fisheries over the years the Coho fishery has been conducted would provide more information on potential sex and size bias of these different capture methodologies. Large Coho databases already exist for such analysis.

6. A comprehensive compilation and critical analysis of various steelhead population estimation procedures/Indexes would provide an indication of the precision (i.e., agreement between methods) of this derived value and the Petersen method in general on the Bulkley/Morice system. Such other procedures include mark-recaptures on tributaries, fence counts, Steelhead Harvest Analysis data, creel surveys, and the Tyee Test Fishery. The literature for the Bulkley and Skeena steelhead is conspicuously lacking such attempted correlation between estimates to evaluate correspondence and highlight issues/problems.

IN ADDITION TO THESE RECOMMENDATIONS ON IMPROVING PERFORMANCE, THIS STUDY HAS HIGHLIGHTED TWO OTHER ASPECTS TO BE CONSIDERED:

1. A comprehensive literature review and compilation, and critical analysis, of all information on steelhead in the Bulkley River. Such a review should include all studies conducted on biology, catch rate, survival estimates, recruitment, periods of freshwater residency, marine duration, mortality, changes in fishing regulations/policy, methods of estimating population size, etc. A complete document detailing the biology, fishery and management of steelhead in the Bulkley River would collate all known information, in contrast to the current state with it strewn throughout libraries and offices throughout the province. Such a project would make available to non-government organizations and individuals the wealth of information currently available; this would allow informed and intelligent discussion and management suggestions from outside government.

2. The use of Toboggan Creek as an indicator stream for the Bulkley River should be critically addressed. Preliminary evidence suggests that it represents < 1.0% of the Bulkley steelhead stock. Continued tagging of steelhead at Moricetown will provide further data with respect to the proportion which terminate their migration in Toboggan Creek. Use of this system will not allow an in-season estimate, as the Tyee Test Fishery does; it is likely however to provide a much more accurate estimate.

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