Results of Steelhead Stock Monitoring (1988-2006) in the Bella Coola River and Implications for Population Recovery

Ronald A. Ptolemy[1], Mike Ramsay[2], Dean Peard[2] and Darin Sollitt[2]

Prepared for:

Ministry of Environment, Fish & Wildlife Science and Allocation, Williams Lake, British Columbia

Habitat Conservation Trust Fund, Victoria, British Columbia

September, 2006

---

[1] 4th Floor, 2975 Jutland Rd., PO Box 9338 STN PROV GOVT, Victoria, B.C., V8W 9M1
Ron.Ptolemy@gov.bc.ca

[2] 400-640 Borland Rd., Williams Lake, B.C., V2G 4T1

Abstract

Empirical stock-recruitment information confined to freshwater carrying capacity for salmonids can be used to justify biological reference points that trigger the need for management actions. Ideally this information is derived from accurate numbers of spawners and resultant recruits (smolts) which are monitored over a large time frame with large fluctuations in spawner abundance. Specific to steelhead, there are few smolt-adult functions available and these are likely applicable to small streams only. To determine the capacity of a very large watershed for steelhead, a measure of potential smolt yield or actual run size is usually required. Alternatively, potential egg deposition (redd counts) or fry abundance can be proxies for spawner abundance to qualify conservation concerns and escapement needs. Some information on limit reference point is needed using fry counts and an estimate of habitat capacity for parr. During 1967-1995, adult steelhead catch in a sport and First Nations fishery varied widely prior to the 1995 steelhead fishery closure. In the absence of adult catch data, we explored an empirical approach for estimating potential smolt yield and stock productivity of the Bella Coola River. To provide an index of stock productivity, we used September total removal surveys of fry and parr to describe a logistic curve approximating minimum fry counts that maximize parr abundance. Fry and yearling parr densities were derived from shallow, local meso-habitats ($100m^2$) along the stream margin using maximum likelihood (ML) estimates of fish abundance. Population estimates were made with multiple-pass electrofishing and thorough recovery of stunned fish at fixed location index stations. Sample size was optimized for efficiency and to achieve a detection of 25% change in mean population density. Snorkel observation of parr distribution tempered the use of electrofishing data. Strata sub-sampling was based on weighted usable area per strata and potential biomass. In total, 245 sites were sampled during seventeen years in seven reach strata representing 52 km of juvenile rearing habitat in the Atnarko River mainstem below Stillwater Lake, Burnt Bridge Creek, Salloomt River, Noosgulch River, and three small Atnarko tributaries (Young, Hotnarko, and Camera Sidechannel. The logistic curve inflection for mean fry density in Year X versus mean Age (1+) parr density in Year (X+1) suggested a N_{MSY} fry density of 80 Fish per Unit of suitable fry habitat. The equivalent conservation level spawner number was 800 spawners for the Bella Coola tributary aggregate (12 spawners or 6 females per km) or 900 spawners for the entire Bella Coola watershed. The carrying capacity of the Bella Coola River for both early and late-run races (25 thousand smolts) was estimated at 3,900 adults based on 9% fry-to-smolt survival (smolt age 3+yr); 20% repeat spawner frequency and a nominal marine survival of 13%. The precautionary threshold escapement needs for the watershed represent 23% of the capacity. The implied Extreme Conservation Concern level is 300 adults for the Atnarko or about 100 early-run adults in the key snorkel census reaches during March. Mean fry density at index stations (threshold 75-80 FPU) and related adult escapement appears to be in the precautionary threshold range of 0.15-0.30 or higher of capacity in the last six years (one generation) since closure of the steelhead fishery (Nov. 1995). This should allow recovery to the target reference point in one generation. Present conservation measures have resulted in higher parr abundance (near capacity) in most years as a precursor to

maximum smolt yield despite low escapement and poor fisheries. Contrary to speculated population extinction, this is not so; based on total weight of evidence. Healthy runs that can be fished can result in the near future when marine survival rates rebound, moderate-high survival rates are sustained and in-river mortality continues to be minimized.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Photos

1.0. Introduction

1.1. Background

Closure of the Bella Coola steelhead fishery in 1995 marked an abrupt change and conservation turning point from the high sports catch and significant harvest seven years earlier (Figure 1; overlay plot of numbers of steelhead per year). Total annual catch and harvest has oscillated through time with two or more peaks and valleys since 1967. Conservation of steelhead (*Oncorhynchus mykiss*) homing to natal spawning streams in the remote central mainland coast, including the Bella Coola River watershed, remains a management priority for the Government of British Columbia. There is public concern over steelhead conservation which links to globally depressed ocean survival which started in the early 1990s and still persists (Smith 1999; Ward 2000; Lill 2002). Concern may be understated considering Bella Coola River steelhead have traditionally been subject to considerable exploitation and in-river mortality (2700 harvested in 1975). Total annual harvest by the First Nations Food Fishery and by-catch reached 1618 steelhead in 1982 resulting in an estimated exploitation rate of 53% (Nelson et al. 1998). The sports harvest has been as high as 2461 steelhead in 1967-68 and this is biased high. The long-term trend has been towards much reduced sports harvest as managed by increasing restrictive regulation (553 harvested in 1988-89 fiscal). Inferred escapement for Bella Coola River steelhead, historically a top five sports harvest location for the Province in the earliest years of record, was the lowest during the 1995 brood year (English et al. 1999). The steelhead harvest and by-catch has been subject to ongoing inter-government dispute resolution over the food fishery as permitted by DFO (Wilkinson 1978; Wilkinson 1979; Leggett 1984). Some concerned anglers alleged stock extinction in 1996 and called for a new hatchery smolt program. Since November 1995, when the fishery was closed to all steelhead angling, considerable Provincial resources have been applied to quantify true spawner abundance (Nelson et al. 1998; English et al. 1998; English et al. 1999a; English et al. 1999b; Burt and Horchik 1998; Burt and Horchik 1999; Burt and Assoc. 2000) and various aspects of population ecology (run timing, distribution, habitat use, habitat partitioning, survival, habitat preferences). Since the 1995 closure, there have been no catch statistics to monitor parental escapement and stock status, which has lead to this alternative analysis. It is based on combined partial adult snorkel counts and systematic, repeated electrofishing surveys of juvenile steelhead.

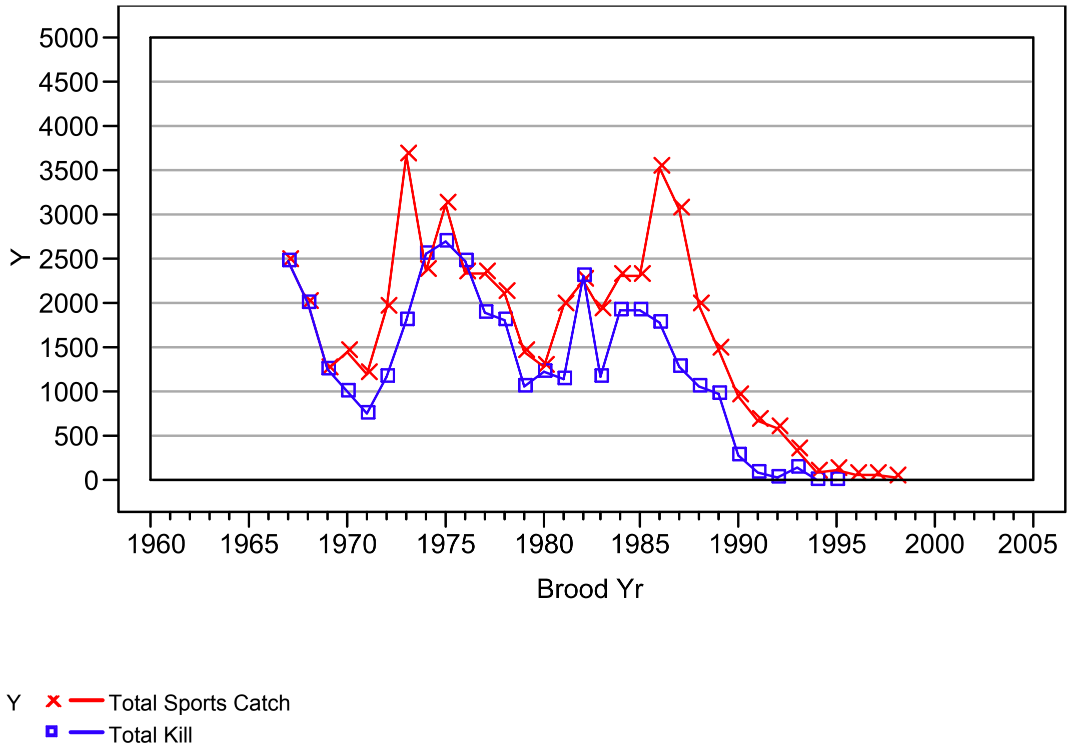


Figure 1. Overlay of steelhead sports catch and total harvest by brood year for the Bella Coola River. Sports catch data started in 1967 and the sports-fishery was closed in 1995.

Stock size and recruitment is a cornerstone function or curve in fishery science. This function has been described as biological reference points (Caddy and Mahon 1995) used to set sustainable fisheries, and to perform population viability analysis. These data sets are problematic due to high environmental variability, large observational errors, and non-transferability of results to new locations. While the Province has modeled robust reference points for steelhead based largely on Keogh River, the data requirements to estimate carrying capacity using adult counts is not practicable here or in most streams of concern. There remains a critical need to use other indices of escapement and stream carrying capacity. The status of Bella Coola River steelhead is presently assessed by monitoring "early" adult escapement (snorkel and helicopter aerial counts), which includes fish that have migrated into the Atnarko River prior to late winter baseflows (February-April) of about 20% mean annual flow. These low flows restrict passage over shallow riffles (Atnarko River) and seasonal barriers to migration do frequently occur in the deltas of small streams such as Burnt Bridge Creek. While this is a relatively efficient census of over-wintering pre-spawners, it is incomplete for the entire population since it does not include the majority (ca.70%; Nuxalk net-fishery statistics) of adults returning in April-June ("Spring Component" or Late Run). Figure 2 from English et al. (1999) describes the mean weekly CPUE for steelhead in the lower

Bella Coola River from long-term netting records (Figure 2). Spring surveys (redds or adults) are impractical due to seasonal snowmelt. The melt causes very high and turbid flows in both Bella Coola River and its tributaries. The default monitoring has relied on September sampling of the abundance of juvenile steelhead (fry and parr), which is collected annually by electrofishing at fixed index stations in the Atnarko River, Burnt Bridge Creek and other locations used by steelhead. These data were used to infer year-class or Brood strength; secondarily, they were also used to back-calculate escapement using various biostandards. Until now there has been no practical or cost-effective way (tower counts, weirs, resistivity fences, traps, fish-wheels, redd counts) of accounting for late run steelhead entering the Bella Coola. If steelhead managers could estimate the level of escapement and recruitment through fry and parr counts, which fail to meet management targets such as, sustained, maximum smolt yield, the opportunities for qualifying the endangered status and reopening the fishery would become more obvious than now exists. There are both social and economic demands to revitalize the local, fragile economy using steelhead recovery as one option.

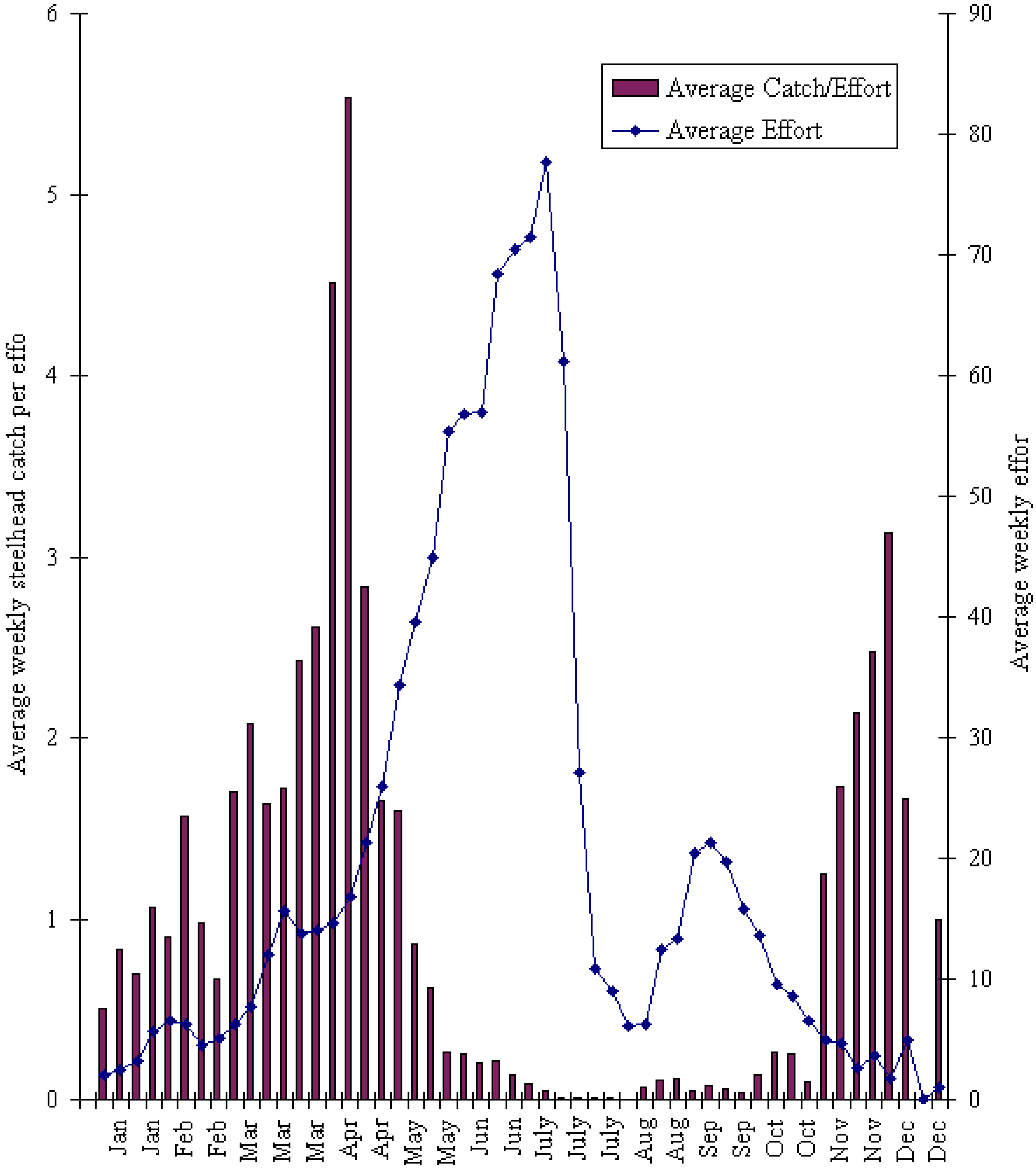


Figure 2. Average weekly steelhead catch per effort and fishing effort for Nuxalk net fisheries in the lower Bella Coola River, 1978-90 (Source: DFO fishery officer estimates). Fishing effort is the mean number of gillnet sets plus drifts per statistical week, averaged over the 13-year period from 1978-90.

Recently a precautionary approach has been advocated, in which management actions are determined by stock status. The status levels are made with respect to predetermined, science-based reference points (Quinn et al. 1990; Caddy and Mahon 1995; Richards and Maguire 1998). As described in Johnston et al. (2000), the Provincial framework for steelhead conservation consists of target, precautionary threshold and limit reference points. The bracket points respectively define desirable and highly undesirable states of stock status.

A disadvantage of this approach for broad application to British Columbia steelhead is that stock-specific information about “adult” productivity and carrying capacity (i.e., parameters α and β, respectively in the Beverton-Holt model) are not usually available and are required to determine the reference points mentioned above. In most instances, counts do not exist which are unaffected by harvest or by-catch over a long period to understand what “capacity” is. The carrying capacity estimate, at the very least, is required - approximations of both reference points as constant ratios of the carrying capacity (TRP = approx. 0.3 times carrying capacity, LRP = 0.15-0.20 times carrying capacity) were found to perform adequately in model simulations (Johnston et al. 2000).

Potential smolt production or, minimally, parr production is a common metric of freshwater carrying capacity for steelhead and Atlantic salmon. A habitat-based model for estimating potential steelhead smolt yield (e.g. Russell 1987; Ptolemy 1988; Tautz et al. 1992; van Dishoeck et al. 1999; Riley et al. 1998; many others) has been applied by our agency to many British Columbia streams, including the Bella Coola River (English et al. 1999; Burt and Horchik 1998), but the model incorporates several unrealistic assumptions that likely result in inaccuracy. First, the model assumes that freshwater survival is independent of the initial density or threshold during the fry-to-smolt stage (fry-to-smolt survival is constant) and also assumes “at-capacity” fry density. Research has suggested, however, that for steelhead, freshwater production is limited by survival at the fry-to-parr stage (Ward and Slaney 1993; Johnson and Cooper 1992; Ward 1996). For steelhead in the Keogh River, BC, and Snow Creek, Washington State, the relationship between adult escapement, potential egg deposition, fry abundance and subsequent abundance of both parr and smolts was strongly asymptotic, whereas the relationship between escapement and subsequent fry abundance was linear except at extremely high adult abundance (2-4 times capacity) (Ptolemy 1987). This relationship seems to apply broadly to anadromous salmonids with a lengthy freshwater residency including (e.g. coho salmon, *O. kisutch*: Hartman et al. 1996; Bradford et al. 2000; Atlantic salmon, *Salmo salar*: Bagliniere and Champigneulle 1986; Beland 1996; sea-trout, *S. trutta*: Elliot 1993). In this paper, we assume that our measures of steelhead fry abundance are an adequate index of the spawning population size and the relation of fry density to potential egg deposition is essentially positive and linear. This is the same rationale used by Fisheries and Oceans in their indexing of coho streams using fry count data (Simpson et al. 1999).

The Tautz et al. (1992) Skeena steelhead capacity model is largely insensitive to physical habitat quality (particularly parr stage) and this may affect smolt carrying capacity (Bocking and English 1992). It also does not critically distinguish a medium survival rate from fry-to-yearling from a low rate (Symons 1979). Model predictions of steelhead parr numbers from a high fry density (at capacity) assume unlimited parr rearing space in large rivers. Model validation using known smolt counts has shown that both parr and smolt predictions for Keogh or Snow Creek-sized streams are biased high by several-fold. More credible estimates are derived from empirical fry-parr relationships using the Symons (1979) “medium” survivorships based on dominant smolt age. Provisional estimate for steelhead capacity for the Bella Coola River watershed is about six thousand adults at 13% marine survival from a freshwater capacity of 46,000 smolts (Burt 2000). The estimate is likely biased high and affected by a target fry densities of 300 individuals per 100m^2 suitable habitat (at capacity).

Useful stock-recruitment data for steelhead in Pacific Northwest is restricted to the results from a few studies on small streams. Given the large uncertainty of existing model-based estimates of carrying capacity for other streams; the nearly complete lack of biostandards such as adult female escapement per stream km; ill-defined egg deposition needs or target fry density for larger BC streams; and the economic, social and recreational importance of Bella Coola River steelhead; a review and refinement of capacity are warranted.

1.2. Rationale for size mixture analysis

Adult steelhead counts are restricted to tower counts in the summer-fall and late winter snorkel counts within the Atnarko River. The question is what fraction of the annual total escapement is comprised by this early-run group; how variable is it from year to year; and can it be routinely used to manage a steelhead fishery?

We know the steelhead spawning period for the Bella Coola River is unusually protracted (Wilkinson 1978) and have speculated the unusually large variation in “fry” size (fork length <85 mm) in the fall reflects this (Ptolemy and Russell 1982). We also know with reasonable certainty that steelhead return to the Bella Coola River year-round in three timing modes (Wilkinson 1979). Observed spawning occurs from late March to early July or about 18 weeks dependent on temperature. Minimum stream temperatures suitable for spawning are near 5 ° C (daily average); these commonly occur in late March to mid-April and are variable from year-to-year dependent on streamflows and weather. Published accumulated temperature units (ATU) for steelhead from fertilized egg to emergence is about 600 ATU. This infers an early-July emergence of fry at a mean temperature of 8° C would be possible if spawning occurred 75 days earlier (by mid-April). Stuart (1981) reported newly emerged fry of 29-36 mm in the mainstem Atnarko River during July 22-24, 1980; sampling by Ptolemy. From radio-telemetry data (English et al. 1999) we generally know that early-run fish spawn first (late March-May) while spring fish spawn later (May-July). There is a large space used in common by the two races however temporal differences in spawning can allow racial or genetic separation; there is some evidence for late-run or "Spring" fish to spawn predominately in the lower tributaries (Salloomt River, Noosgulch River, Burnt Bridge Creek) and lower reaches of the Atnarko River however there is a large overlap of spawner groups in the mainstem Atnarko River. Spatial separation of winter and summer-run races is not evident in the Bella Coola River as compared elsewhere where partial barriers promote reproductive isolation (Smith 1968). Fry emergence is naturally earlier for early spawners and growth is more advanced than for progeny of late spawners. Exploratory electrofishing in July 1980 in the Atnarko River mainstem and side-channels (Stuart 1981) revealed fry size that implies much earlier emergence than June even though spawning was observed in June. We interpret the atypical variance (SD/Mean or CV = 30%) in size of fry at the time of mid-September juvenile surveys is primarily due to racial differences in timing of spawning and extended spawning. Elsewhere, the CV is closer to 15% in streams known to have only late spawning fish such as Salloomt, Noosgulch, and Burnt Bridge. CV values of 10-15% are typical of narrow spawning periods (file data).

The CV approximates 15% in other streams such as the Keogh, Dean, Coquihalla, Chilliwack and many other cases (file data) where run timing and spawning occur over a narrower timing window. We use the size mixture analysis (MacDonald and Pitcher 1979; 1985) of fry captured in late summer to estimate size statistics (mean, proportions and sigmas or SD) represented by various groups of steelhead spawners. The intent of the proportions and standard error estimated by MIX program was to utilize the March counts of adult steelhead and compute total escapement based on the ratio of adults: proportion of large fry in a bimodal length frequency analysis. A key assumption is that there is no appreciable egg-to-fry mortality difference between early and late spawning groups. This is despite moderate June flushing flows and potential redd scour or emergent fry loss through a mobilized streambed and high stream velocities near shore in July. We also assume the March snorkel counts of over-wintering adults are unbiased and subject to varying sighting efficiency.

This study explores the relation between parental spawning escapement (spawners), as indexed by March counts of adults and the proportion of large fry they were represented by, and the abundance of juvenile steelhead trout (recruits) in the Bella Coola watershed. The objectives of this study are:

1. To describe mean steelhead fry and parr densities in a given year.
2. To describe how densities change from one year to the next.
3. Use the fry counts to determine the sample size needed to detect a change of 25% in mean density from one year to the next.
4. To qualify the total spawning escapement of steelhead in the Bella Coola since 1988 with respect to biological reference points.
5. To determine an appropriate level of fry abundance as a precautionary threshold.
6. To compare the steelhead fry counts from this study with those of previous escapement studies within the Bella Coola watershed, to an adjacent

watershed (Dean River) and to other steelhead abundance indices or stock status.
7. To detect and classify the change (if any) of the endangered status of Bella Coola steelhead during the study duration.
8. To recommend a target reference point (fry density and/or adult numbers) that would be used to open the fishery in the future given a sustained, high count.

2.0. Methods

2.1. Study area

The physical scope of our project is extensive, covering the limited portion of the Bella Coola watershed (910-290700) delineated by the known steelhead distribution (i.e., Bella Coola River mainstem, Atnarko River confluence to Stillwater Lake) including other anadromous portions of the primary (Nusatsum River, Sawmill Creek, Salloomt River, Noosgulch River, Burnt Bridge Creek) and the secondary networks (Camera Side-channel, Young Creek, Hotnarko River; Appendix 2). Previous studies have identified the distribution of juvenile steelhead (Wilkinson 1978; Wilkinson 1979) and distribution, timing and relative abundance of adult steehead (English et al. 1999). The study area includes 61 km of the Bella Coola River mainstem and approximately 62 km of steelhead-bearing tributary habitat.

The Bella Coola River has supported a substantial population of steelhead trout (*Oncorhynchus mykiss*), numbering in the low thousands, which is wild in origin. Indirect population indices (angler catch and weekly gill-net catch) suggest that spawning runs (before harvest) during the past 25 years have varied by more than an order-of-magnitude. Numbers have varied from approximately 200 (may be suspect) in 1995 to 3700 in 1974 with a sustained downturn post-1989 below previous minimums in 1980-81(Nelson et al. 1998). Escapements have generally exceeded 1000 spawners each year prior to 1990. Previous usable-habitat assisted studies (Bovee 1978) have quantified the total amount of suitable steelhead fry space that integrates validated depth-velocity criteria (Burt and Horchik 1998). The total number of weighted usable habitat units (100m^2 per unit) for the Bella Coola stream network, excluding low fry density reaches such as the mainstem Bella Coola, Nusatsum and Talchako rivers, is 2700 units or about 17% total wetted stream area in mid-September. We favor those area-based protocols established for Atlantic salmon (Elson 1975; Symons 1979; Beland 1996) specific to egg deposition or fry density or adult number targets that likely apply directly to species with similar life-history (steelhead) and freshwater ecology.

Other salmonids inhabiting the study area include chinook (*Oncorhynchus tsawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), chum salmon (*O. keta*), pink salmon (*O. gobuscha*), coastal cutthroat trout (*O. clarki clarki*), and resident rainbow trout (*O. mykiss*) as well as Dolly Varden char (*Salvelinus malma*), and mountain whitefish (*Prosopium williamsoni*). Longnose dace (*Rhinichthys cataractae*), prickly sculpin

(*Cottus asper*), slimy sculpin (*Cottus aleuticus*), Pacific lamprey (*Lampetra tridentata*), and three-spined stickleback (*Gasteroteus aculeatus*) are also numerous (this study).

The Bella Coola River is a large, glacially fed sixth-order river draining a catchment area of 5130 km^2; mean annual discharge (mad) is about 150 $m^3 \bullet s^{-1}$ at the mouth. It is located in the central mainland coast of British Columbia (coastal Cariboo Region) and drains into the Pacific Ocean at North Bentinck Arm. The primary glacial input is the Talchako River (mad = 60 $m^3 \bullet s^{-1}$) and its headwaters (Monarch ice fields) and they join the Atnarko River (27.7 $m^3 \bullet s^{-1}$) to form the Bella Coola River. The study primarily addresses Burnt Bridge Creek (3.7 $m^3 \bullet s^{-1}$), Salloomt River (8.8 $m^3 \bullet s^{-1}$), Noosgulch River (5.6 $m^3 \bullet s^{-1}$) and the Atnarko River. In aggregate, they account for approximately 90% of the steelhead spawning and nursery habitats weighted by use and not area. The Atnarko and Burnt Bridge are nominally protected by Tweedsmuir Provincial Park and exhibit near-pristine habitats. We maintain that any perceived change in annual fish abundance (fry and parr) is largely an artifact of marine survivorship (smolt-adult) and in-river mortality of adults; changes are unlikely due to freshwater habitat shifts since they are largely pristine and cannot be used to account for abundance oscillations in Figure 1. Detailed description of the watershed's ecological setting, hydrology and estimates of weighted usable area (WUA) for steelhead juveniles are provided in Burt and Horchik (1998).

The Bella Coola River upstream of Burnt Bridge Creek has continuous daily flow records at Water Survey of Canada Station 08FB007 which provides a historic record of natural river flows since 1965. Mean annual discharge (mad) is 89 $m^3 \bullet s^{-1}$ from a catchment of 3730 km^2. The Bella Coola River integrates flows from wetter, gauged sub-basins such as the Nusatsum River and Salloomt River before entering the estuary. The Bella Coola River station has recorded extremes of 828 $m^3 \bullet s^{-1}$ (maximum instantaneous) and 5.69 $m^3 \bullet s^{-1}$ (minimum daily). Sustained highest flows are recorded from May-September where mean monthly flows exceed 89 $m^3 \bullet s^{-1}$. The river typically experiences a dry, freeze-up period in February or March when flows drop to 15.5 $m^3 \bullet s^{-1}$ or 18%mad. Lowest daily flow averages 23%mad in 1 of 2 years and the extreme of record is 3.8 $m^3 \bullet s^{-1}$ or 14%mad on Dec.15, 2001. Figure 3 (2001) is representative of the flow pattern and seasonal flow magnitude for the Bella Coola River. The flow pattern is the consequence of a rain-snow-glacial driven hydrology. Flows are typically low during December-April, high during June-August, and moderate-high during shoulder months (May and October). Minor freshets of about 30 $m^3 \bullet s^{-1}$ or higher can occur during the winter-spring. Streamflows in the Atnarko River show similar seasonal patterns however with reduced magnitude (30%) and reduced flows in July-November. Figure 4 (2001) is representative of the flow pattern and seasonal flow magnitude for the Atnarko River. The flows in the Atnarko River are primarily snowmelt driven with groundwater baseflows.

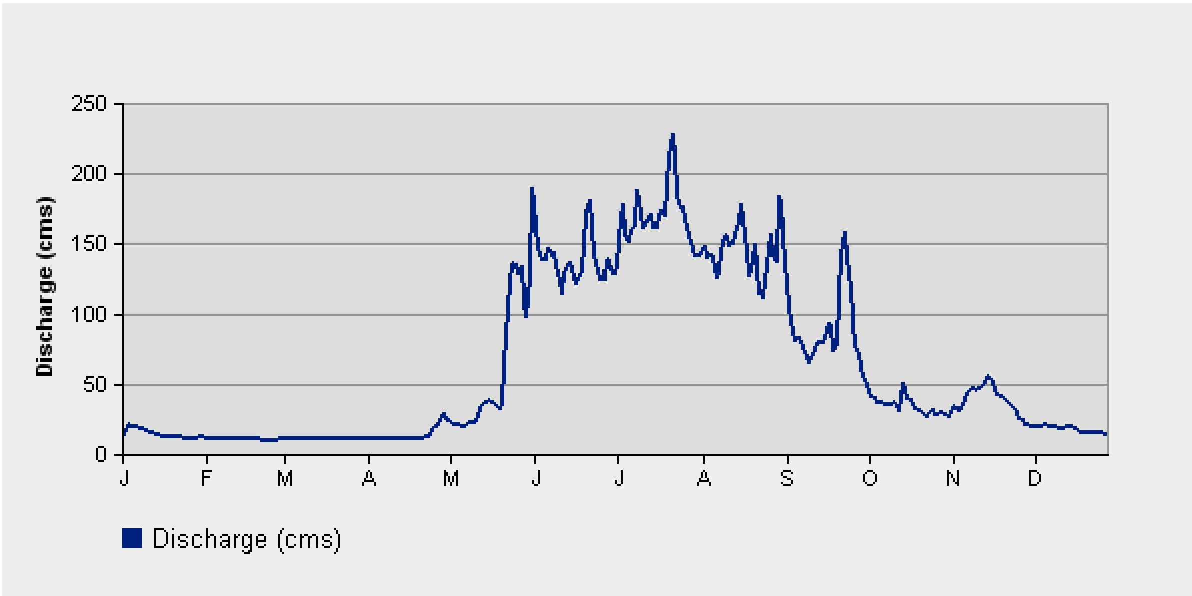


Figure 3. Annual hydrograph for the Bella Coola River in 2001.

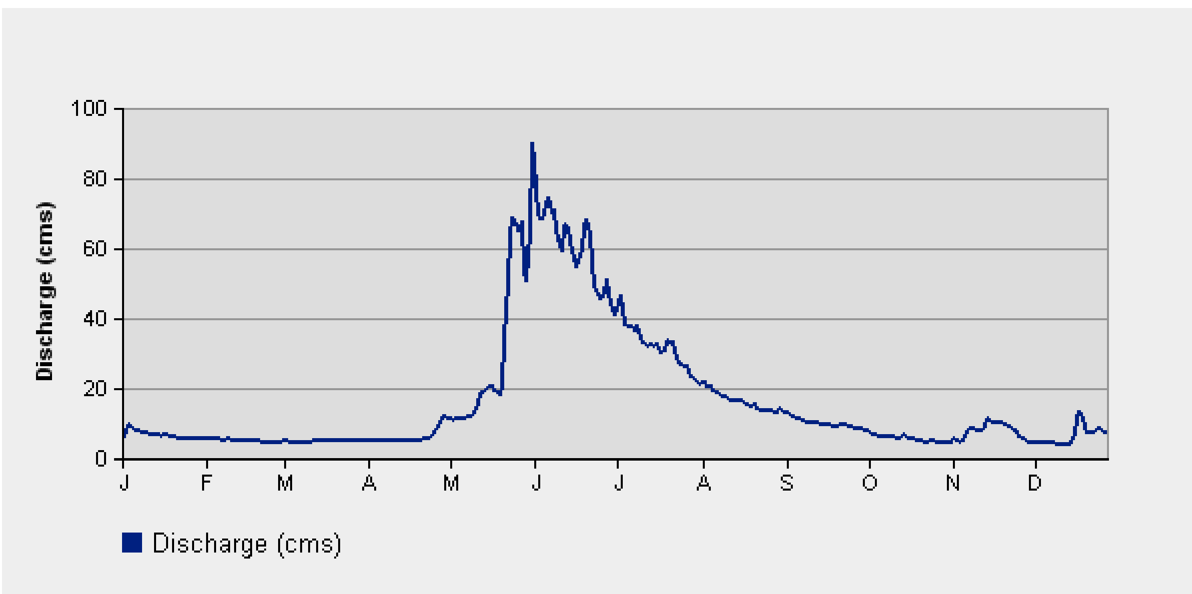


Figure 4. Annual hydrograph for the Atnarko River in 2001.

The mean monthly flows (%mad) in the Atnarko River standardized to the long-term mean annual discharge (mad) is displayed in Figure 5. Lowest flows of 31%mad occur in March (snorkel survey timing) and September flows of 57%mad occur at the time of electrofishing surveys. Excellent salmonid spawning and passage flows of 50% mad or better occur in April-November. Shorter-term passage flows are occasionally seen over days in December-January.

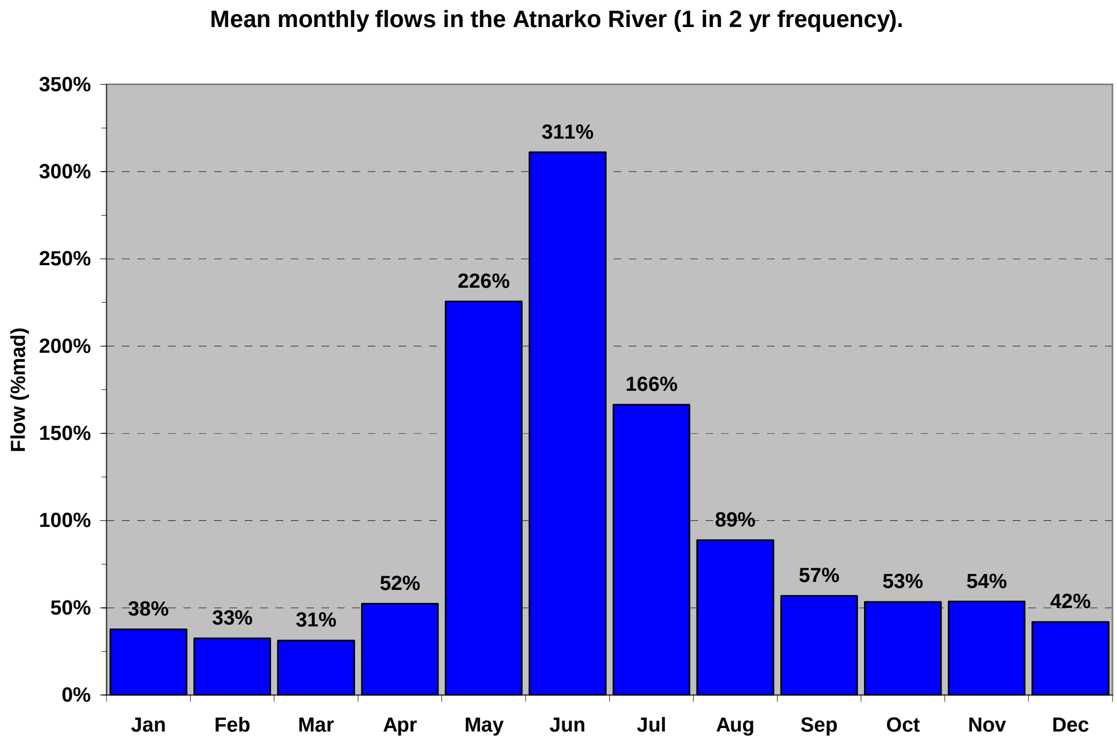


Figure 5. Mean monthly flows in the Atnarko River standardized to percent of mean annual discharge (long-term).

2.2. Study design

2.2.1. Stratification of sampling effort

Following the stratified random sampling strategy of Elliott (1971) for aquatic taxa with a contagious (clumped) distribution, we stratified fish population sampling by homogeneous reach (productivity, discharge, gradient, width, sinuosity, dominant substrate) and usable habitat type; delineating four mainstem reaches in the Atnarko River and one reach for each of Burnt Bridge Creek, Salloomt River, and Noosgulch River (Appendix 2). We used proportionate allocation of effort and assumed that our measures of suitable habitat for steelhead fry were realistic based on their clumped "near-shore" spatial distribution and consistent, preferred use of edge habitat (shallow riffles and flats) and in a broad range of particle sizes from gravel to boulder. Sample locations were chosen to maximize fry captures so that inferences about annual changes in counts could be made without undue waste of sampling effort. The location and repeated measures of fish abundance at relatively fixed intervals along the length of each reach provided systematic measures of abundance, which reduced the chance proximity to potential spawning sites. We aimed to achieve a precision about the mean annual fry abundance of about 25% of mean. We were informed by the variation in density due to habitat suitability, reach or stream character and stream productivity; this was complimented by other quantitative studies. A 25%change in density between years corresponds to a change of $\log_{10}(1.25)$ or 0.097 on the log scale.

Monitoring of fry levels in this experiment, with repeated measures, utilizes unbalanced data over time. Due to varying study objectives with time, stochastic sampling problems and resources, sample sizes varied over the years, which created an unbalanced dataset. The experimental layout attempted to sample the same locations each year and repeat the locations over time. The factor we were interested in is yearly differences with respect to conservation thresholds. The question is how steelhead fry densities change over time in response to year effects caused by variable spawner numbers. The sample locations or reaches are fixed effects; access was affected by ease of accessibility.

2.2.2. Site selection and physical attributes.

Fish population sampling was conducted using a stratified systematic sampling design (Hankin 1986; Hankin and Reeves 1988) whereby for each mainstem or tributary strata, sites were distributed along the entire length as evenly as possible given road access constraints. Remote sites were accessed by helicopter. Each site area measured near $100m^2$ and fish density was expressed in fish number per $100m^2$ or fish per unit (FPU). A minimum area of $100m^2$ was sought to avoid displacement of larger fish through perimeter net setting. Sites offering natural physical barriers such as mid-channel bars or braids were preferred since upstream-downstream barriers were easier to install. Steelhead fry were typically bounded by high velocities close to shore; barrier nets extended well beyond their distribution with the bottom net angled with mid-channel position about 2 m upstream of the shore reference point. This was done to maximize capture of drifting animals by shunting and collection of fry near shore (Photo 1).

Our experiment involves repeated measures of both fish and habitat over time at the same index station. Most often, the return to the same sample location was met by the use of the same line of net-weighting boulders used in the previous year.

Physical site attributes were re-recorded each year during site layout. Repeat habitat inventories included habitat classification (riffle, rapid, cascade, glide, run, or pool) at each site, descriptions of depth-velocity profile at 0.25-0.5 m intervals perpendicular to flow with shorter intervals over high velocity gradients, riparian vegetation, channel confinement, bed material composition, dominant particle size (D_{max} and D_{90} cm), large woody debris content, substrate embeddedness, site length, site wetted width, estimated available cover, and maximum depth. Photographs and UTM coordinates were taken of each site for future reference. Where appropriate, the surveyor also assigned a habitat suitability index per life-stage based on expert appraisal. A more detailed account is described in Burt and Horchik (1998).

2.2.3. Index counts of adult steelhead

Adult enumeration surveys were undertaken by expert snorkellers outfitted in dry suits, mask and snorkel. Surveys occurred during late winter baseflows (February-April) under the best viewing conditions possible. Counts were not calibrated for variable observer and sighting efficiency. Aerial counts were also made of the Atnarko River and Bella Coola River from a helicopter. Specific to aerial surveys, over-flight counts are not considered reliable since fish holding in deep water, within bank undercuts, under log jams or under riffled surfaces are missed according to field trials. Aerial counts did confirm steelhead presence in sections that were not snorkeled for practical reasons (lakes, rapids, canyon water). Our snorkel counts provide relative abundance (uncorrected for sighting efficiency). As such, they do not describe total early-run size however the counts probably account for the majority (90%) of the stream length occupied by early fish according to limited radio-telemetry studies (English et al. 1999).

The snorkel surveys encompassed two sections of the Atnarko River mainstem; the first was from WSC Station downstream to Spawning Channel (linear distance of 10 km); the second was from Line Cabin Station located 2.4 km below Hotnarko confluence to just above the Janet Creek confluence (river distance of 8 km). Each section was further subdivided into two segments to permit 2-hr or less exposure to cold water (1° C). Each survey used a 2-4 person crew and counts by lane were attempted using similar methods of Slaney and Martin (1987) with repeat counts for large fish groups. Counts were recorded by species on waterproof slates. We annotated all surveys for bias due to inadequate coverage of the stream width and likelihood of fish avoidance of the counters. Occasionally an on-shore spotter recorded movement of steelhead groups around the snorkellers and these fish were occasionally undetected by them.

2.2.4. Multiple-pass electrofishing

Wadeable units (<1.5 m deep) in the study area were sampled using three-sided shore sites. Upstream and downstream boundary stop nets were placed perpendicular to the shore and the off-shore side of the site was bounded by water too swift to be utilized by fry or, if the boulder content was high, a mid-channel bar or 13 mm square mesh nylon gillnet (parr-net) was employed to retain steelhead parr. Nets were configured into stable position with guy ropes, bipod stays, and anchors to a distance of up to 8m from shore despite at-station river widths of 18m or more; outer boundaries were limited by velocities exceeding 100 $cm \cdot s^{-1}$. The lead line was knitted to the bottom contours with boulders placed as weights along the lead line. This was done to avoid loss of stunned fish that drift downstream with stream currents and contain lateral escaping parr in mid-channel. Blocking seines (6 mm square) at upstream and downstream limits were used to prevent immigration and emigration during multiple-pass depletion for maximum likelihood estimation (Van Deventer and Platts 1989). The downstream net allowed complete recovery of stunned fish in swift-water habitats.

Steelhead fry and parr were captured by a 2 or 3-person crew using a DC backpack electrofishing unit (typically a Smith Root Type 8a or Coffelt gas-powered shocker) using similar methods of capture, shocker settings (650 v) and population estimate methods of Beland (1996). The significant exception from Beland's approach involves securing the electrofisher unit on-shore with a 20m anode cord lead to the pole/catch net (Narver 1972) (Photo 2). A large 1 m^2 cathod screen was also deployed into the center of the sampled area using a long lead from the shore-based unit. This facilitated faster, safer and more efficient capture of all species and especially recovery of fry (25-40 mm FL) from cobble-boulder intersticial spaces. Most fish were captured by the anode pole operator with a 19-cm dia. nylon sieve (catch net) mounted within the anode ring; the diameter was large enough to capture smolt-sized fish of 17 cm. The anode operator frequently turned over rocks to hand-recover fish that had drifted into intersticial spaces; permanent loss of these fish is often a major source of negative bias in population estimates regardless of high capture probabilities.

At each site, electrofishing was initiated at the downstream net, and consisted of a thorough surprise/ambush search in an upstream direction, followed by a systematic sweep back towards the downstream net. Each "catch" (c1, c2, c3, etc.) effort involved multiple passes and the same search pattern was replicated in "catch 2". At the three-sided shore sites, electrofishing proceeded always from the fast water forming the off-shore boundary towards the shore, to avoid chasing larger juveniles from the site.

Increases in measurement error caused by these exceptions to total site enclosure were assumed to be slight and offset by greater sampling efficiency afforded by shore-based electrofishing. The clumped distribution of fish and uniform areas of highest catch rate were noted. This was done to validate habitat suitability index curves and the extent of usable width.

All fish captured during electrofishing were anaesthetized, identified as to species, measured to the nearest mm (fork length, FL), weighed (sub-sample), and released alive back into the site following the completion of sampling. A portion of the steelhead parr captured from each reach were also sampled for scales, which were taken from the sides of fish approximately 2-4 scale rows above the lateral line and between the back of the dorsal fin and the insertion of the anal fin. To facilitate length-at-age frequency analysis, scale samples were mounted on glass slides and labeled with the site number, date, species and fish length. Selection of fish for scale sampling was enhanced by viewing the length-frequency data onsite at the time of fish measuring and referring to previous sampling.

We sampled juvenile steelhead in this consistent manner from 1988 to 2005. We also make reference to comparable data collected by Ptolemy for a few index stations completed in during 1980-84 in exploratory surveys. Except for 1988 when we sampled in late August, we electrofished during mid-September to minimize the effects of sampling date upon fry and parr abundance; to maximize fry size differences between early and late emerging fish; and to ensure satisfactory electrofishing conditions prior to the onset of over-wintering behavior. Over-wintering stream temperatures of 7 °C or less are common after late October in the Atnarko River below Janet Creek and persist until about early May; near zero temperatures occur sporadically in late December-March. Sampling in October is vulnerable to large fall freshets.

2.3. Data analyses

2.3.1. Weighted usable fraction adjustment of observed steelhead fry density

The ability to discriminate among-year fish abundance based on index sampling data is essential for stock-recruit analysis. Previous exploratory studies have accredited considerable variability (order-of-magnitude) in steelhead fry abundance to site-to-site hydraulic and habitat suitability. At-station conditions are never exactly the same from one year to the next due to mobile streambeds, changes in channel geometry, and sediment deposition. The total amount of suitable fry at the watershed scale was not expected to change significantly as inferred from previous habitat-flow simulations. Annual random sampling of edge habitats can add considerable statistical noise to the signal of abundance changes given the likelihood of sampling poorer habitats in one year compared to another or by chance sampling reaches with marginal spawner use. To better resolve true changes in annual fish abundance, we standardized fry density by dividing the raw population density by the weighted usable area fraction (0.00 to 1.00) at each site as part of a multi-stage analysis. Upward adjustments were generally small (WUA>0.70) when the sample site location generally met suitability criteria for fry; however some sites or reaches consistently had high velocities ($1 \text{ m} \bullet \text{s}^{-1}$) near shore due to high flows contained within narrow, U-shaped channels which resulted in low WUA fractions (minimum of 0.20). Alternatively, some sample areas contained zero velocities and upward adjustment to observed density was large (WUA<0.3). Mean September flows in the Atnarko River represent about 57%mad which tends to fill the channel toe-width and creates high velocities near shore; spawning habitats are ideal for large Chinook salmon at this flow (above the optima of 45%mad) however fry rearing habitat tends to be restricted to shallow margins. These locations were sampled to maintain equitable distribution through the space used by all spawners. We will provide support for the relationship between fry density and WUA in the results; the WUA outputs are according to Appendix 1 showing the Habitat Suitability Indices (HSI curves) for depth and velocity.

2.3.2. Steelhead parr habitat review and among-year density comparison

For similar reasons and statistical rigor provided for fry counts (fish preference and habitat-bias), we used observed parr density in qualifying habitats (e.g. minimum count of 3 in $100m^2$) but with statistical adjustment for depth-velocity and D_{90} character. Steelhead parr are most often associated with moderate depths and turbulence among large boulders (riffle, rapid, and cascade meso-habitats) according to direct snorkel accounts and electrofishing results across many BC streams (Facchin and Slaney 1977). We reviewed the stream transect data and photographs to ensure a consistent measure of D_{90} applied despite different observers. We were interested in comparing like-habitats among years to better resolve annual differences in parr density by minimizing "habitat" noise. We computed the geometric mean and asymmetric 95%CI (Elliott 1971) for each year using observed density (obs FPU/[WUA*30/D90]) from all qualifying stations. A check on the adjustment was made for sites with high WUA (>0.4) and D90 near 30 cm to ensure qualifying sites contained the highest parr density consistent with the Allen Plot. High suitability parr sites were primarily observed in Atnarko River Reach 2, Burnt Bridge Creek, and Young Creek which are dominated by riffle, rapid and cascade habitats with large D_{90} particles (diameters>30 cm). Conversely, low to zero parr abundance were aligned with low gradient reaches dominated by gravel or small cobble; the exception exists at large woody debris (LWD) sites near velocity shear zones where very high parr densities were commonly observed during exploratory snorkel surveys. Atnarko Reaches 1 and 3 supported relatively low parr densities overall and their reach level LWD content is low-moderate according to March snorkel surveys and low elevation helicopter reconnaissance (see Photos 9 and 11 representing low habitat suitability for parr versus Photo 6 representing high suitability at the reach level). See Figure 6 for the %composition of meso-habitats for each Reach and note the high frequency of riffle-cascade habitats for Atnarko Reach 2 and other high gradient reaches.

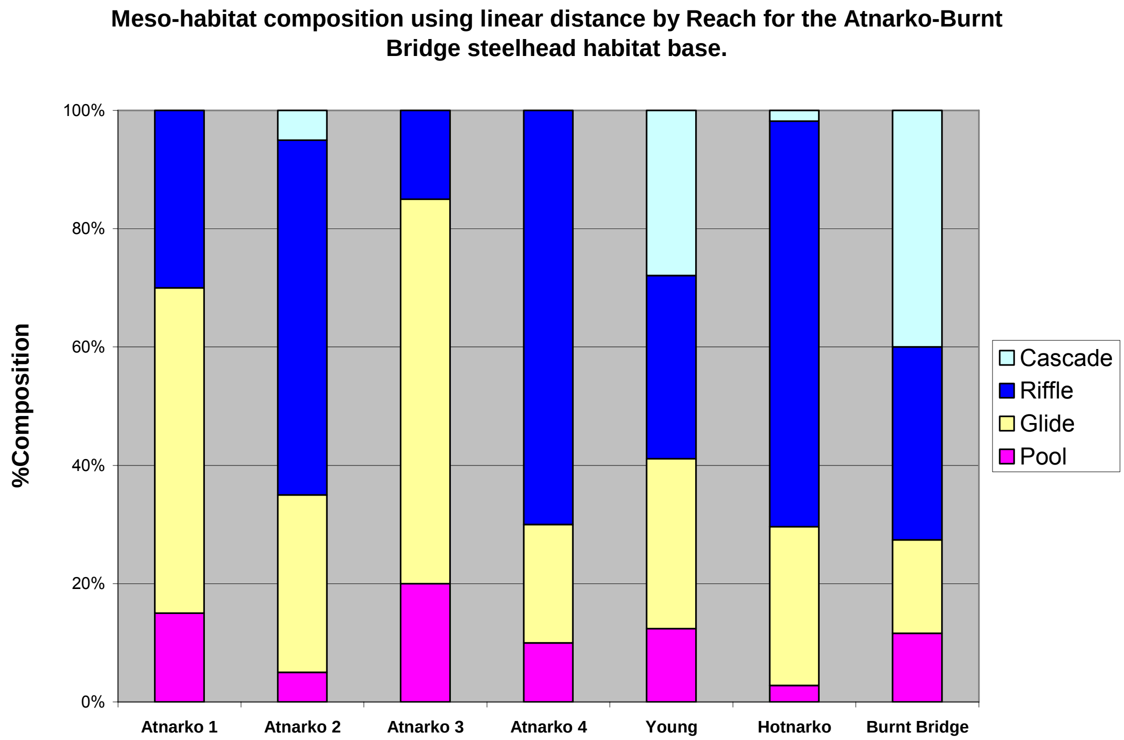


Figure 6. Percentage composition of each meso-habitat in each reach.

2.3.3. Density-size scatterplot for all years (Allen Plot)

We examined maximum rearing capacity at the meso-habitat scale of the Bella Coola River by synthesizing an Allen Plot using density at size for each salmonid species and age for all sample years. Numerous empirical field (Ptolemy 1993) and laboratory studies (Grant and Kramer 1990) have affirmed "summer-rearing" density is ubiquitously related to the inverse of fish size due to territorial needs (Allen 1969) of fish during the growth season. The maximum envelope elevation was set at 95^{th} percentile biomass and was an average over all age groups of steelhead. The slope is typically -1. We included all data regardless of habitat suitability or year. Not unexpectedly, the maximum densities were allied with preferred habitat of that species and size class. Variation in fish density at size may have been the result of either inadequate recruitment, proximity to spawning sites, and/or habitat suitability variability.

2.3.4. Statistical tests

The analysis of this experiment uses repeated maximum likelihood estimates or counts per $100m^2$. The population estimates were coupled with repeated measurements of habitat at every site and for every year. These are taken over time at various locations to monitor the population levels of steelhead fry and parr. This is a common monitoring approach for determining the health of B.C. streams by measuring the density of juvenile fish. If this density declines over time or falls below a biological reference point, it may be an indication that the "health" of the stream is declining and/or the stock of fish is under stress.

The randomization structure uses fixed locations at regular intervals over the study length; sites were chosen for ease of accessibility so the effects are fixed. This structured effect is considered as non-important since we were interested in year-to-year changes.

Observed fish counts per $100m^2$ were transformed as $\log_{10}$(Density) since annual variation increased proportionately with annual mean. Density relates to standardized or adjusted fish counts in suitable habitat. The model for Density is:

$$\text{Density} = \text{Observed Count} \bullet (\text{WUA})^{-1}$$

where WUA is the weighted usable fraction which ranges from 0 to 1.

Since not every site in a stratum was measured every year, an analysis on the averages is considered approximate. We summarized the density data to a single value of lon10(Density) for each strata-year combination. The ANOVA model to be fit to the Bella Coola data is:

Log10(Density) = Strata Year

Where the Strata term serves as the blocking factor, the Year term serves as the treatment factor, and random variation is assumed. The model was fit using the Analyze>Fit Model platform of SAS JMP 6.0.0 software.

For those years with higher sampling rates (1996-2005), we also examined annual differences using sites as the blocking factor. This agrees with the notion that particular sites were consistently low or high in any year.

Multiple year comparisons of counts were made with Tukey's LSMeans differences test using an alpha level of 0.05.

Standard parametric regression was used to test the relation between the dependent variable (density of juvenile steelhead at index stations) and the independent variable (estimated escapement of adult steelhead). Data were analyzed and plotted using the statistical functions in JMP 6 (SAS 2006). JMP software was also used to describe the basic statistical character (CV) of the fry length frequency distribution prior to the MIX analysis. Alpha significance level of 0.05 was used in various tests.

3.0. Results

3.1. Sample size by shore-based electrofishing

We electrofished and completed population estimates at 400 sites in the Bella Coola River system during 1980-2005. All sites were below anadromous barriers (Appendices 1 and 3). For steelhead monitoring purposes, annual sample size varied from 7 in the early 1990s to 18 in 1999 with an average of 12 per year. About thirteen sites were routinely sampled since the steelhead closure (1996). Additional sites near double those described for the Atnarko were sampled in the Bella Coola River mainstem, Salloomt River, Noosgulch R., Nusatsum R., and smaller tributaries as per Burt and Horchik (1998) for both steelhead and cutthroat. Appendix 3 summarizes all electrofished sample sites by reach and year. A grand total of 400 sites were subject to maximum likelihood estimation in the Bella Coola River watershed since 1980 and it shows 279 samples directed at steelhead streams. The remaining samples apply to mainly coho, cutthroat and Dolly Varden streams. The marked increase in sampling rate in 1996 coincided with the steelhead closure of 1995; a peak of 82 sample sites occurred in 1997. High water conditions in September 2002 eliminated any practical examination of smaller tributary streams (cutthroat).

Water temperature during fish population sampling ranged from 9°C to 15°C in the Atnarko River, and from 8°C to 14°C in various tributaries using calibrated digital thermometers. Fish were noticeably active at all times during sampling.

3.2. Precision of Local Site Population Estimates

3.2.1. Accuracy of steelhead fry number per area electrofished

The precision of fry standing stock was expressed by the maximum likelihood (ML) estimator (Van Deventer and Platts 1989), which produced 95%CI for "*n*". Catch efficiency was high according the mean p value on catch 1, which averaged 0.83 with low variance (CV = 7%). In all cases the lower 95%CI equated to the sum catch for the multiple passes. The asymmetric lower and upper CI were $0.97 \times n$ and the upper CI was $1.13 \times n$. The estimated population size per site was generally 1.03×(total catch), which suggests the catch efficiency after two catches was very high at 97% efficiency. For the purpose of this study, the first-stage error (CL<10% of "*n*") is considered inconsequential and we focused on second-stage errors dealing with variable habitat suitability among sites due to stream hydraulics and sample size.

3.2.2 Accuracy of steelhead parr number per area electrofished

The precision of parr standing stock was expressed by the maximum likelihood estimator (Van Deventer and Platts 1989), which produced 95%CI for "*n*". Catch efficiency was very high according the mean p value on catch 1, which averaged 0.97 with low variance (CV = 7%). In all cases the lower 95%CI equated to the sum catch for the multiple passes. We noted that zero catch of parr in about 30% of cases each year was consistent with depths (<10 cm) too shallow to support larger fish or sites which were dominated by gravel-cobble and contained no cover. Sampling was designed primarily to address fry abundance in suitable habitats. Sites with consistent zero parr captures were found in Atnarko reaches 1 and 3. The asymmetric lower and upper CI was 1.00×*n* and the upper CI was 1.10×*n*. The estimated population size per site equated to total catch or 1.000× (total catch), which suggests the catch efficiency after two catches, was very high near 100% efficiency. For the purpose of this study, the first-stage error (CL<5% of "*n*") is considered inconsequential and we focused on second-stage errors dealing with variable habitat suitability among sites due to stream hydraulics, particle size (d_{90}) or refuge cover, proximity to riffles-rapids (food source) and sample size.

We assumed the ML removal estimates to represent "true" fish abundance at the index stations. Although, negative bias in multiple-pass electrofishing abundance estimates has been demonstrated in numerous studies (e.g., Peterson and Cederholm 1984; Riley and Fausch 1992; Rodgers et al. 1992), based on the relatively high capture probabilities and good depletion patterns for all of the two-catch electrofishing data collected in this study, we assumed that the degree of negative bias (Riley and Fausch 1992) in the ML estimates, if any, would be very slight and uniform over the years. We did not observe any fish after catch 2 or 3 was completed and no residual fish reacted to continued electrofishing as a test. Further, we turned over rocks in the sample area to retrieve stunned fish. It was always possible that stunned fish could be lost from the sample if fish disappear below boulders and were not noticed by the electrofishers. Loss of stunned fish would violate the assumption of equal probability-of-capture among removal sessions. The ML removal estimates were not radically different to our historic estimates using methods of Seber and LeCren (1967).

3.3. Steelhead fry size and MIX program results

3.3.1 Aggregate sample size by year and size statistics prior to MIX analysis

We were able to collect through intense depletion methods, hand recovery of fish from the stream bottom and modest sampled area, a large number of steelhead fry within the fork length range of 25 to 85 mm each year. Larger fry were aged from scales and confirmed as Age 0+ fish with no winter annulus. Total number of steelhead fry collected and measured to the nearest mm was 11,463 during the study. Annual total catch varied from 148 fry in 1992 to 2408 fry in 1997 (Appendix 5). The broad range in catch reflects both a change in area sampled or sample size and recruitment. Total area sampled in 1992 was 483 m^2 compared to 1,170 m^2 in 1997.

Mean size and standard deviation prior to MIX analysis are summarized in Table 1. The coefficient of variation is relatively large at about 20 to 31% and averages 25%.

Appendix 2 displays the frequency distribution for each year. The distributions are positively skewed and are multimodal. By contrast, in 1988, the CV for Dean River steelhead fry is relatively small at 15%, and the average size is larger than fry captured in the Atnarko River for the same year and time. We judged that each year's catch generally contained two size modes of fry (bimodal). For example in 2001 sample, we detected the first mode at 35 mm and a second mode at 55 mm. The probable size overlap was 40-50mm. We assume that progeny of resident rainbow were too few and too small to be detected to account for the large capture rate of smaller fry except in low flow years that were warmer than average (1998, 2002). Progeny of resident rainbow trout were less than 25mm FL. In addition, the large swings in fry abundance from year-to-year were most likely due to variable steelhead numbers rather than static and low numbers of smaller resident rainbow adults counted in March surveys.

Table 1. Summary of steelhead fry catch and size statistics prior to MIX analysis.

Year	N	Mean	SE	SD	SE	CV (%)
1988	839	**34.6**	0.33	9.3	0.26	26.9
1990	154	**52.2**	1.02	11.6	0.74	22.2
1991	365	**44.1**	0.49	9.3	0.36	21.1
1992	148	**52.4**	0.83	10.1	0.59	19.3
1993	513	**48.6**	0.53	11.9	0.38	24.5
1994	363	**49.2**	0.48	9.0	0.34	18.3
1995	287	**43.1**	0.66	11.1	0.49	25.8
1996	356	**46.5**	0.76	14.3	0.56	30.8
1997	2408	**48.5**	0.22	10.8	0.16	22.2
1998	739	**49.6**	0.44	12.0	0.32	24.2
1999	1112	**40.4**	0.35	11.6	0.26	28.6
2000	1110	**48.0**	0.39	13.1	0.29	27.3
2001	1908	**42.1**	0.27	11.7	0.2	27.8
2002	461	**46.3**	0.65	13.8	0.48	29.8
2003	700	**47.5**	0.43	11.3	0.31	23.8
2004	412	**47.1**	0.54	11.0		23.3
2005	609	**44.0**	0.44	11.0		25.0
All	**11463**					**25.0**
1988 Dean	1568	**38.8**	0.15	5.9	0.11	15.1

3.3.2. MIX program and proportions of early versus late run fry

We fitted a quasi-Newton algorithm (MIX release 3.1aa) to each year's catch of fry after selecting an appropriate distribution. We did not constrain proportions or means; sigmas were held constant at 15% of mean. The distribution employed was most often normal and achieved a Chi-square that was highly significant (P<0.000). Occasionally a lognormal distribution was best. Table 2 summarizes the results for proportions, means and sigmas.

"Early" fry averaged 58 mm in mid-September and were presumed to have been progeny of early-run adults countable in March and spawning soon after with increasing flows near 50%mad. These fish were 19 mm larger than late fry that averaged 40 mm. The proportion of early fry in the total fry sample each year averaged 0.35 with a large CV of 44%. The lowest proportion was in 1994 at 0.11. The highest proportion was in 1990 at 0.57 followed by 0.54 in 1999. We concluded that an accurate estimate of total adult escapement using a fixed proportion of large fry was not feasible given the large error bounds. If a fixed proportion were applied to a "high" adult count such as in March 1999, we would have incorrectly classified the conservation status for that year. We found the MIX-derived average proportion (0.35 ±0.079; mean ± 2SE) of early fry does compare favorably with the proportion of adult steelhead caught before April as early-run fish in the Nuxalk fishery (ca. 0.30). The 95%CI for the mean proportion of early emerging fry is 0.27-0.43 and this relates to the adult numbers that are counted in March.

The within year sigma values (SD) in the MIX analysis were more consistent with adult spawning over a narrower time window as CV values of 15% were computed.

Table 2. Summary of Size Frequency Analysis of "Fry" of Steelhead Origin from the Bella Coola River, British Columbia.

	Proportion		**Size (mm)**	
Brood Year	Late	Early	Late	Early
1988	0.83	0.17	31.3	51.7
1990	0.43	0.57	40.3	60.6
1991	0.83	0.17	41.2	59.4
1992	0.47	0.53	45.6	57.1
1993	0.48	0.52	39.6	56.7
1994	0.89	0.11	47.5	62
1995	0.83	0.17	38.2	59.8
1996	0.62	0.38	37.4	64.5
1997	0.8	0.2	45.3	60.9
1998	0.5	0.5	40.8	58.6
1999	0.46	0.54	32.2	47.2
2000	0.75	0.25	41.1	62.8
2001	0.72	0.28	36.1	58.1
2002	0.67	0.33	38.9	62.6
2003	0.64	0.36	41.5	59.2
2004	0.53	0.47	39.2	55.6
2005	0.62	0.38	36.9	54.3
N	17			
Mean	0.650	0.350	39.6	58.2
SD	0.155	0.155	4.3	4.6
CV	24%	44%	11%	8%

We noticed that fry size varied from year to year between the two groups and they appeared to be synchronous (Figure 7). Both early and late fry were larger in low flow years when stream temperatures were warmer such as 1998. Mean 1998 August flows were about 61% normal or below the lower quartile. This contrasts to a high flow (122% normal; above the upper quartile) and cooler summer in 1999 when steelhead fry size was much reduced. Captures of small fry (<37mm) were significant and represented 50% of the total number of fry collected. We were confident that most of these fish were likely progeny of steelhead versus resident rainbow trout based on relatively constant and low potential egg deposition by resident rainbow trout inferred from constant counts of resident adults in March.

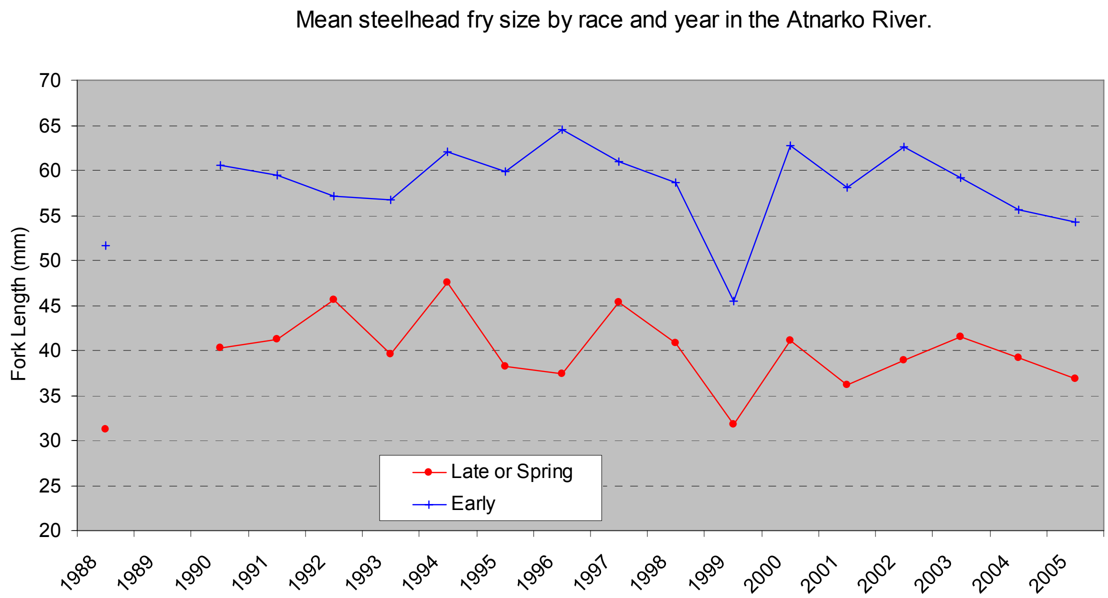


Figure 7. Size trend for early and late fry by brood year.

3.4. Juvenile steelhead populations

3.4.1. Estimates of observed age-0+ abundance by site

Fry counts (number per 100m^2) varied considerably among sites despite standardization to WUA of 1, within and among years. Allocation of sites per strata or reach and their weightings based on hydraulically suitable habitat are summarized in Table 3. Sites are coded by distance upstream from a confluence; AT008 is an Atnarko River site 0.8 km upstream of the confluence with the Bella Coola River.

Table 3. Site allocations by strata and weightings in the Bella Coola River.

Strata	Stream	Weight	Site Codes
A	Atnarko R1	427	AT008, AT029, AT047, AT050
B	Atnarko R2+Camera+Young	699	AT108, AT121, AT121, AT123, AT178, AT201, AT218, CC015, CC0012, YO005
C	Atnarko R3+R4+Hotnarko	881	AT257, AT264, AT269, AT318, AT340, HO009
D	Burnt Bridge Creek	360	BB017, BB 050
E	Salloomt River	242	SA040
F	Noosgulch River	58	NO005
G	Bella Coola River	1440	BC108, BC324, BC369, BC556, BC518

In a strong brood year such as 2001, fry counts were highest in Strata B where counts ranged from 84-436. Counts were lowest in Strata G or the Bella Coola River mainstem and ranged from 9-18.

Annual geometric means varied among Brood years from lows ranging from 35-39 FPU to highs ranging from 187-190 FPU. The minima were most frequent in the early 1990s and the maxima are evident prior to (1988) and following the collapse of the fishery (2001). Intermediate fry densities are described for most years (Appendix 4). Most densities appeared to very low in comparison to habitat capacity.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	39	9898.300	253.803	5.0605
Error	192	9629.435	50.153	Prob > F
C. Total	231	19527.736		<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Year	16	16	4054.6300	5.0528	<.0001
Site	23	23	5511.8099	4.7782	<.0001

Figure 8. Displays the strata-weighted mean fry density by year.

The precision of mean fry density by year is expressed as ±2SE in %mean varied from 15 to 69 and averaged 34% of the weighted standard mean despite using stratified data. The lowest precisions were for the period 1988-94 when sample sizes were small (6-8). The highest precisions (15-20% mean) were for years (1997-2000) where the sample sizes were large (13-19). The histogram plot in Figure 9 includes the 95% confidence limits about the mean WUA-adjusted fry density. We consider the limits as reasonable for ecological surveys if a tolerable 95% confidence limit of ±25%mean is achieved; this is equivalent to standard error of about 10% of the mean. Results for 1988 (broad limits) reflect limited coverage of the study area and small sample size. This is because the survey design was reconnaissance and exploratory in nature.

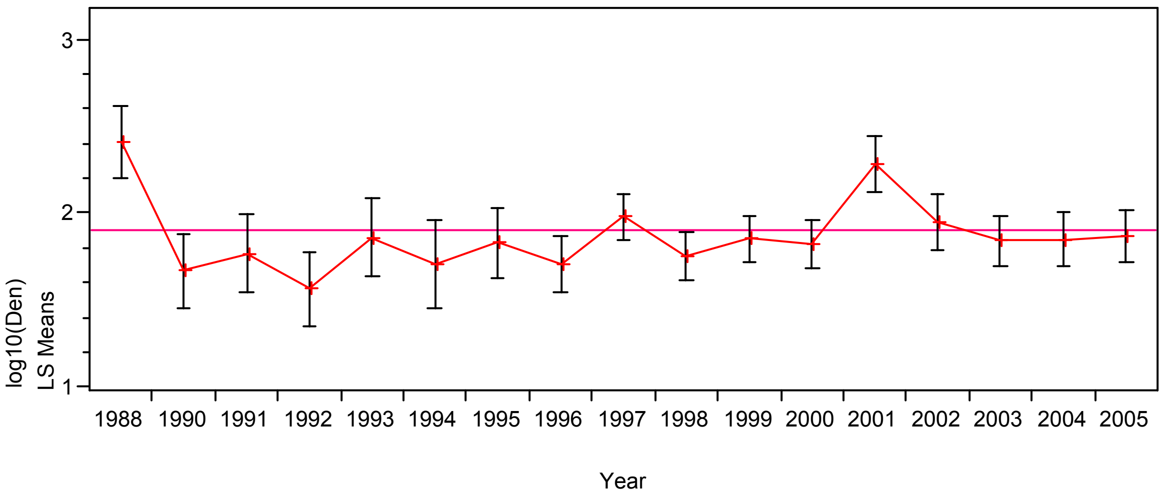


Figure 9. Log10(density) least squares mean steelhead fry density by brood year, 95%CI and reference level at log10(80 fry/100m2).

Level				Least Sq Mean
1988	A			2.4024076
2001	A	B		2.2833436
1997	A	B	C	1.9788977
2002	A	B	C	1.9453263
2005			C	1.8650307
1993		B	C	1.8599910
1999			C	1.8499902
2004			C	1.8471825
2003			C	1.8414787
1995			C	1.8270584
2000			C	1.8252986
1991			C	1.7661083
1998			C	1.7528101
1996			C	1.7080745
1994			C	1.7055436
1990			C	1.6702631
1992			C	1.5628343

Levels not connected by same letter are significantly different.

3.4.2. Relation between a single site population estimate, group mean and annual mean steelhead fry abundance

We were curious whether long-term steelhead fry abundance collected at several index stations tracked our annual abundance measures using all index stations for the Bella Coola River. If it did, it might provide insights on reliance of a more limited but efficient future monitoring program and historic recruitment prior to the fishery collapse in the early 1990s.

Fry counts for the Atnarko River at Boat Launch Site (AT108) exist since 1981 while conducting stock assessment in the Bella Coola valley. We applied a simple linear regression of counts at site AT108 on the geomean for the Bella Coola River. The scatterplot and trend line is shown in Figure 10.

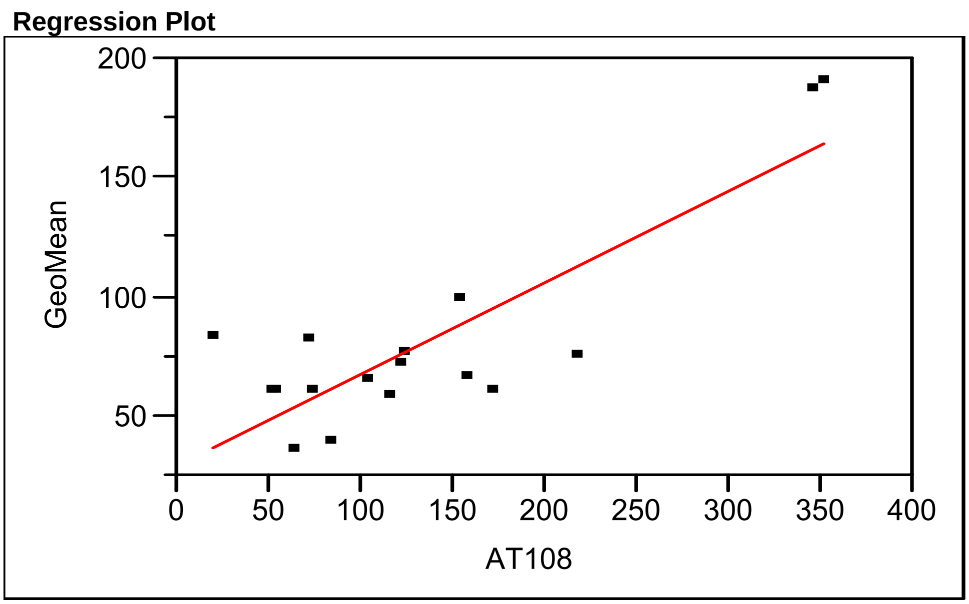


Figure 10. Site versus system-wide correlation in fry abundance.

Table 4. Table showing results of ANOVA test comparing geomean of all sites and site AT108.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	21558.842	21558.8	37.3584
Error	15	8656.217	577.1	Prob > F
C. Total	16	30215.059		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	28.435194	10.28448	2.76	0.0144
AT108	0.3872479	0.063357	6.11	<.0001

The model displays a surprisingly good statistical fit (ANOVA, F ratio=37, p<0.0001)(Table 4). The prediction interval is relatively small and we can safely infer steelhead escapement for the 1980s was generally much higher than it is now except for the 2001 Brood Year.

Steelhead fry counts at AT108 in 1981-83 gave respective local densities of 156, 163, and 202 FPU. We already know the steelhead population supported a healthy fishery (Steelhead Harvest Analysis) and adequate escapement according to LGL analysis of 575-1182 adults. The inferred mean fry abundance for the Bella Coola River was 90-107 FPU; this is above a probable precautionary point of about 80 FPU (see following results). The harvest numbers were quite high at 1000-2000 during this time in the Bella Coola River however this level was likely sustainable given above average marine survivals in the early 1980s inferred from the Keogh steelhead project (Ward 2000).

3.4.3. Linear function between steelhead fry abundance and suitable habitat

While we did not validate the fry count-WUA linear relationship with a formal test derived from sampling broad range in habitat suitability, we did utilize our data for 1988 and 2001 for ANOVA to illustrate lack of falsification of weighted usable area fraction. Data for both years were chosen for the plot since we assumed that all habitats would be more fully occupied in a very strong brood year than in a weak brood year. We also used the survey data since a very broad range in habitat suitability (24-100%) were sampled and suit regression purposes. Similar results were observed for all remaining surveys.

Table 5. Tables showing the results of ANOVA and regression tests comparing fry densities and WUA.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	65573.82	65573.8	5.8889
Error	17	189296.91	11135.1	Prob > F
C. Total	18	254870.74		0.0266

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-18.70623	84.01491	-0.22	0.8265
WUA	283.37802	116.7746	2.43	0.0266

Summary of Fit

RSquare	0.257283
RSquare Adj	0.213593
Root Mean Square Error	105.523
Mean of Response	176.5263
Observations (or Sum Wgts)	19

The fry density-WUA plot and regression statistics are described in Table 5. The regression in the ANOVA is significant (F ratio = 5.89; p = 0.05). The slope (b = 283) and correlation coefficient (r = 0.463) are significant (P<0.05). The intercept (-19) was not significantly different from zero (t ratio = -0.22), which supports the transformation of raw fish count to standardized count for habitats that are 100% suitable. The plot reveals no strong falsification of the weighted usable area fraction (Figure 11). This is demonstrated by the lack of data points in the upper left quadrant (i.e. high densities in low suitability sites). Low densities at high suitability sites would not falsify the use curves since chance proximity to spawning sites; larger fry size and biomass; re-watering of previously dry side-channels and poor recruitment potential could be reasonable mitigating factors.

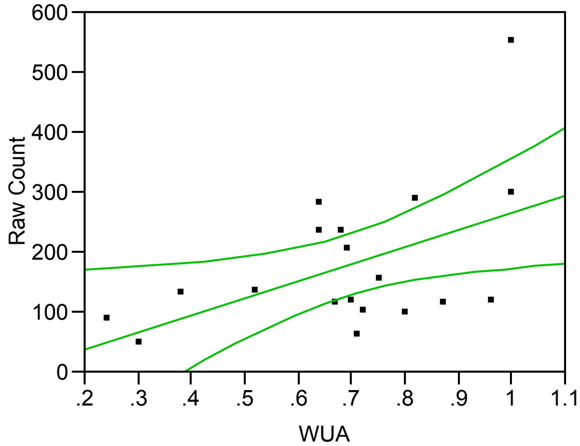


Figure 11. Fry density and WUA plot, trend line and 95%CI for the mean.

3.4.4. Estimates of observed age-1+ abundance

Figure 12 provides estimates of standardized yearling steelhead parr standing stock for the Atnarko River aggregate by year. Observed parr densities (unadjusted) were generally low (<2 FPU) in 50% cases except for those sites where habitat suitability was high following strong brood years. Since the primary monitoring goal since 1988 was to evaluate fry abundance in preferred shallow habitats as an index of spawner numbers, sampled conditions were not always ideal for the capture of parr-sized steelhead. When we did sample suitable parr habitats, we did observe significant parr densities up to 30 yearlings per 100m^2. We viewed these relatively high densities as being representative of high parr numbers observed in mid-channel habitats through snorkel evaluation.

Density (raw or observed) variation within and among years was considerable, and apparently due to sampling biases. Within year differences were too large to demonstrate statistical differences among years without standardizing the data set. We elected to use qualifying sites according to depth-velocity-D90 criteria as a filter. This approach is comparable to Guay et al. (2000) methods for assessing Atlantic salmon parr abundance.

Observed yearling parr densities at the site level ranged from 0 to 30 FPU among all years. The highest density was seen at Young Creek in 1998. Figure 12 summarizes geometric mean densities and 95%CL for those qualifying sites that were suitable for parr. Annual differences in standardized parr density were apparent and confirmed by ANOVA. Mean annual parr densities varied from a low of 10.5 FPU in 1993 to a high of 39.3 FPU in 1998. Relatively high parr densities (25 FPU) were observed in six of sixteen years namely 1988, 1994, 1996, 1998, 1999, 2002 and 2003. Moderate-high densities averaging 20-30 FPU were observed in four years (1992, 1997, 1999, and 2000) and low-moderate densities (<20 FPU) in three years (1991, 1993, and 1995).

The precision of annual means was moderate and varied from 10% to 30% of the geometric mean. Figure 12 shows the annual geometric means ± 2SE with parr census year on the X-axis.

Moderate depths, turbulent flows, and large D_{90} characterized all of the local sites that contained the highest steelhead parr densities. Preferred conditions include high velocities over boulder substrates. We found that parr density was positively correlated to 90^{th} percentile particle diameter or D_{90}. Photos 3, 5, 7, 8, and 10 show typical meso-habitats heavily utilized by parr. At the reach level, cover and habitat diversity was low in Reach 1 and 3 of the Atnarko River (Photos 9 and 11) due to low gradient, small substrates and limited large woody debris. Cover (D90) and habitat diversity was highest in Reach 2 (Figure 6), Burnt Bridge Creek and Young Creek.

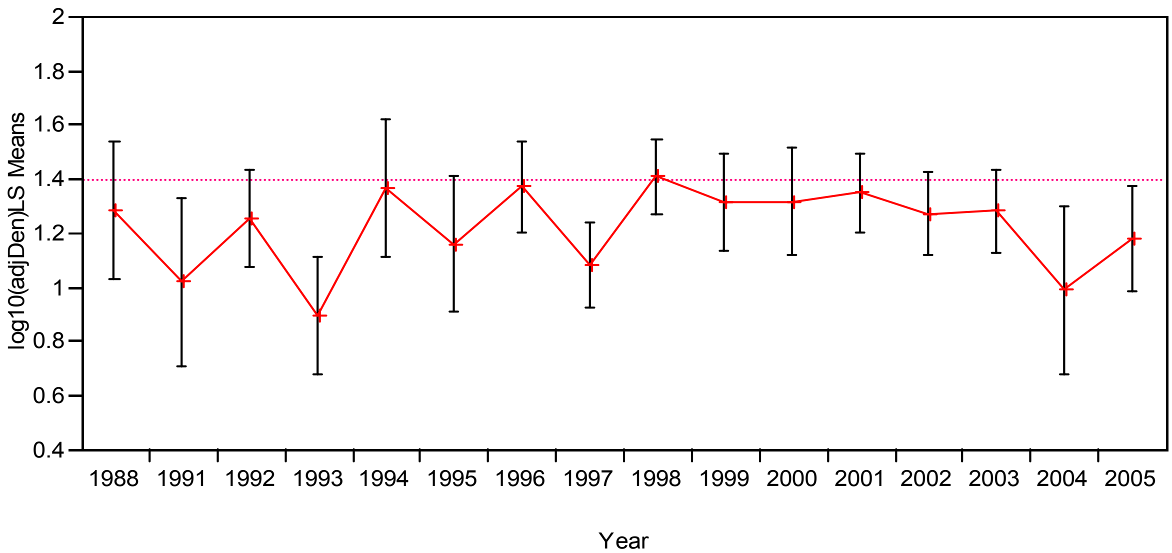


Figure 12. Standardized steelhead parr abundance by survey year.

3.4.5. Steelhead age-0 fry and age-1+ parr relationship

A watershed level standing stock estimate for age-1+ parr was deemed beyond the capabilities of our electrofishing survey and one is not computed here. However, a generalized curve for fry and parr density by brood year was considered useful to explore an expected asymptotic curve and to set a precautionary threshold for fry (PT).

The curve is displayed in Figure 13 and the precision about each coordinate is moderate as suggested above.

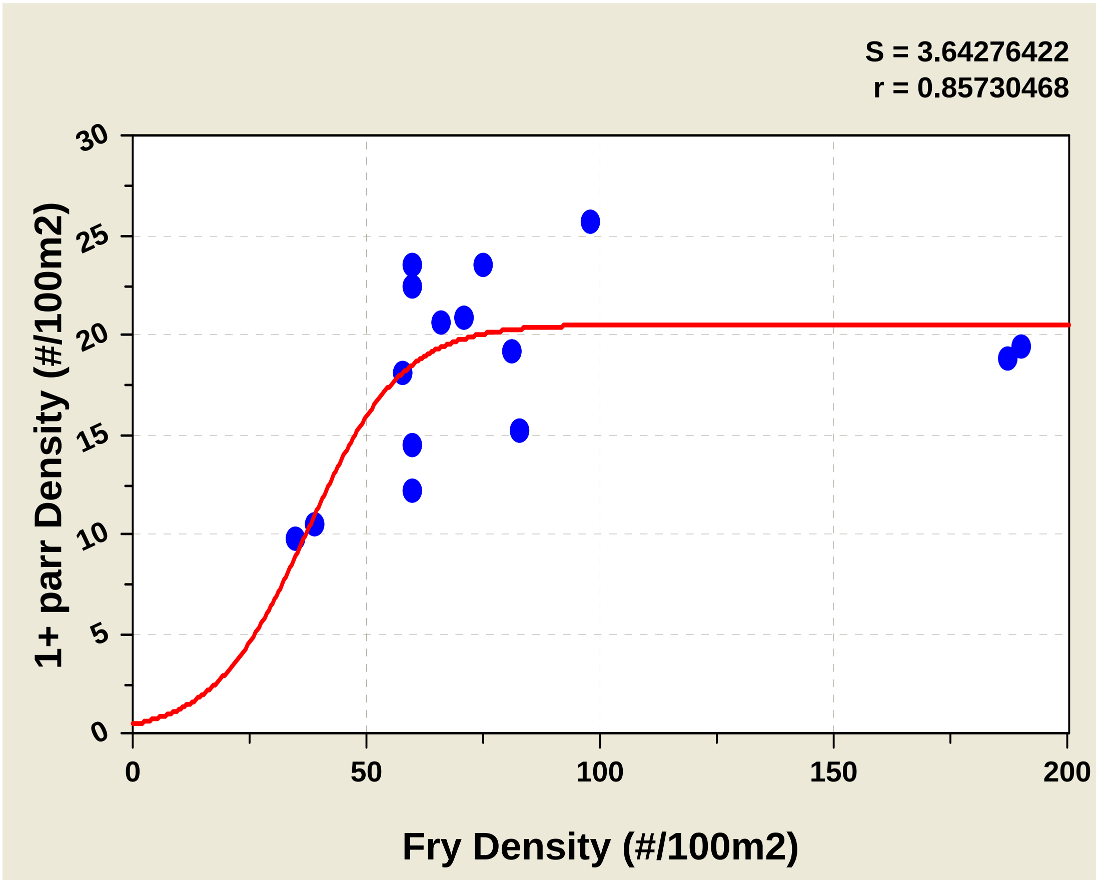


Figure 13. Scatterplot and trend for parr abundance in Year X+1 and fry abundance in Year X.

Logistic Model: y=a/(1+b*exp(-cx))

Coefficient Data:

a = 20.7

b = 41.2

c = 0.099

Logistic Model: y=a/(1+b*exp(-cx))

Standard Error: 3.64

Correlation Coefficient: 0.857

The fit converged to a tolerance of 1e-006 in 19 iterations. No weighting used.

The capacity (“a” term) is about 20 yearling parr per 100m^2. The PT for steelhead fry is about 80 FPU or 0.8 fry/m^2 with large error term (SE = 3.6); the minimum estimate is 75 FPU. The ceiling of 20 yearling parr per unit is the similar to the maximum census density in our Allen Plot. A more complete description of maximum fish densities is described in the Allen Plot results.

3.5. Habitat carrying capacity and Allen Plot characteristics

We plotted raw or observed fish density (FPU) on the Y-axis with paired mean size (g) on the X-axis for all species and ages in the Atnarko River-Burnt Bridge grouping to derive a scatterplot or Allen Plot named after K.R. Allen (1969). The results for all years and sites are shown in Figure 14 as a log-log plot. An envelope describing peak or maximum densities at carrying capacity of local habitats is about 264 g/Unit; the envelope is estimated as the 95th percentile biomass. The slope is -1 and implies density is proportionate to the reciprocal of size. Allen suggested that stream salmonids are territorial and that territory size (area or 1/density) increases proportionate to fish size.

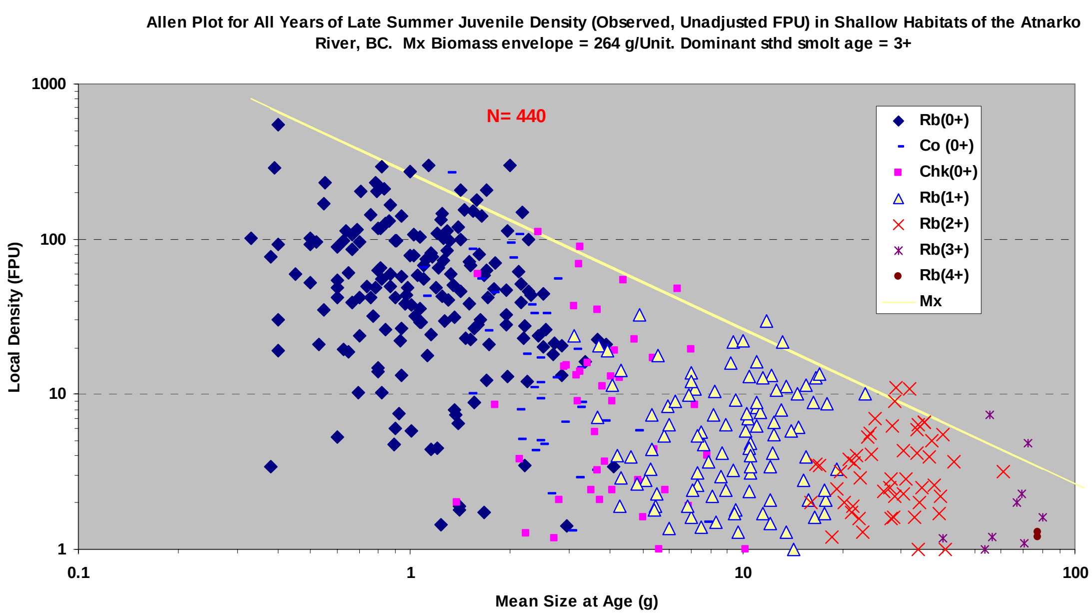


Figure 14. Standard Allen Plot illustrating fish density variation with size due to territorial needs and competition.

Results for all years confirm that fish density at size per species vary more than an order-of-magnitude. The plot also shows that very high densities were observed for most species and ages despite biased sampling in shallow habitats however steelhead fry densities were more often nearest the envelope. Age (2+) steelhead parr were generally closer to the mean size of smolts (50g) and confirm the dominant smolt age as Age (3+) as per Wilkinson (1978).

Based on the information in the scatter plot , we can make assumptions about size and density at age. The scatter is largely a wedge of points with the thin end on the right limb. Occasionally one or two data points exceed the envelope and are considered outliers. There is considerable variation in density at any given size (2-orders of magnitude) and this is largely due to variation in habitat suitability and sample bias. Zones of icon colour are apparent as bands along the X-axis reflecting age groups. There is considerable range in size of steelhead fry (0.33-2.6 g) and this is related to time of sampling (August versus September); recruitment level or brood strength, and late emergence under colder, higher flows such as in 1999. Flows in 1999 were at the Upper Quartile or greater from June1-Oct.31. Steelhead parr size approach the generic smolt size of 50 g after Age 2+. The maximum size of Age 2+ parr was near 40 g. At-capacity estimates of maximum abundance in suitable habitat for each species and age is size dependent. Using nominal mean weights of steelhead in September, the habitat capacity or maximum density in suitable habitat for 1.4 g fry was 190 FPU; for 10 g yearlings the capacity was 26 FPU; and for Age 2+ parr averaging 35 g it was 8 FPU.

The biomass envelope is double that predicted by the Ptolemy (1993) model for maximum fish density in fluvial habitats. The model utilizes a conservative water chemistry predictor for fish food supply (square root of total alkalinity) and it predicts a biomass of 151 g (± 18%) per 100m^2 unit per species/age group. The model assumes that density equates to the reciprocal of size times biomass. The late summer baseflow alkalinity is 17.4 mg/L with Nitrate-Nitrogen concentration of 50 µg/L and Total Phosphorus of 6 µg/L. Biomass of salmonids in the Atnarko River is comparable to that of the Dean River in 1988; both streams drain the productive Central Interior EcoProvince and each has a large source of salmon carcasses. Added N and P loading is known for enriched streams however these nutrients are quickly assimilated by the ecosystem and do not always register in routine water quality testing. Enhanced biomass may also be the result of rich sources of salmon eggs and flesh that is consumed by live fish in otherwise sterile streams. This is particularly true and applicable to the small coho-cutthroat-Dolly Varden streams in the lower Bella Coola River valley; this is based on empirical fish density-size data forming an Allen Plot.

Possible among species competitive interaction and reduced density due to size-overlapping groups between steelhead and Chinook appears to be naturally minimized. Chinook salmon fry are intermediate in size between steelhead fry and yearlings. Observed maximum Chinook fry density was about 88 FPU at a mean size of 4 g. Coho fry biomass envelope is generally about double that for Chinook, trout and char. However the scatterplot shows much lower coho densities. This might be expected in shallow, faster and less preferred habitats compared to pools. WUA adjustments on observed coho densities yields much higher standardized abundance consistent with a biomass near 600 g/Unit.

Despite known sampling limitations in large rivers and general inability to sample deeper, faster habitats containing older, larger fish, we did occasionally catch Age 3+ and Age 4+ steelhead or rainbow trout. This was attributed to experienced crew, total net enclosure and shore-based electrofishing.

3.6 Implications for estimating stock-recruitment parameters

Results for the Bella Coola River indicate that relatively precise and accurate estimates of yearling steelhead parr standing stock can be obtained using a shore-based shockers and multi-pass electrofishing despite the possibility of under-estimation (Riley and Fausch 1992). It remains possible that a more rapid and efficient assessment using snorkel surveys can be employed in the future which would improve the sample size, reach-average parr density estimate and system coverage. However, whether this data, collected over a number of years, will be useful for estimating more refined stock-recruitment parameters for Bella Coola River steelhead using parameters (i.e. freshwater productivity and carrying capacity; Johnston et al. 2000), depends on how well the underlying assumptions of the study are met. These assumptions include: i) estimates of total adult steelhead escapement will also be reasonably precise and accurate, ii) the relationship between escapement or fry abundance and parr standing stock is strongly asymptotic and sufficient variation in escapement will occur during subsequent years to provide data points well above and below MSY, iii) the portion of the Bella Coola River system included in the study represents the major spawning and rearing areas and is a sensitive index to changes in the density and spatial distribution of steelhead fry and parr, and iv) the stock-recruitment relationship for steelhead is not masked by our inability to distinguish steelhead from resident rainbow during the juvenile survey.

3.6.1. Adult escapement estimates

We approximated the annual steelhead escapement by utilizing the estimated proportion of large fry representing the early-run component and adjusting the March snorkel count of “early-run” or winter fish upwards. The result was an estimate for both winter and spring steelhead returning to the Atnarko River and Burnt Bridge Creek. The 95%CI was computed from the SE statistics for proportion in the MIX program. Snorkel counts varied from a low of 46 adults in 1995 to a high of 540 adults in 2001 (Table 6). The proportion of large fry caught in September electrofishing varied from 0.11 in 1994 to 0.57 in 1990. There were no adult counts in 1992-94 (no surveys) or in 2005 (aborted survey).

Table 6. Summary of late Winter Snorkel and Other Surveys of the Atnarko River

Year	Date	Method	Sect 1	Sect 2	Total	Reliability	Reasons
1977	Mar.16-17	snorkel	9	145	154	Low	too few crew
1982	Mar.29	boat	90		90	Low	not calibrated
1991	Mar.15	aerial	21	72	93	Low	biased low
1995	Feb.28	aerial	31	15	46	Low	biased low
1996	Mar.25	aerial	16	84	100	Low	biased low
1997	Feb.21-23	aerial+snorkel	15	103	118	Moderate	mix of techniques
1998	Apr.5-11	aerial+snorkel	20	51	71	Moderate	mix of techniques
1999	Mar.4-5	snorkel	180	272	452	High	adequate crew and good sighting conditions
2000	Mar.7-9	snorkel	58	93	151	High	adequate crew and good sighting conditions
2001	Mar.5-7	snorkel	185	355	540	High	adequate crew and good sighting conditions
2002	Mar.26-28	snorkel	40	254	294	High	adequate crew and good sighting conditions
2003	Mar.27-29	snorkel	85	99	184	High	adequate crew and good sighting conditions
2004	Mar. 8-10	snorkel	41	309	350	High	adequate crew and good sighting conditions
2006	Mar. 28-29	snorkel	93	231	324	High	adequate crew and good sighting conditions

Section 1 is below Young Creek

Section 2 is above Young Creek

We provide a qualitative assessment of snorkel or aerial count reliability in Table 6. Our confidence in the counts was highest when survey flows were at or below the first quartile flows for the time of year, stream transparency was highest and when we had adequate crew coverage. Lowest reliability was associated with flows in the third quartile, poor stream transparency or inadequate crew coverage.

3.6.2. Relation between standardized fry abundance (brood strength) and escapement

We examined the relationship between fry abundance and paired escapement by brood year using March adult counts and the proportion they represent by the fraction of large (early) fry they produced.

The ANOVA results (Table 7) demonstrates that a positive relationship exists between adult counts and fry counts. Adult counts and estimated proportion of large fry explain 84% of the annual variation in fry abundance. Data inputs were those described in Section 3.5.1.

The model is:

Fry Count = 37+ 0.07• Expanded Adult Count

Table 7. Comparison between March adult counts and the proportional representation of large (early) fry.

Summary of Fit

RSquare	0.853854
RSquare Adj	0.835586
Root Mean Square Error	15.54427
Mean of Response	84.5
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11293.506	11293.5	46.7399
Error	8	1932.994	241.6	Prob > F
C. Total	9	13226.500		0.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	37.032272	8.507013	4.35	0.0024
Expanded Adult Count	0.0699902	0.010237	6.84	0.0001

The scatterplot and linear regression is displayed in Figure 15. The regression ANOVA is highly significant (F ratio = 47; $p < 0.001$) and we concluded that a strong relationship exists between fry density and the number of potential spawners they were recruited from. The regression is not intended to forecast adults based on brood strength of fry and subsequent smolt production. We understand the relationship between fry and smolts is always asymptotic; marine survival can vary by an order-of-magnitude; and marine survival is not predictable at present.

To achieve a precautionary threshold of 80 fry per 100m^2 of suitable habitat in the Bella Coola River, we concluded we would require about 600 steelhead in total for the study area or a March snorkel count of about 210 fish in the Atnarko River. We further assumed that a target reference point (TRP) is greater than the PT. If the ratio of TRP to PT were 1.5:1, the TRP fry density of 120 FPU, as a system mean, would be adequate to fully recruit adjacent parr habitat after the fry had survived to the following year. The TRP equivalence for March snorkel count of adults is ~320 steelhead. At the other end of the relative abundance spectrum, the limit reference point (LRP) represents the lowest limit. If the LRP is 0.5 of PT, then the limit reference point for fry counts is 40 fry per 100m^2 and the equivalent March adult count is 105 steelhead. Adult counts in the magnitude of LRP are considered in the Extreme Conservation Concern Zone. Regardless of adult count quality in Section 3.6.1; there have been four years in the last twelve years of record that suggest the population has been in the extreme conservation zone. At a relative abundance level of 1 or system capacity, the fry capacity is 320 FPU in suitable habitat; the adult capacity is 4000 adults and the March snorkel count maximizes at 1100 adults at a marine survival rate of 13%. There is some direct evidence that marine survival rates for steelhead in the Keogh River can vary from 3 to 26% (Ward et al. 2005) in the absence of fishery mortality. The marine survival rate of Bella Coola steelhead is unknown but may mimic to some degree the Keogh results.

The fry-escapement plot also suggests that fry densities are generally higher at low escapement than expected, which might suggest a systematic negative bias in our snorkel counts at low adult abundance. We acknowledge the likelihood of under-counting in our March snorkel surveys; we examine in the next section an alternative or back-calculated escapement based on the amount of suitable fry space and certain biostandards such as fecundity and egg-to-fry survival. This alternative provides a better and more complete tracking of probable escapement for contrasting to other surveys and results.

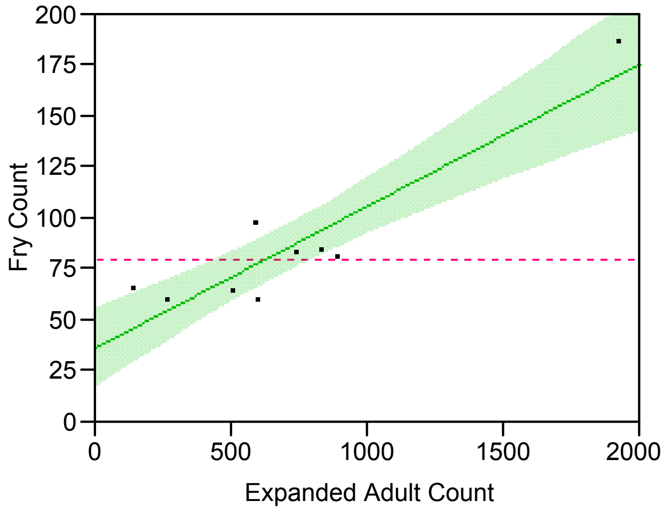


Figure 15. Scatterplot of fry density and brood strength or escapement. Fry count reference level set at 80.

3.6.3. Back calculated egg deposition and escapement based on mean fry density and fixed amount of suitable fry space

We computed the escapement necessary to account for the observed fry recruitment level each year by making the following assumptions. In general, we hypothesized that a large fry population or calibrated fry density resulted from many spawners and a small population resulted from few spawners. The specific assumptions include: 1) 2373 units of suitable fry space in the study area; 2) egg-to-fry survival is 13%; 3) mean fecundity of Bella Coola steelhead is 5600 eggs per female; and 4) sex ratio is 1:1. These assumptions are consistent with previous studies (Burt 2000) and follow the freshwater survival rate for Age 3+ steelhead smolt using Symon's (1979) medium survival protocol for Atlantic salmon. The egg-to-smolt survival rate is 1.20%; the fry-smolt survival is 0.012/0.13 or 9.25%, and the Age 1+ parr-to-smolt survival is 0.012/0.053 or 22.6%. We computed the minimum (threshold) escapement as:

$$\text{Spawners} = (\text{Mean Fry Density})\bullet(2373)\bullet(0.13)^{-1}\bullet(\text{Fecundity})^{-1}\bullet(2)$$

The results are shown in Figure 16 and they apply to the Bella Coola River system and the marker line at 600 spawners is the PT value, which sustains maximum parr and smolt production with the least number of spawners. A fishery may be contemplated at spawner numbers of double the precautionary level or about 1200 adult steelhead.

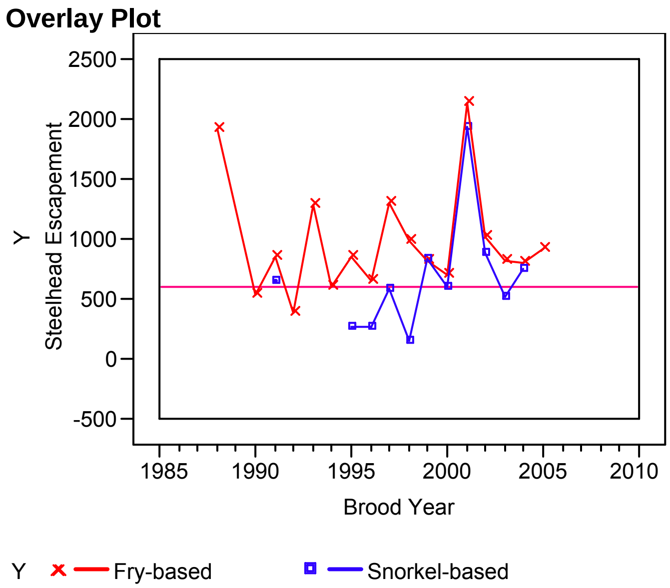


Figure 16. Annual Bella Coola steelhead escapement estimates based on snorkel and fry surveys (1988 – 2005).

The fry-based escapement estimate varies from a low of 382 spawners in 1992 Brood Year to a high of 2136 spawners in 2001. The overlay plot demonstrates a similar trend in abundance between the two methods for determining escapement. In comparison to the snorkel-based results, the correlation between the two independent estimators (R^2 = 0.62; r = 0.79, *df* = 9) is highly significant. The snorkel-based estimates are, on average, 66% of those based on fry abundance. Significant departures between the two escapement estimators occur in the period 1995-1998 where the ratio of snorkel-based to fry-based is about 0.33. We qualified our snorkel counts at that period as low to moderately reliable.

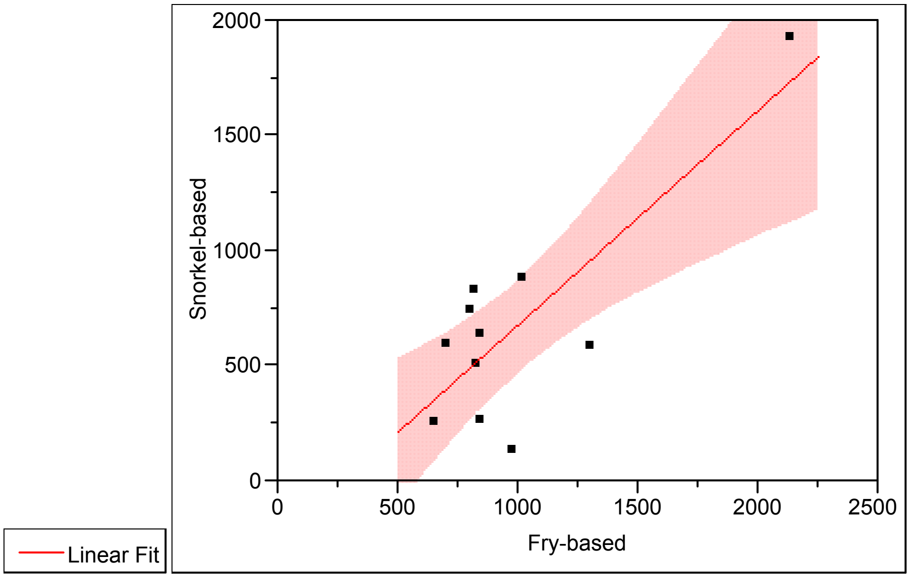


Figure 17. Regression analysis of steelhead escapement estimates derived from fry and snorkel surveys.

Linear Fit
Snorkel-based = -250 + 0.93 Fry-based.

Table 8. Statistical comparison between steelhead escapement estimates derived from fry and snorkel surveys**.**

Summary of Fit

RSquare	0.66039
RSquare Adj	0.622656
Root Mean Square Error	295.0649
Mean of Response	675.4255
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1523694.6	1523695	17.5010
Error	9	783569.9	87063	Prob > F
C. Total	10	2307264.4		0.0024

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-250.2911	238.4968	-1.05	0.3213
Fry-based	0.9334387	0.223128	4.18	0.0024

It appears the fry-based estimates are reasonable approximations and the results apply to more years than does the snorkel method. We were fortunate to have experienced a strong brood year in 2001 to expand the range in spawner abundance useful to explore the statistical relationship between spawners and juvenile recruits.

3.6.4. Resident rainbow trout abundance in the Study Area and implications for correctly assessing steelhead stock status

While we were unable to detect a third size component representing progeny of resident rainbow spawners in our MIX analysis and compute rainbow fry density, we computed a theoretical density. We could not dismiss the likelihood that our steelhead fry densities do include rainbow trout; we did not have exact information on time and location of their spawning. If the two forms of O. mykiss have over-lapping spawning areas, we could approximate the mean "resident" fry density by prorating the potential egg deposition or fry number over the known area of suitable space for fry. We also had several estimates of the total rainbow trout population from our September 1998 and March snorkel counts.

We did this using our snorkel counts of all species with a focus on resident rainbows (<65 cm FL). We assumed that our March counts were reasonable approximations of true population size (N = 562 in 2002) and a sex ratio is 1:1. The mean size from fish captures and snorkel inspection is about 45 cm fork length and the mean fecundity is near 700-1000 eggs per female. Using an egg-to-fry survival of 13% and total suitable area of 2373 units, a mean resident rainbow fry density of 10-15 FPU is derived and is dependent on actual mean fecundity.

We concluded that a density of 10-15 FPU representing resident rainbow trout offspring was relatively small in comparison to that for steelhead except for very low steelhead escapement years like 1992 Brood Year. The value is essentially equivalent to our error term for annual steelhead fry means.

3.6.5. Trends in escapements using other data sources and correlation with the Bella Coola River estimates

We compared estimates of steelhead escapement from several data sources to that of the Bella Coola River to better appreciate what indices can be tracked to assess stock status in the most meaningful and cost-effective way. LGL Limited through English et al (1999) and Nelson et al. (1998) provide annual estimates of escapement for the Bella Coola River based on fishery indices. The following Figure 18 shows a good correspondence for magnitude and trend pattern between our fry-based estimate and the LGL estimate. The regression ANOVA is marginally significant for slope; the intercept is not different from zero. The comparison shows the CPUE-based estimate (LGL) is about 60% of the fry-based model however the explained variation (36%) is low. Data for 1995 is an outlier where the fry-based estimate of escapement is much higher than that of the LGL estimator.

LGL Escap = 325 + 0.6•(Fry-based Escapement)

Table 9. Statistical comparison between steelhead abundance estimates based on fishery indices (LGL) and the fry based model.

Summary of Fit

RSquare	0.435644
RSquare Adj	0.355022
Root Mean Square Error	357.4252
Mean of Response	917.5556
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	690314.9	690315	5.4035
Error	7	894269.3	127753	Prob > F
C. Total	8	1584584.2		0.0530

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	324.90612	281.4171	1.15	0.2862
Fry-based Escapement	0.6145691	0.264382	2.32	0.0530

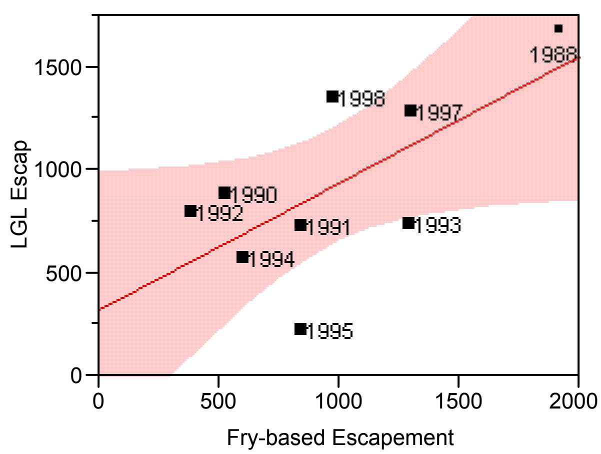


Figure 18. Regression analysis of steelhead fry based escapement estimates and LGL escapement analysis based on fishery indices.

Since steelhead smolts emigrating from the Bella Coola River enter into the same marine receiving area as the Dean River fish and we understand the stream productivity of the two watersheds are similar, we examined the relation of steelhead escapement between them according to the Brood Year on the Bella Coola River and Return Year for Dean River. We found a weak, positive trend (R^2 = 0.39) for the data supplied by Dean Peard (pers. comm.) and our estimates for the Bella Coola River (Figure 19). However we did observe some major, unexplained outliers so the ability to accurately track what is occurring on the Bella Coola River using inferences for Dean steelhead catch is limited (Figure 20).

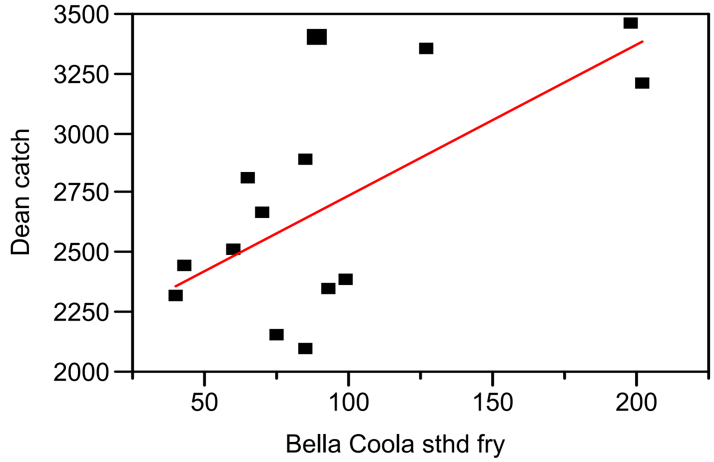


Figure 19. Scatter plot comparison between aggregate annual Dean River steelhead catch and mean annual Bella Coola fry densities.

Table 10. Statistical comparison between aggregate steelhead catch during the Dean River sports fishery and corresponding fry densities in the Bella Coola River.

Summary of Fit

RSquare	0.434796
RSquare Adj	0.387695
Root Mean Square Error	372.6176
Mean of Response	2709.357
Observations (or Sum Wgts)	14

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1281703.0	1281703	9.2313
Error	12	1666126.2	138844	Prob > F
C. Total	13	2947829.2		0.0103

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2109.7019	221.0669	9.54	<.0001
Bella Coola sthd fry	6.3074182	2.075971	3.04	0.0103

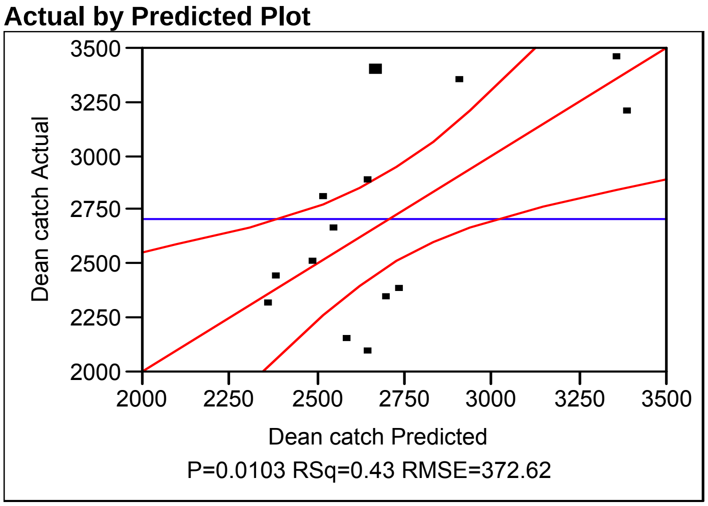


Figure 20. Scatter plot comparing Dean River catch and predicted catch based on observed Bella Coola fry densities.

In another trial, we examined the relation between the Tyee Index for Skeena "summer" steelhead returns and Bella Coola fry count (standardized fry density). We assumed the Skeena steelhead returning in Year X were the same group of ocean fish that returned to the Bella Coola later the same year and into the next. It appears the steelhead returns to the Bella Coola River are not in synchrony with other northern populations (Skeena), any more than they are for those from southern watersheds (e.g. Keogh River). The regression ANOVA was non-significant (F ratio = 0.66; p = 0.43). The expected linear function was diminished by a high fry count on the Bella Coola River in 1988 and a low Tyee index. The high Tyee Index for 1998 was met by a low fry count on the Bella Coola in 1999.

Table 11. ANOVA comparison between the Tyee Test Fishery (Skeena) steelhead abundance estimate and Bella Cola fry densities.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1357.596	1357.60	0.6591
Error	14	28838.404	2059.89	Prob > F
C. Total	15	30196.000		0.4305

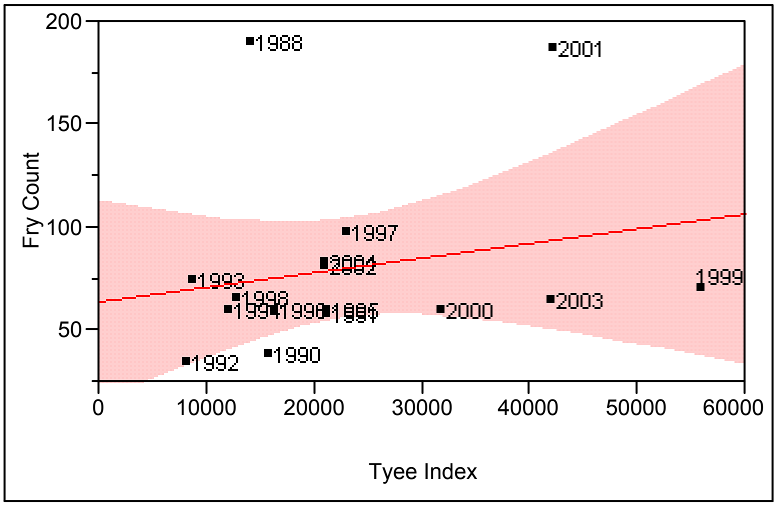


Figure 21. Annual steelhead abundance based on the Tyee Test Fishery (index) versus Bella Coola fry density.

3.7. Bella Coola River steelhead smolt capacity and escapement needs

We constructed a steelhead production summary for the Bella Coola River by integrating results of this study, certain biostandards; reach weightings and physical surveys of previous specialized stream inventories. The reach details and bolded sections describing the report's study area are captured in Appendix 4. The Atnarko-Burnt Bridge-Salloomt-Noosgulch aggregate account for 3500 adults from a system total of 4000; this represents 88% of the total adult capacity for the Bella Coola River. The minimum escapement (PT level) required to sustain the adult capacity is 900. The adult numbers assume a nominal marine survival for 25 thousand smolts and 20% repeat spawners.

The predicted smolt yield for the Atnarko River mainstem (Reaches 1-4) is 16 thousand steelhead from a wetted area of 11,400 units and stream length of 34.9 km. The smolt yield per 100m^2 unit is 1.4 smolts•(Unit)$^{-1}$ or 460 smolts per km. Previous biostandards (Lill and Tautz 1983) of 2.8 smolts•(Unit)$^{-1}$ suggest our estimate for the Atnarko River is highly conservative (lower). A roving snorkel check of parr rearing capacity by meso-habitat in the future may use the inferred yearling parr number that survives to the smolt stage. From Results section 3.5.3, the yearling parr survival to smolt stage is 22.6%. The lineal density of Age (1+) parr is then 2000 parr/km or 200 parr/100m or 6.2 FPU total wetted area. From the results presented in Section 3.5, we conclude a reach-wide parr density of 6.2 FPU or 25% suitability is very conservative but realistic based on the low potential parr capacity in Reaches 1 and 3 and moderate-high capability in Reaches 2 and 4. We assume that 26 FPU is a realistic yearling parr capacity in suitable habitat despite shore-based electrofishing.

Recent steelhead recovery planning (Lill 2002) uses a simple metric to qualify adult capacity, TRP and LRP adult escapement needs. The metric is adult numbers per stream km. To ensure compatible results, we restricted our estimate for the Bella Coola River to those productive areas only and discounted stream lengths associated with zero or low steelhead use (mainstem Bella Coola; Talchako River). The adult capacity estimate for the Atnarko River aggregate per km is 3,600 steelhead adults from 60.3 km or 60 adults per km. This is about double the value for small, unproductive streams such as the Keogh River (31 adults/km).

Steelhead escapement needs for the study area equate to 900 spawners including repeat spawners. The need increases in the absence of larger, repeat spawners. The PT or "conservation concern" metric for the aggregate Bella Coola tributaries is 10 spawners•km^{-1}. The related TRP escapement in which a fishery might be considered is 15 spawners•km^{-1}. The system-wide limit reference point is 5 spawners•km^{-1}and for the Atnarko River it is 12 spawners•km^{-1}. Egg deposition needs prorated over total wetted area at the precautionary level is 80 eggs/Unit; the requirement at the conservation threshold or TRP level is 120 eggs/Unit. Our value for TRP egg deposition is half of the current conservation target for Canadian rivers of 240 eggs•(100m^2 fluvial habitat)$^{-1}$, which is intended to optimize Atlantic smolt production (Elson 1975; Chadwick 1982). There are no Canadian standards for steelhead egg deposition. We understand that egg deposition needs are complex and vary according to stream size, flow, food supply, quality of parr rearing space, relative proximity of rearing and spawning locations, and accessible stream length. The steelhead TRP egg deposition levels are 70 and 200 eggs• (100m^2 fluvial habitat)$^{-1}$ respectively for Snow Creek and Keogh River.

4.0 Discussion

Quantification of steelhead population size and escapement needs in large rivers is daunting; especially in a remote, glacial watershed. It is even more challenging in the presence of numerous salmon-feeding grizzly bears. Our findings and approach confirm that correlation population method outlined by Ricker (1971) is an appropriate and practicable way of estimating the escapement level of adult fish in a large population. We found that our ability to use fry recruits as a proxy for number of females and the total spawning population was satisfactory. This is despite the awkward problem of estimating fish population size from estimates of the total number of eggs laid during a spawning season, the stock fecundity, variable and high frequency of large repeat spawners with high fecundity, size and sex composition of the population, egg-to-fry survival and the amount of suitable fry habitat (Cushing 1957; Saville 1964; Tautz and Slaney 1982). We independently derived an estimate of the spawning population by integrating the snorkel counts of early run (August-

January) steelhead with the fraction of large fry counted in the total catch of fry in September.

The size of juvenile steelhead may be affected by parental spawning date (Einum and Fleming 2000; Seamons et al. 2004), which can influence the length frequency distribution of fry and possibly parr. The relevant biological advantage to spawning early is partially related to earlier claim on rearing territories (Chandler and Bjornn 1988; Titus and Mosegaard 1991), territorial advantages conferred from being big (Keeley and McPhail 1998) and more efficient use of available habitat (e.g. use of deeper, faster space). On a downside, earlier emergence may force small fish into less suitable areas due to high flows or deposited eggs may be more prone to scour flows. The results of our study of fry length frequency showed there are two primary size modes, there is a large range in fork length, which produces in a higher than normal CV. This is consistent with the results of Seamons et al. (2004) for Snow Creek steelhead. Both studies confirmed the prediction that offspring size was strongly related to spawner arrival date and spawning time. The apparent fraction of fry that were likely the progeny of early run steelhead closely resembles the fraction of early run steelhead to the Bella Coola River (Wilkinson 1978, 1979) and the run size components in the Nuxalk fishery (Nelson et al. 1998).

Fry and parr densities vary considerably by year and location in our study area as they do most elsewhere in natural streams (Reiser and Bjornn 1979; Ptolemy 1987; Mills 1991; Ptolemy 1993; Ptolemy, unpublished data). Throughout the steelhead life cycle, each developmental stage utilizes different habitats by season; habitat availability can determine recruitment levels to the smolt stage.

The limiting factor for maximizing smolt production is most often the availability of suitable habitat at the parr stage however in this case, freshwater smolt production and adult returns can be ultimately limited by the size of the spawning population in respect of conservation needs. Parr survival to the smolt stage depends upon food supply and space for which individuals compete (Allen 1969; Kalleberg 1958). We have provided a profile of the space (meso-habitat type) in which the highest parr densities occur and the extent of this habitat by reach within the Bella Coola River. Parr seem to exploit stream locations in or near fast water that are most profitable to them (Fausch 1984). This is in response to effective feeding on drift prey originating from riffles (Hughes 1992) and through association with riffles, rapids, and runs (Hartman 1965). The availability of riffle-rapid-cascade habitats and the interfaces with runs and pools, in our case, tends to limit population size and we term this as “carrying capacity” (Egglishaw and Shackley 1977). We also refer to “carrying capacity” at the meso-habitat scale, which is the scale electrofishing, or snorkeling is conducted at.

Interactions with Chinook salmon, which are enhanced from the DFO Snootli Hatchery in Hagensborg, may also affect utilization of habitat by steelhead. This interaction is minimized and mitigated by the limited size overlap apparent among steelhead juveniles and Chinook; this can be seen from the Atnarko Allen Plot consistent with findings of Bjornn (1978). We observed relatively high steelhead parr or fry densities in suitable habitats in the presence of high Chinook fry densities, which suggests that competitive interactions are minimal in this instance and mitigated by fish size differences. Examples of locally high sympatric densities of Chinook and steelhead are described in Table 12; the densities are not calibrated for habitat suitability however they suggest the biomass near 260g/Unit per species size class is achieved. The cell biomass below, range from 149 to 600 g/Unit with no consistent dominance of one species over another.

Table 12. Cases with high Chinook and juvenile steelhead densities within the same local habitat.

Year	Site	Steelhead Density (Size, g)	Chinook Fry Density (Size, g)
1996	AT125	8.9 FPU (16.7g)	54.3 FPU (4.8g)
1997	AT008	300 FPU (2g)	89 FPU (3.3g)
1997	AT027	207 FPU (1.7g)	112 FPU (2.4g)
1999	BB017	16.1 (11g)	48 FPU (6.4g)

Winter can be a serious seasonal bottleneck for smolt production in streams with snowmelt-driven hydrology (winter baseflows and icing) during which density-dependent processes occur (Bjornn 1971; Mason 1976). The availability of suitable space has often been cited as one of the main limiting factors (Rimmer et. al 1985; Naslund 1989; Nickelson et al. 1992; Heggenes et al. 1993; Cunjak 1996; Harwood et al. 2002; Maki-Petays 1999) in some salmonid populations. For example, Smith and Griffith (1994) found that rainbow trout survival was higher in enclosures with cobble substrates than in those without, even though both enclosures excluded predators. The presence of suitably sized rocks in the enclosures allowed trout to shelter in the intersticial spaces; the spaces removed the fish from adverse ice movement-dislodgement but also provided them with a reduced energy expenditure in daylight. We suspect those reaches in our study with high frequency of boulder habitats and empirically high steelhead parr summer densities offer a considerable over-wintering advantage to both fry and parr. Maki-Petays (1999) concluded that stream areas with cobble-boulder substrate sizes were preferred by over-wintering trout especially those fish larger than 10 cm. Due to the reduced swimming ability of fish at cold temperatures (Rimmer et al. 1985; Graham et al. 1996), the intersticial spaces of coarse substrates may be a prime determinate of the suitability of the Bella Coola drainage network area as wintering grounds for steelhead juveniles. Boulder habitats of steelhead streams with large winter freshets (e.g. Salloomt River) are preferred for similar reasons especially if they are not embedded with sediment (Bjornn et al. 1977). It is the stability of large boulder matrices under channel forming flows that is the mechanism for enhanced fish survival; with smaller particle diameters being more prone to scour and bedload movement (Bustard and Narver 1975; Reiser et al. 1988).

We have described relatively large steelhead fry densities in small substrate dominated reaches in the Atnarko River (Reaches 1 and 3). Fortunately it is likely that at the onset of winter, most fry abandon their summer habitats and move to adjacent wintering areas where either large woody debris occurs or where coarser substrates are available. This hypothesis is supported by many authors, who have documented considerable distances (200m or more) moved by juvenile trout and salmon in search of suitable over-wintering habitats (Cunjak et al. 1998; Chrisholm et al. 1987).

We were able to utilize a rare finding that fish density is positively correlated with weighted usable area unlike many contrary cases in the scientific literature (Shirvell 1986, 1989; Fausch et al. 1988). Habitat models can be expected to correlate closely with fish abundance only if a species' and size classes' tolerable range for a habitat variable is exceeded (Shirvell 1989). We were confident that our HSI for steelhead fry adequately simulated the non-random or clumped spatial distribution in sampled streams as others have found (Guay et al. 2000). This may explain why trout fry densities in this study were related to the availability of suitable depths and velocities where the habitat preference indices explained 57% or more of the variation among-sites for certain strong brood years. We were able to use WUA as covariate with the local population density to then compare the adjusted or calibrated density to a common benchmark based on comparable suitable space. The two different benchmarks relate to 1. maximum density or biomass at capacity and 2. target fry density that optimizes parr and smolt production. Our unbiased fry density could then be prorated over the known total amount of habitat suited for fry. Our "at capacity" biomass for the Atnarko River is about 264g per Unit of suitable space per size class inferred as the envelope curve in the Allen Plot.

Standardized fry counts in Year X from the Bella Coola River provide a useful, efficient and practical tool to predict the nominal abundance and distribution of steelhead age 1+ parr in Year X+1. Data collected in this study indicate a strong curvilinear fit between parr and fry abundance. Two independent measures of quantifying escapement suggest that our estimate of fry abundance is linear with escapement over the range of observed data. We conclude that smolt production is likely optimized if yearling parr density begins to plateau at a modest fry density of 80 FPU. This modest density is less than one third of the previous fry capacity target of 300 FPU (Burt 2001) however it is double or more of conservation targets in smaller streams such as Keogh River and Snow Creek. Recent fry counts suggest the spawning population has fluctuated largely within the conservation concern zone with occasional brood years (1993, 1997, 1998, 2001 and 2002) in the routine management zone. There is one instance (1992) where the escapement equated to an extreme conservation level however the electrofishing data are limited. If we equate our strongest brood years including 1988 and 2001 with a large run size, a “healthy” or fishable population occurred in one year since the 1995 steelhead closure. The re-opening of the steelhead fishery might hinge on a half-generation length of three continuous years where the escapement significantly exceeds the spawning target and resultant mean fry density averages 120 FPU throughout the Bella Coola River. However a conceptual framework for management of steelhead in British Columbia (Johnston et al. 2002) suggests that a precautionary threshold of 30-35% of adult capacity (1200-1400) is required to maintaining higher escapements for sports and FN fisheries. Our estimates of fry-based escapement since the closure, which have spanned almost two fish generations, range from 650 to 2140 fish and the average was 1000 steelhead (excluding 2001 brood). These counts are within the conservation concern zone and warrant temporary closure or as a minimum, steelhead catch-and-release.

We suggest a complementary approach to that based on adult or smolt numbers by Johnston et al. 2002. Our approach is well grounded by research elsewhere on the relation of fry abundance with smolt production (Ellliot 1998). Adult and smolt counts per stream are well beyond the capabilities of most agencies. We utilize empirical fry-parr abundance data to infer stock status. Specific to the Bella Coola watershed, we are suggesting that a PT fry density for steelhead is 80 FPU in suitable habitat to achieve 100%capacity for parr and presumably smolts. Metrics that use relative abundance as per Johnston et. al. (2002) can be used to approximate stock status. We assume that carrying capacity for parr is the goal of conservation efforts and that a precautionary threshold (PT) for fry is a good metric to monitor as a proxy for counting spawners. Biological reference points bracketing PT by 50% were used to set the LRP and TRP levels of fry abundance. A fry density of 40 FPU is equivalent to LRP for future smolts or previous adult spawners. We also imply a mean yearling parr density in suitable habitat that is one third of the capacity estimate (e.g. 9 FPU) is a clear indication that spawner numbers and fry abundance were insufficient to fill habitat capacity and the stock abundance is in the ECC zone (Figure 22).

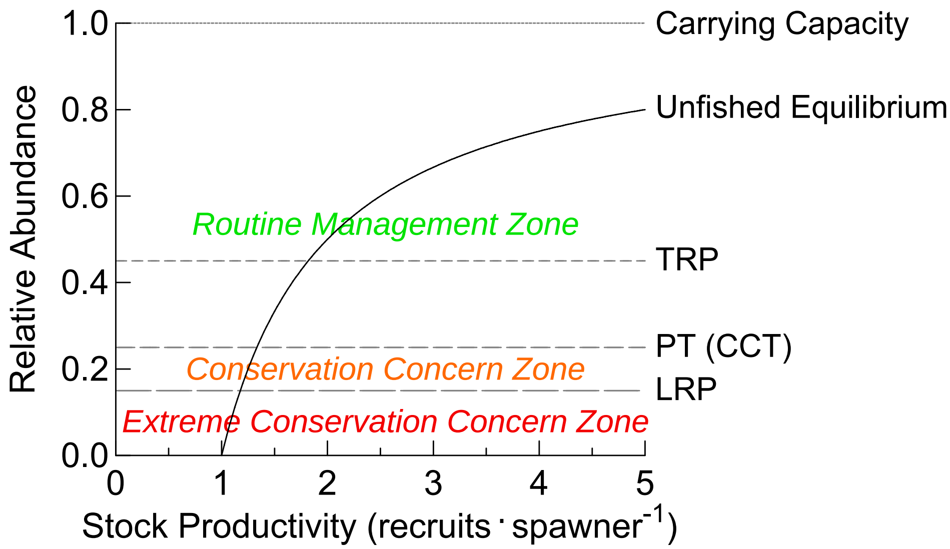


Figure 22. Proposed basic framework for steelhead management, showing the locations of abundance thresholds and management zones. The conservation concern threshold (CCT) is a minimum target reference point that is used as a precautionary threshold (PT) to initiate management actions to return the population to an operational target reference point (TRP) within the routine management zone. "Carrying capacity" here is the asymptotic maximum recruitment, not the unfished equilibrium abundance.

5.0 Conclusions

Overall, we consider the innovative and indirect techniques we applied to have been adequate, but not perfect, for the purpose of confidently estimating or "qualifying" steelhead escapement in the Bella Coola River. Determining abundance trends for a low abundance population that is widely distributed over a very large watershed is a formidable technical problem. Our cost-effective surveys allowed us to set useful biological reference points for managing a wild population. We remain optimistic that the steelhead population is positioned to fully recover once marine survival rate has rebounded. The combined weight of evidence for fry and parr reference densities (50-100% target) and adult abundance suggests conservation threshold is always reached in recent years. Several years' monitoring data for both escapement and recruitment variables are required to re-open the fishery from its closed state. The next few years will be critical to monitor. Local logistical and financial support to do this is essential. We emphasize the stock is far from extinct. There remains no legitimate conservation reason to intervene with hatchery smolt releases to restore the wild population since wild escapements are at or above the PT level since 1996. Again, in view of the strong 2001 brood year for steelhead and adult abundance that was about 2.4X the required escapement, the population is posed to quickly respond to improvements in marine survivorship. The PT level of adult abundance applies to most recent years and does not safely allow any level of fishery use, harvest and mortality. We conclude the steelhead fishery should remain closed until a sustained level of high spawner numbers (fry proxy) is sustained for three consecutive years or one half fish generation.

6.0 Acknowledgements

The authors would like to thank Maurice Lirette, Tom Wilkinson, and Tom Johnston for their critical review and valuable input. Tom Wilkinson pioneered steelhead research on the Bella Coola River and provided all of the 1990-95 data. He was also the first to examine its sports fishery in 1976 for both steelhead and cutthroat. The support of Ted Down, Jack Leggett and Art Tautz is much appreciated. We are deeply indebted to our electrofishing team for their concentration and diligence while working among the large grizzly bear population. The British Columbia Habitat Conservation Trust Fund provided financial support for this study. MoE and BC Parks staff contributed logistical and field support. Our survey was enhanced by superior accommodation, transportation and helicopter services provided by the Bella Coola businesses.

7.0 References

Allen, K.R. 1969. Limitations on production in salmonid populations in streams, p. 3-18. In T.G. Northcote [ed.] Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver.

Bagliniere, J.L., and A. Champigneulle. 1986. Population estimates of juvenile Atlantic salmon as indices of smolt production in the R. Scorff, Brittany. J. Fish. Biol. **29**: 467-482.

Beland, K.F. 1996. The relation between redd counts and Atlantic salmon parr populations in the Dennys River, Maine. Can. J. Fish. Aquat. Sci. **53**: 513-519.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Trans. Amer. Fish. Soc. **100**:423-438.

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. Klamt, E. Chacho, and C. Schaye. 1977. Transport of granitic sediment in streams and its effects on insects and fish. For. Wildl. and Range Experiment Stn., Completion Report, Water Resour. Res. Insta. Project B-036-IDA, Univ. Idaho, Moscow. 43pp.

Bjornn, T.C. 1978. Survival, production, and yield of trout and Chinook salmon in the lemhi River, Idaho. Bull. No. 27, Coll. of For., Wildl. and Range Sci., Univ. Idaho, Moscow. 57pp.

Bocking, R. and K. English. 1992. Evaluation of the Skeena steelhead habitat model. Report for Ministry of Environment, Lands and Parks, Victoria, B.C.: 70 p.

Bovee, K.D. 1978. Probability–of-use criteria for the family *Salmonidae*. Instream Flow Information Paper: No. 4. Fort Collins, Colorado, Cooperative Instream Flow service Group. 80pp.

Burt, D.W. and J.W. Horchik. 1998. Habitat, abundance, and rearing capacity of salmonids in the Bella Coola Watershed. Report for Ministry of Fisheries, Victoria, B.C., and Ministry of Environment, Lands and Parks, Williams Lake, B.C.: 97 p.

Burt, D.W. and J.W. Horchik. 1999. Bella Coola juvenile steelhead and searun cutthroat stock assessment, 1998. Report for Ministry of Fisheries, Victoria, B.C., and Ministry of Environment, Lands and Parks, Williams Lake, B.C.: 101 p.

Burt, D.W. 2000. Bella Coola juvenile steelhead and searun cutthroat stock assessment, 1999. Report for Ministry of Fisheries, Victoria, B.C., and Ministry of Environment, Lands and Parks, Williams Lake, B.C.: 76 p.

Bustard, D.R., and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Onchorychus kisutch*) and steelhead trout (*O. mykiss*). Journal of the Fisheries Research Board of Canada **32**: 667-680.

Chadwick, E.M.P. 1982. Stock-recruitment for Atlantic salmon (*Salmo salar*) in Newfoundland rivers. Can. J. Fish. Aquat. Sci. **39**: 1496-1501.

Chandler, G.L., and Bjornn, T.C. 1988. Abundance, growth, and interactions of juvenile steelhead relative to time of emergence. Trans. Am. Fish. Soc. **117**: 432-443.

Chrisholm, I.M., W.A. Hubert, and T.A. Weshe. 1987. Winter stream conditions and use of habitat by brook trout in high-elevation Wyoming streams. Trans. Am. Fish. Soc. **116**: 176-184.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Fish. Aquat. Sci. 53: 267-282.

Cunjak, R.A., T.D. Prowse, and D.L. Parrish. 1998. Atlantic salmon in winter: “the season of parr discontent.” Can. J. Fish. Aquat. Sci. **55**(Suppl. 1):161-180.

Cushing, D.H. 1957. The number of pilchards in the Channel. Rep. Bd. Agric. Fish., Fish. Invest., Lond. Ser. 2, **21**, 5, 1-27.

Egglishaw, H.J., and Shackley, P.E. 1977. Growth, survival and production of juvenile salmon and trout in a Scottish stream, 1966-75. J. Fish. Biol. **11**: 647-672.

Elliott, J.M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biological Association Scientific Publication No. 25: 156 p.

Elliott, J. M. (1993). The self-thinning rule applied to juvenile sea-trout, *Salmo trutta*. *Journal of Animal Ecology* **62:** 371 379.

Elliott, J. M. (1993). A 25-year study of production of juvenile sea-trout, *Salmo trutta*, in an English Lake District stream. *Canadian Special Publication of Fisheries and Aquatic Sciences* **118:** 109-22.

Elliot, J. M. (1996). The relationship between smolt density and fry density in salmonids. *Journal of Fish Biology* **48** (5): 1030-1032.

Elson, P.F. 1975. Atlantic salmon rivers: smolt production and optimum spawning, an overview of natural production. Spec. Publ. Ser. Int. Atl. Salmon Found. No.**6**. pp. 96-119.

English, K.K., R.F. Alexander, T.C. Nelson, and M.K. Ramsay. 1999. Assessment of the distribution, timing, and abundance of adult steelhead returns to the Bella Coola River
Watershed in 1997 and 1998. Report for Ministry of Environment, Lands and Parks, Williams Lake, and Ministry of Fisheries, Victoria, B.C.

Einum, S., and I.A. Fleming. 2000. Selection against late emergence and small offspring in Atlantic salmon (*Salmo salar*). Evolution, **54**: 628-639.

Facchin, A. and P.A. Slaney. 1977. Management implications of substrate utilization during the summer by juvenile steelhead (O. mykiss) in the South Alouette River. Province of British Columbia, Ministry of Recreation and Conservation, Fisheries Technical Circular No. **32**: 19 pp.

Fausch, K.D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Canm. J. Zool. **62**: 441-451.

Graham,W.D., Thorpe, J.E., and N.B. Metcalfe. 1996. Seasonal current holding performance of juvenile Atlantic salmon in relation to temperature and smolting. Can. J. Fish. Aquat. Sci. **53**: 80-86.

Grant, J.W.A., and D.L. Kramer. 1990. Territory size as a predictor of the upper limit of density of juvenile salmonids in streams. Can. J. Fish. Aquat. Sci. **47**: 1724-1737.

Hankin, D.G. 1986. Sampling designs for estimating the total number of fish in small streams. USDA Forest Service Research Paper PNW-360: 33 p

Hankin, D. G. and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. **45**:834-844.

Hartman, G.F. 1965. The role of behaviour in the ecology and interaction of under-yaerling coho salmon and steelhead trout. Jour. Fish. Res. Bd. Canada **22**: 1035-1081.

Hartman, G.F., J.C. Scrivener, and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high energy coastal stream in British Columbia, and their implication for restoring fish habitat. Can. J. Fish. Aquat. Sci. **53(**Supp. 1):237-251.

Harwood, A.J., N.B. Metcalfe, S.W. Griffiths, and J.C. Armstrong. 2002. Intra- and inter-specific competition for winter concealment habitat in juvenile salmonids. Can. J. Fish. Aquat. Sci. **59**: 1515-1523.

Heggenes, J., Krog, O.M.W., Lindas, O.R., Dokk, J.G., and Bremnes, T. 1993. Homeostatic behavioural responses in a changing environment: brown trout (*Salmo trutta*) become nocturnal during winter. J. Anim. Ecol. **62**: 295-308.

Hughes, N.F. 1992. Selection of positions by drift-feeding salmonids in dominance hierarchies: model and test for Arctic grayling (*Thymallus arcticus*) in sub-arctic mountain streams, interior Alaska. Can. J. Fish. Aquat. Sci. **49**: 1999-2008.

Johnson, T.H. and R. Cooper. 1992. Snow Creek anadromous fish research. Annual Performance Report 92-5. Fisheries Management Division, Washington Depart. Of Wildlife. 56 pp.

Johnston, N.T., Parkinson, E.A., Tautz, A.F., and Ward, B.R. 2000. Biological reference points for the conservation and management of steelhead, *Oncorhynchus mykiss*. Canadian Stock Assessment Secretariat, Research Document 2000/126. Pp. 96.

Johnston, N.T., Parkinson, E.A., Tautz, A.F., and Ward, B.R. 2002. Biological reference points from deterministic stock-recruit relationships. BC Ministry of Water, Land, and Air Protection, Fisheries Project Report RD100. Pp. 47.

Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar and Salmo trutta*). Inst. Freshw. Res. Drottinngholm Rep. **39**: 55-98.

Keeley, E.R., and McPhail, J.D. 1998. Food abundance, intruder pressure, and body size as determinates of territory size in juvenile steelhead trout (*O. mykiss*). Behaviour, **135**: 65-82.

Leggett, J.W. May 1984. Letter to Willie Mackenzie, Fisheries and Oceans, Kitimat, B.C..File No. 40.300502, Williams Lake, B.C.: 3 p.

Lill, A.F. and A.F. Tautz. 1983. Opportunities for salmonid enhancement projects in British Columbia and the Yukon. Preliminary report by the Enhancement Opportunities Subcommittee to the Salmonid Enhancement Phase II Planning Committee. Department of Fisheries and Oceans.

Lill, A.F. 2002. Greater Georgia Basin Steelhead Recovery Action Plan. Report prepared for the Pacific Salmon Foundation. 107pp.

MacDonald, P.D.M., and Pitcher, T.J. 1979. Age-groups from size-frequency data; a versatile and efficient method of analyzing mixture distributions. J. Fish. Res. Board Can. **36**: 987-1001.

Maki-Petays, A. 1999. Habitat requirements of juvenile salmonids: towards ecologically-based fisheries management in boreal streams. Dep. Of Biology, Oulu University Library. 29pp.

Mason, J.C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. J. Wildl. Managame. **40**: 775-788.

Narver, D.W. 1972. Some possible effects of logging on two eastern Vancouver Island streams. Fish. Res. Bd. Canada Tech. Rep. **323**: 53pp.

Naslund, I. 1989. Effects of habitat improvement on the brown trout, *Salmo trutta* L., populations of a northern Swedish stream. Aquacult. Fish. Managem. **20**: 463-474.

Nelson, T.C., R.F. Alexander, K.K. English, and R.A. Ptolemy. 1998. Compilation of stock assessment information for Bella Coola River steelhead. Report for Ministry of Environment, Lands and Parks, and Ministry of Fisheries, Victoria, B.C.: 116 p.

Nickelson, T.E., Rodgers, J.D. Johnson, S.L., and Solazzi, M.F. 1992. Seasonal changes in habitat use by juvenile coho salmon (*O. kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. **49**: 783-789.

Mills, D. 1991. Strategies for the rehabilitation of Atlantic salmon. The Atlantic Salmon Trust, Pitlochry.

Peterson, N.P. and C.J. Cedarholm. 1984. A comparison of the removal and mark-recapture methods of population estimation for juvenile coho salmon in a small stream. N. Am. J. Fish. Manage. **4**:99-102

Ptolemy, R.A. and J.L.R. Russell. 1982. Fry stocking assessment of the upper Salloomt River. Unpublished Fisheries Reconnaissance Report, BC Fish and Wildlife Branch, Victoria, B.C. 14pp.

Ptolemy, R.A. 1988. Low angler catch of steelhead from Vancouver Island's largest river, the Nimpkish River; an analysis of a paradox in smolt production. Fisheries Assessment and Improvement Unit Report FAIU-11, Fisheries Management Section, Ministry of Environment, Victoria, B.C. 76pp.

Ptolemy, R.A. 1989. Effects of highway construction and mitigation on summer steelhead in the Coquihalla River, British Columbia. Fisheries Assessment and Improvement Unit Report FAIU-14, Fisheries Management Section, Ministry of Environment, Victoria, B.C. 148 pp.

Ptolemy, R.A. 1993. Maximum salmonid densities in fluvial habitats in British Columbia. p. 223-250. *In*: L. Berg and P.W. Delaney, editors. Proceedings of the Coho Workshop, Nanaimo, B.C., May 26-28, 1992.

Quinn, T.J., R. Fagen, and J. Zheng. 1990. Threshold management policies for exploited populations. Can. J. Fish. Aquat. Sci. **47**:2016-2029.

Reiser, D.W., and Bjornn, T.C. 1979. Habitat requirements of anadromous salmonids. General Tech. Rep. PNW-96 of the U.S. Depart. Of Agriculture, Forest Service, Pacific Northwest Forest and Range Experimental Station, pp.37-38.

Reiser, D.W., M.P. Ramey, and T.R. Lambert. 1988. Review of flushing flow requirements in regulated streams. *In* W.R. Nelson, J.R. Dwyer, and W.E.

Greenberg, editors. Flushing and Scouring Flows for habitat Maintenance in Regulated Streams. Washington, DC: US Environmental Protection Agency.

Richards, L. J., and J.J. Maguire. 1998. Recent international agreements and the precautionary approach: new directions for fisheries management science. Can. J. Fish. Aquat. Sci. **55**:1545-1552.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board. Can. Bull. **191**. 382 p.

Ricker, W.E. 1971. Methods for assessment of fish production in freshwaters. IBP Handbook No. 3. Blackwell Scientific Publications. Oxford and Edinburg. Pages 160-162.

Riley, S.C. and K.D. Fausch. 1992. Underestimation of trout population size by maximum likelihood removal estimates in small streams. N. Amer. J. Fish. Manage. **12**:768-776.

Riley, S.C., R.L. Haedrich, and R.J. Gibson. 1993. Negative bias in removal estimates of Atlantic salmon parr relative to stream size. J. Freshw. Ecol. 8:97-101.

Riley, S.C., J. Korman, J. Buszowski, R. Hill, and R.A. Ptolemy. 1998. Habitat-based assessment of steelhead production and escapement in tributaries of the Mid-Fraser River. Unpubl. MS., Prepared for BC Fisheries, Victoria, B.C. 36pp.

Rimmer, D.M., Sauders, R.L., and Paim, U. 1985. Effects of temperature and season on the position holding performance of juvenile Atlantic salmon (*Salmo salar*). Can. J. Zool. **63**: 92-96.

Rodgers, J.D, M. F. Solazzi, S. L. Johnson, and M. A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. N. Amer. J. Fish. Manage. **12**:79-86.

Russell, J.R.L. 1987. Steelhead production characteristics of the Chilliwack-Vedder River system. Fisheries Project Report FIU-07. Fisheries Improvement Unit, Recreational Fisheries Branch, Victoria, B.C. 29pp.

Saville, A. 1964. Estimation of the abundance of a fish stock from egg and larval surveys. Rapp. P.-v. Reun. Cons. Perm. Int. Explor. Mer **155**, 164-170.

Seber, G.A.F. and E.D. LeCren. 1967. Estimating population parameters from catches large relative to the population. Journal of Animal Ecology **36**: 631-643.

Seamons, T.R., P. Bentzen, and T.P. Quinn. 2004. The effects of adult length and arrival data on individual reproductive successes in wild steelhead trout (*O. mykiss*). Can. J. Fish. Aquat. Sci. **61**: 193-204.

Shirvell, C.S. 1986. Pitfalls of physical habitat simulation in the instream flow incremental methodology. Can. Tech. Rep. Fish. Aquat. Sci. **1460**: 68p.

Shirvell, C.S. 1989. Habitat models and their predictive capability to infer habitat effects on stock size, p. 173-179. *In* C.D.Levings, L.B.Holtby, and M.A.Henderson [ed.] Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. **105**.

Slaney, P.A. and A.D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. N. Amer. J. Fish. Manage. **7**: 117-122.

Smith, B.D. 1999. Assessment of wild steelhead (*Oncorhynchus kisutch*) abundance trends in British Columbia (1967/68-1995/96) using the steelhead harvest questionnaire. Province of British Columbia, Ministry of Fisheries, Fisheries Branch, Fisheries Management Report No. 110. 87 p.

Smith, S.B. 1968. Reproductive isolation in summer and winter races of steelhead trout. *In*: Symposium on Salmon and Trout in Streams.

Smith, R.W., and Griffith, J.S. 1994. Survival of rainbow trout during their first winter in the Henrys Fork of the Snake River, Idaho. Trans. Am. Fish. Soc. **123**: 747-756.

Stuart, K.M. 1981. Habitat assessment and salmonid production in Camera Sidechannel (Atnarko River), with reference to enhancement opportunities. Fish Habitat Improvement Section, Fish and Wildlife Branch, Victoria, B.C.

Symons, P.E.K. 1979. Estimated escapement of Atlantic salmon (*Salmo salar*) for maximum smolt production in rivers of different productivity. J. Fish. Res. Board Can. **36**: 132-140.

Tautz, A.F. and P.A. Slaney. 1982. Preliminary biostandards for anadromous rainbow and cutthroat trout in British Columbia. Unpublished data, B.C. Ministry of Environment, Vancouver: 1 p.

Tautz, A.F., B.R. Ward, and R.A. Ptolemy. 1992. Steelhead trout productivity and stream carrying capacity for rivers of the Skeena drainage. PSARC working paper S92-6, Pacific Stock Assessment Review Committee, B.C. Ministry of Environment, Lands and Parks, Fisheries Branch. 45 p.

Titus, R.G., and Mosegaard, H. 1991. Selection for growth potential among migratory brown trout (*Salmo trutta*) fry competing for territories: evidence from otoliths. Can. J. Fish. Aquat. Sci. **48**: 19-27.

Van Deventer, J.A. and W.S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data-users guide for **Microfish 3.0**. Gen. Tech. Rep. INT-254. Ogden, UT: U.S. Depart. Agriculture, Forest Service, Intermountain Research Station. 29 pp.

van Dishoeck, P., J. Korman and R.A. Ptolemy. 1999. Squamish River: Map-based habitat capability modeling. Prep'd for MELP Fish and Wildlife Management, Surrey, B.C. by Aquatic Resources Limited, Vancouver, B.C. (Report ARL 277-1).

Ward, B.R. and P.A. Slaney. 1993. Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead trout. Pages 209-217 in R.J.Gibson and R.E. Cutting [eds.] Production of juvenile Atlantic salmon in natural waters. Can. Spec. Publ. Fish. Aquat. Sci. **118**.

Ward, B.R. 1996. Population dynamics of steelhead trout in a coastal stream, the Keogh River, British Columbia. *In* Stock assessment in inland fisheries. *Edited by* I. Cowx. Fishing News Books, Blackwell Scientific Publications, Oxford, U.K. pp. 308-323.

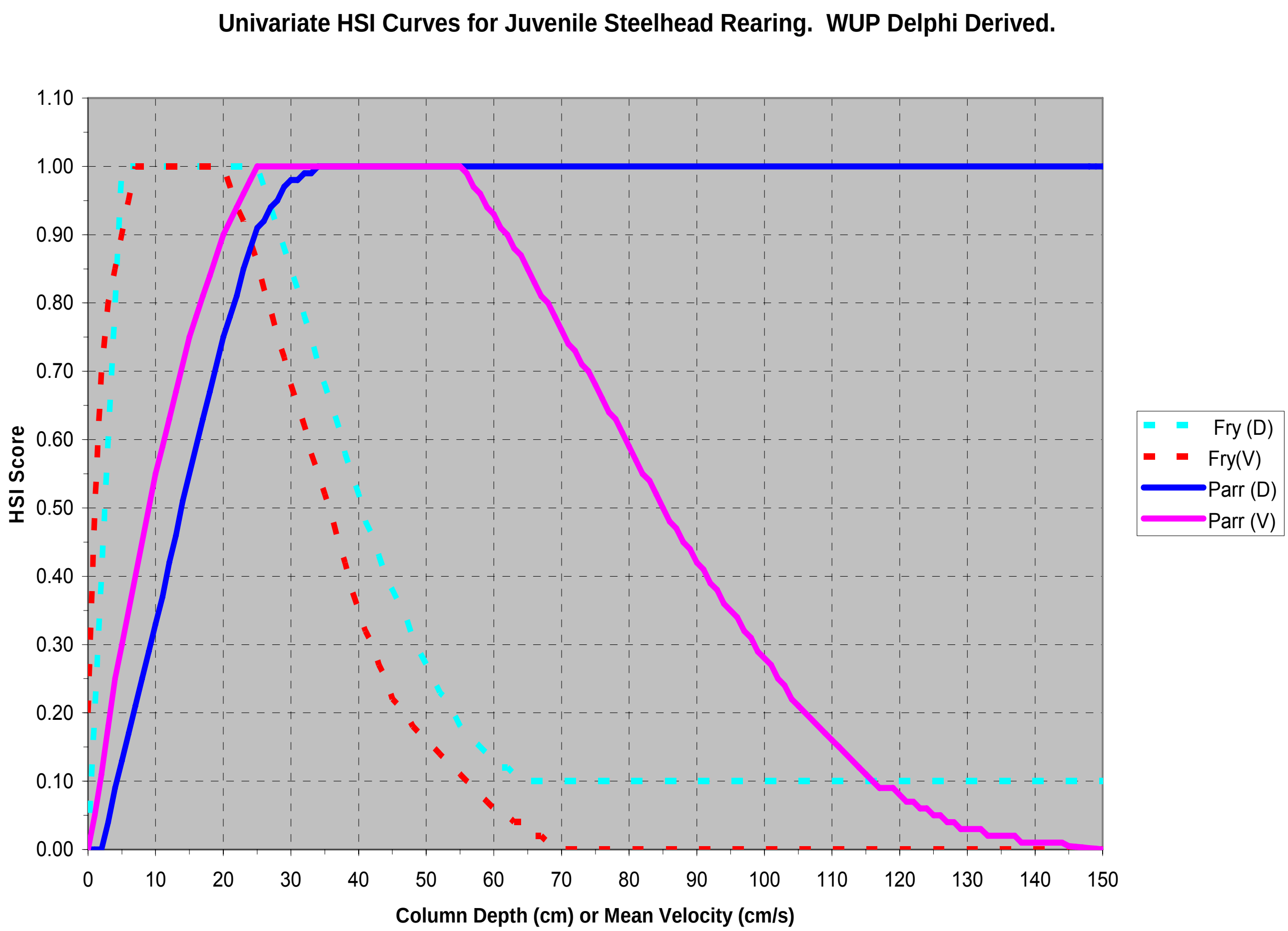
Ward, B.R. 2000. Declivity in steelhead (*Oncorhynchus mykiss*) recruitment at the Keogh River over the past decade. Can. J. Fish. Aquat. Sci. **57**: 298-306.

Wilkinson, T.D. 1978. Salmonid Enhancement Program Atnarko-Bella Coola River Steelhead Survey 1976-1977. BC Fish and Wildlife Branch, Williams Lake, BC. Technical Report F-78-2.

Wilkinson, T.D. 1979. Salmonid Enhancement Program Atnarko-Bella Coola River Steelhead Survey 1977-1978. BC Fish and Wildlife Branch, Williams Lake, BC. Technical Report F-79-2.

8.0 Appendices

Appendix 1. Univariate HSI curves for steelhead fry and parr.



Appendix 2. Location map of electrofishing stations in the Bella Coola River.

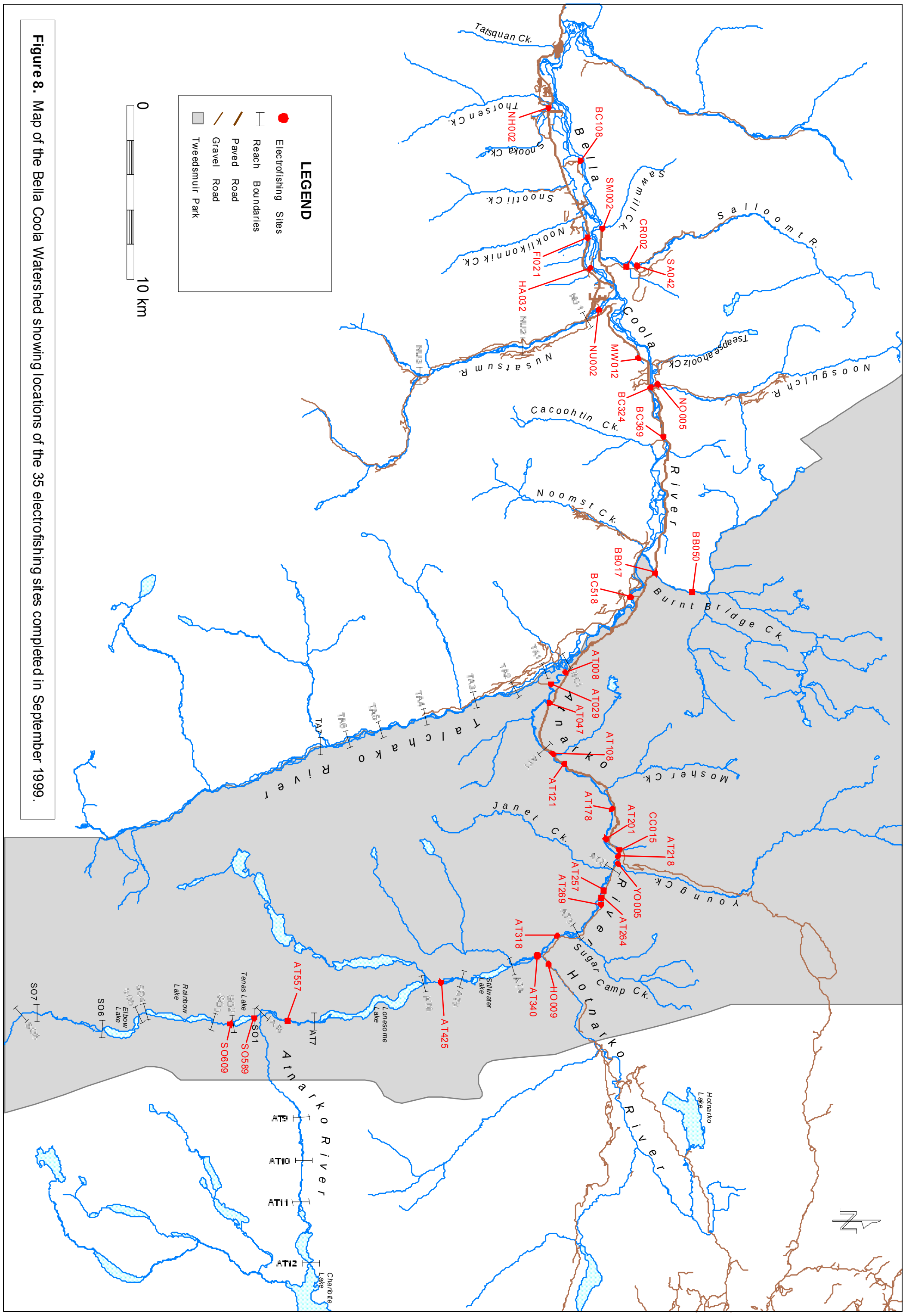
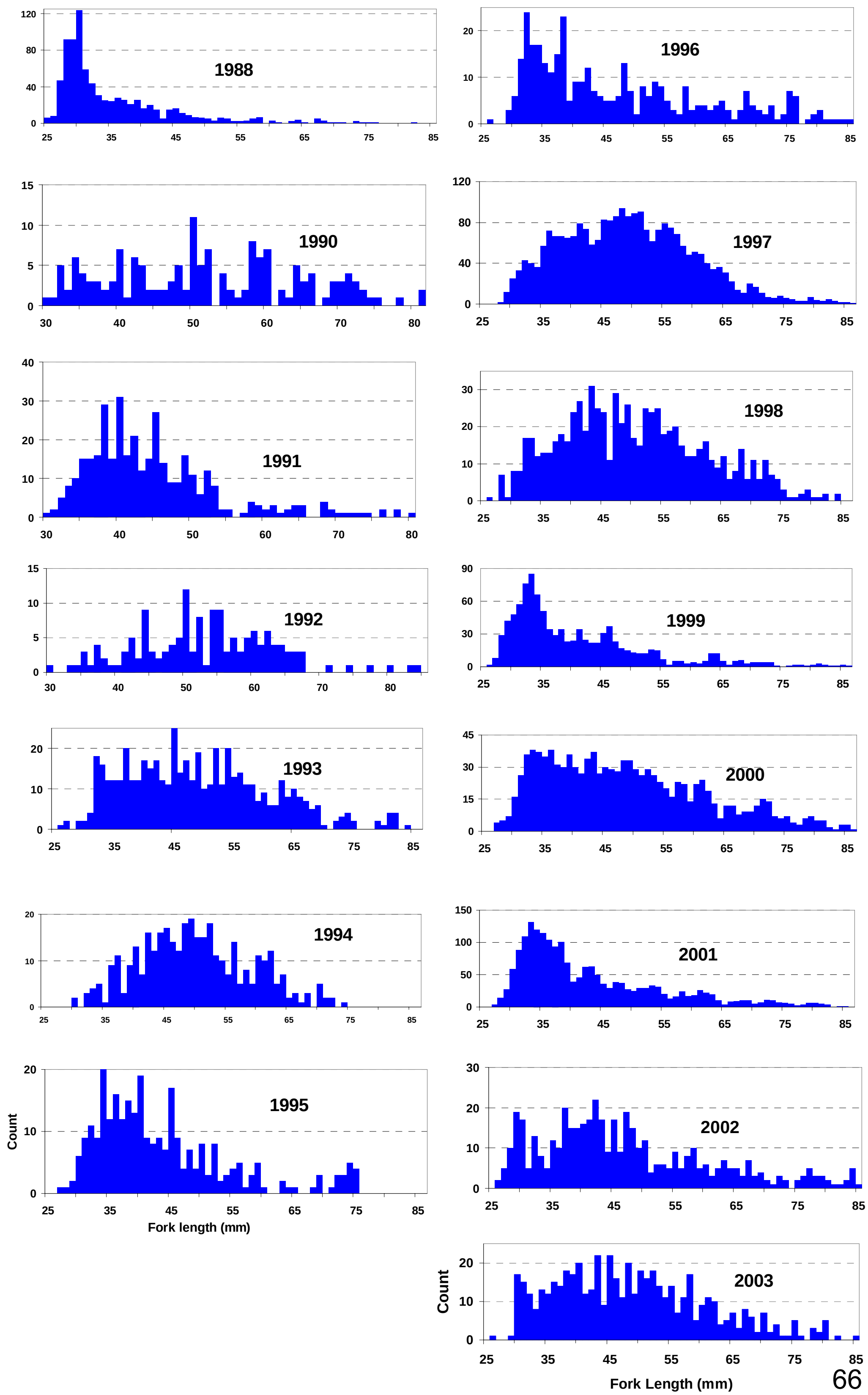


Figure 8. Map of the Bella Coola Watershed showing locations of the 35 electrofishing sites completed in September 1999.

Appendix 3. Length frequency distribution of steelhead fry in the Atnarko River.



Appendix 4. Reach summary statistics of usable area and steelhead production estimates.

Stream	Reach	Order	Description	Width (m)	Length	%WUA	Usable	Fry Pop	Smolts	Adults	Adults	%Total Adults	Min
				wetted	(km)	St fry	Units (100 sq.m)	Critical		N (maiden)	N+repeats	%	Escapement
Atnarko	1	6	Bella Coola to 11km	34.8	9.69	12	427	42700	3950	513	616	13.7	146
Atnarko	2	6	11km to above Young Cr.	33.9	12.7	12	573	57300	5300	689	827	18.4	196
Atnarko	3	6	low gradient above Young Cr.	32.3	6.5	15	310	31000	2868	373	447	9.9	106
Atnarko	4	6	low gradient to Stillwater L.	27.6	6	20	274	27400	2535	329	395	8.8	94
Atnarko	5	6	Stillwater L. to Lonesome L.	23.2	4	10	88	8800	814	106	127	2.8	30
Atnarko	6	6	above Lonesome L.	20.2	5	15	123	12300	1138	148	177	3.9	42
Mosher	1	3	accessible length to barrier	3.3	0.8	20	5	500	46	6	7	0.2	2
Young	1	5	accessible length to barrier	9.6	2	20	126	12600	1166	152	182	4.0	43
Hotnarko	1	5	accessible length to barrier	14.4	3.5	20	297	29700	2747	357	429	9.5	102
Total Atnarko					51.3		1682	222300	20563	2673	3208	71.3	760
Thorsen	1	4	accessible length to barrier	12.4	2.5	35	88	4400	407	53	63	1.4	15
Noohalk	1	3	accessible length to barrier	5.3	3	50	75	3750	347	45	54	1.2	13
Snootli	1	3	accessible length to barrier	7.4	4	35	98	4900	453	59	71	1.6	17
Fish	1	2	accessible length to barrier	1.6	2.5	50	38	1900	176	23	27	0.6	6
Salloompt	1	4	accessible length to barrier	18.1	4	37	242	12100	1119	146	175	3.9	41
Nusatsum	1	5	accessible length to barrier	23	15	4	168	8400	777	101	121	2.7	29
Noosgulch	1	4	accessible length to barrier	16.5	1	35	58	2900	268	35	42	0.9	10
Burnt Bridge	1	4	accessible length to barrier	14.8	4	35	360	36000	3330	433	519	11.5	123
Total Tribs	1				36		1125	74350	6877	894	1073	23.8	254
Bella Coola	1	7	mouth to Atnarko River	64.2	60	4	1440	14400	1332	173	208	4.6	49
Total Bella Coola					147.3		4247	404351	31043	3740	4488	100.0	1063
Noosgulch	1	4	accessible length to barrier	16.5	1	35	58	2900	268	35	42	0.9	10

Appendix 5. Summary of Electrofished Sample Sites by Census Year and Stream.

Stream	**1980**	**1981**	**1982**	**1983**	**1988**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Atnarko River	1	1	1	2	9	5	6	7	6	5	6	12	16	15	15	15	10
South Atnarko River	0				0							1	2	2	2	0	0
Camera Channel	6				0							0	2	1	1	1	0
Hotnarko River	0				0	1						1	1	1	1	1	1
Young Creek	0				0							0	1	1	1	1	0
Noosgulch River	0				1							1	1	1	1	1	1
Tsepseahoolz Creek	0				0							2	2				0
Nusatsum River	0				0							2	2		1	1	0
Salloomt River	6	10	10	7	1							1	2	1	1	1	1
Burnt Bridge Creek	0				1	1	1	1	1	1	1	1	2	2	2		1
Sawmill Creek	0				0							0	4	1	1	2	1
Bella Coola River	0				2		1	0	1	1	1	2	5	2	4	4	4
Total Steelhead-bearing	13	11	11	9	12	7	7	8	7	6	7	21	35	25	26	23	15
Sugar Camp Creek	0											0	1	1			0
Molly Walker Creek	0											2	5	1	1	1	1
Walker Island Sidechannel	0											0	1				0
Airport Sidechannel	0											0	0				0
Dump Creek	0											0	3				0
Noohalk Creek	0								1	1	1	2	1	1	1	1	1
McClellan Creek	0											1	4				0
Edlyn Creek	0											1	4			1	0
Tatsquan Creek	0											0	1				0
Charter Creek	0											0	1				0
Fish Creek	0								1	1	1	2	4	1	1	1	1
Hagensborg Slough	0								1	1	1	2	3	1	1	1	1
Croft Creek	2											1	1	1	1	1	0
Thorsen Creek	0											1	1				0
Snooka Creek	0								1	1	1	0	2				0
Snootli Creek	0											0	1				0
Sato Creek	0											1	4				0
Mill Pond Creek	0											0	1				0
Nooklikonnic Creek	0											1	1				0
Cacoohtin Creek	0											0	0				0
Noomst Creek	0											0	0				0
Total CT/DV-bearing	2	0	0	0	0	0	0	0	4	4	4	14	39	6	5	6	4
Talchalko River	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Grand Total	**15**	**11**	**11**	**9**	**14**	**7**	**8**	**8**	**12**	**11**	**12**	**37**	**82**	**33**	**35**	**33**	**23**

Appendix 6. Site and Strata Summary of Steelhead Fry Densities (WUA adjusted) in the Bella Coola River Aggregate.

Strata	Site	1988	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
A	AT008			218	32	241	196	318	143	316	350	156	81	207	105	195	200	63
A	AT029									218	180	94	88	351	70	50	72	112
A	AT047	551	39	236	46	308	68	280	50	292	207	150	123	298	211	390	150	119
A	AT050	132																
B	AT108	351	83	116	63	217	73	54	52	153	157	121	171	345	71	103	20	124
B	AT121	296			77				33	119	72	94	158	84	59	58	28	42
B	AT122								36	78								
B	AT123								46	115						180		
B	AT178									75	156	37	64	133	70	112	448	131
B	AT201								206	93	35	68	72	436	279	63	68	97
B	AT218	169	5	44	41	41	73	100	41	64	33	40	96	254	68	48	64	39
B	CC015								67	216	99	80	103		127	107	60	116
B	CC012									50								
B	YO005									168	99	124	126			73		155
C	AT257										54	33						
C	AT264								81	16	33	77	55	157	112	145	136	79
C	AT269		19	14	19	21		45			10	119	65		58	35		52
C	AT318	122	68	28	13	20	15	28		28	7	159	50	167	142	34	128	91
C	AT340	139						15		112	26	12	12					
C	HO009		119						33	107	39	46	44	341		60	38	35
D	BB017	156	66	100	55	257	84	46	73	210	163	66	43	94	25	11		74
D	BB050									206	183	61	15				75	
E	SA040								32	44	36		68	113		196	87	65
F	NO005	364							329	391	294	76	180	265		24	54	218
G	BC108									0		22	15	16				
G	BC324									2		0						
G	BC369	21		12		12		18	2	0	8	3	16	18				
G	BC556									2								
G	BC518								12	4	3	8	0	9				

9.0 Photos

Photo 1. Typical downstream net placement; high mid-channel velocities and depths (depth at vertical 2.8m was 0.43 m and velocity was 95 cm•s^{-1}. Steelhead fry were restricted to the first metre near-shore at Site AT269 (Josephines).

Photo 2. Shore-based electrofishing with long leads to anode pole and cathode screen.

Photo 3. Upstream view at Station AT218 (below Young Creek) in 2001. Note boulder riffle-rapid condition where high steelhead parr densities typically occur (Reach 2).

Photo 4. Downstream view of Station AT047 in Reach 1. Note small substrates (gravel) that are unsuitable for steelhead parr. No parr were observed or captured here in 2000. This site is immediately upstream of Corbould's Bridge.

Photo 5. Downstream view of Station BB017 on Burnt Bridge Creek in 2002. Note this station typically supports high steelhead parr densities in most years.

Photo 6. Upstream view in Reach 2 from a helicopter. Note the riffle-rapid-cascade meso-habitat dominance conducive to steelhead parr.

Photo 7. Upstream view of electrofishing Station AT121 in Reach 2 of the Atnarko River mainstem. Moderate-high steelhead parr densities are present within the boulder dominated riffle.

Photo 8. Upstream view of riffle-rapid-cascade habitats in Burnt Bridge Creek.

Photo 9. Typical habitat conditions in Reach 1 Atnarko River. Note small substrates and limited large woody debris. Flows are near 20% mad and reflect winter baseflows**.**

Photo 10. Downstream view at Station YO005 on Young Creek in 2003. Note the large boulder size and cascade habitats. Typically very high steelhead parr densities are observed here.

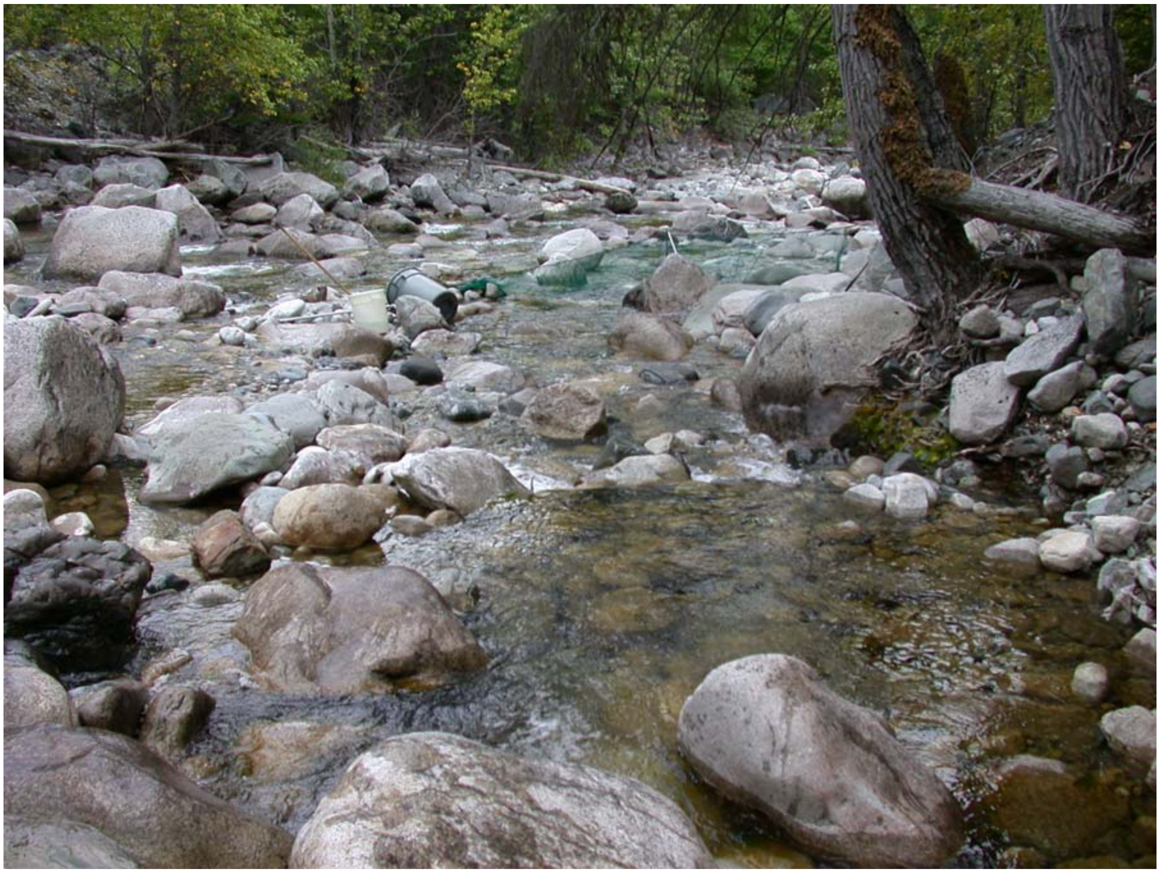


Photo 11. Aerial view of Reach 3 Atnarko River at Josephines Cabin. Note low gradient, gravel-bed conditions. This reach is heavily utilized by salmon spawners and is a key over-wintering or holding area for “early” steelhead. Steelhead parr habitat is limited by LWD content and large substrates in steeper riffles.

Photo 12. Typical accumulation of Giant Pacific stoneflies (*Pteronarcys californica*) in the downstream containment net from rapid site with large boulders. This is one indication of the high stream productivity for benthic invertebrates and fish food supply.