Bridge River Power Development Water Use Plan

Seton River Sockeye Smolt Monitoring

Implementation Year 7

Reference: BRGMON-13

2012 Sampling Results with a Summary of Historical Data

Study Period: April 1, 2012 - March 31, 2013

Jeff Sneep, Bonnie Adolph and Dave Levy
St'at'imc Eco-Resources
Box 1420
Lillooet, B.C.
V0K 1V0

Prepared for:

BC Hydro
6911 Southpoint Drive
Burnaby, BC V3N 4X8

August 23, 2013

Executive Summary

Since 2006, St’át’imc and BC Hydro have collaborated to monitor sockeye smolt mortality associated with entrainment into the Seton powercanal. The mortality associated with turbine passage is being effectively mitigated by shutting down the generator for 6-h duration during peak nighttime smolt migration periods. In those years when there is a maintenance outage that overlaps the smolt migration, there can be full avoidance of impacts for the period of overlap. As part of the St’át’imc - BC Hydro Settlement Agreement, there is a 5% smolt mortality target and monitoring is conducted annually to evaluate the mortality target.

The overall goal of the 2012 sampling was to monitor the timing, magnitude, and diel schedule of the sockeye smolt migration out of Seton Lake, along with physical conditions in the Seton River. An additional goal in 2012 was to further investigate the routing of smolts between the power canal and the bypass structures at Seton Dam under the range of operational conditions available during the sampling period. To accomplish these goals, work in 2012 included:

- operating an inclined plane trap (IPT) in the Seton River below Seton Dam for 6 weeks during the sockeye smolt migration period;
- sampling during day- and nighttime hours to monitor diel migration patterns;
- conducting mark-recapture trials, including the release of marks above and below the dam throughout the monitoring period;
- collecting biological data (i.e., forklengths) from a subset of sampled smolts to enable analysis of trends in smolt size between years;
- monitoring water temperature and ambient light intensity at the sampling site.

Results from 2012 indicated unprecedented high numbers of smolts, totaling an estimated 6 million fish. In an apparent response to the high numbers, sockeye smolts in 2012 were the smallest in physical size on record, suggesting density dependence in growth patterns in Anderson and/or Seton Lakes. An unusual diel pattern was observed with 56% of the smolts outmigrating during daytime periods, possibly in response to the high densities. Smolts in 2012 were effectively protected at the front end of the migration by a seasonal maintenance outage that lasted until May 9, encompassing the peak of the smolt outmigration. Smolt mortality rate in 2012 was estimated as 8% relative to the 5% mortality target. It is likely that the mortality rate in 2012 surpassed the target due to the diversion of large numbers of daytime migrants into the powercanal when no shutdowns were scheduled and the plant was in full operation Since the mortality rate and density estimates are critically dependent on the diversion rate into the powercanal, it is recommended that acoustic tagging using shore-based receivers be considered to refine the estimates.

Table of Contents

1.0 Introduction

The St'at'imc and BC Hydro have worked together since 2006 to devise practical ways for mitigating the mortality of sockeye salmon smolts at the Seton Generating Plant. This mortality is a consequence of smolt entrainment into the Power Canal (Figure 1) and subsequent passage of the fish through the turbine. While many different mitigation approaches have been tested since the plant began operating in 1956, the best opportunity for minimizing smolt entrainment and subsequent mortality appears to be via operational modifications (Groves and Higgins 1995). Options include overlapping the annual maintenance outage with part or all of the smolt migration, or conducting temporary plant shutdowns during peak nightly migration periods.

Under the Settlement Agreement between BC Hydro and St'at'imc Nation, a 5% mortality rate has been specified as a target associated with the entrainment of sockeye smolts into the Seton powercanal. Methods for calculating smolt mortalities have been developed between 2006-2012 and involve field monitoring of smolt abundance and timing in relation to generator operations. During previous years, nightly shutdowns of 6-h duration scheduled between 20:00 – 02:00, implemented during the peak outmigration window of April 20 - May 20, were tested and found to be effective. Starting in 2008, sampling was undertaken in daytime periods as well as nighttime periods to evaluate diel variations in smolt migration patterns. This information is important for refining diel shutdown strategies. As well, sampling was undertaken experimentally in the Power Canal in 2008 to determine the feasibility of directly estimating smolt mortality rates (Levy et al. 2008).

During 2012, the focus was on day and nighttime monitoring of smolts over the migration period. This approach was followed between 2010-2011 when it was discovered that high numbers of smolts out-migrated during daytime periods. As in previous years, a series of mark-recapture tests using Bismark Brown or Neutral Red dye was undertaken to calibrate the trapping and to provide a basis for quantitative population estimates.

Figure 1: Aerial view of Seton Dam and adjacent features.

2.0 Background

Depending on the operation of the Seton facility, salmon smolts can migrate downstream of Seton Dam via one of five exit routes (Figure 2): power canal/turbine, fish ladder, fishwater release, siphon spillway, and radial gate spillway. The entrainment rate is influenced by flow routing; smolts tend to concentrate in the high power canal flow discharges. Previous studies suggested that over 80% of the smolts are entrained into the power canal (Levy et al. 2008) and subject to mortality when they pass through the generating station.

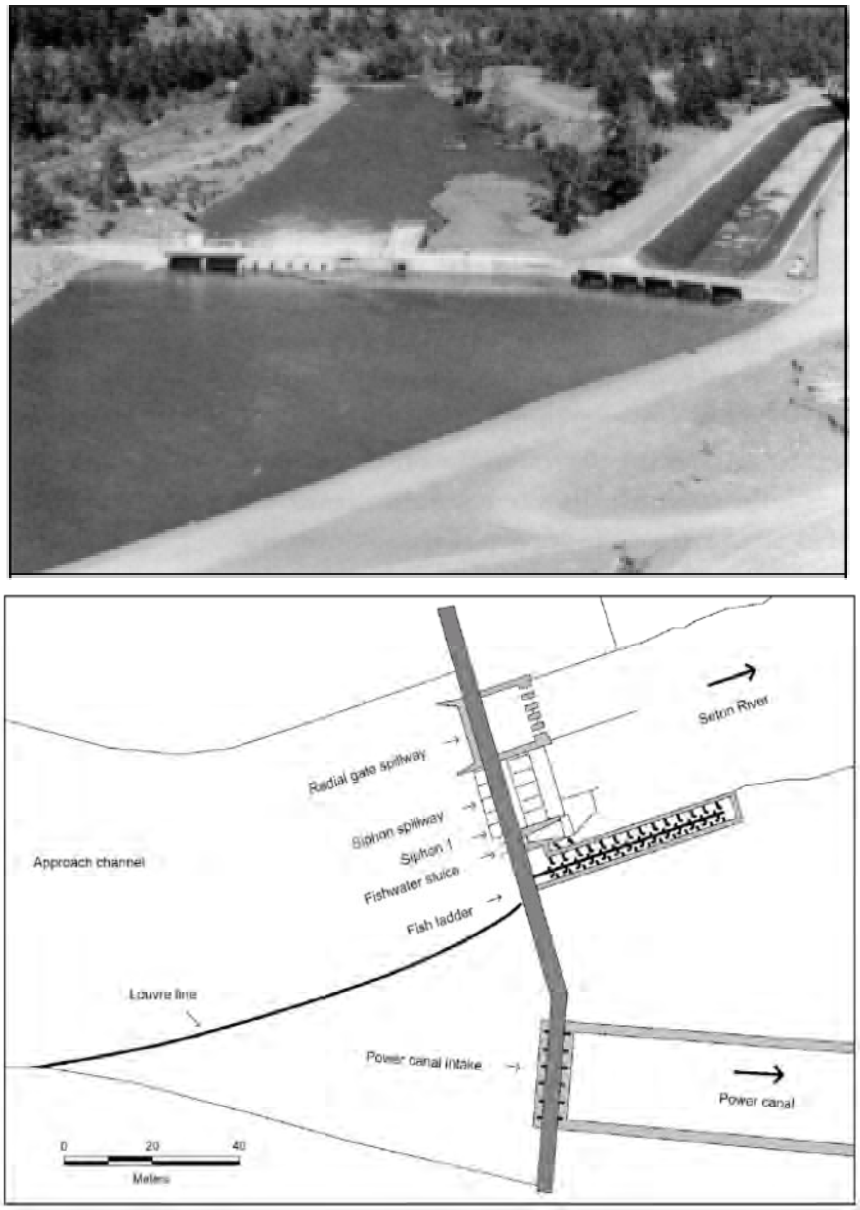


Figure 2. Upper: Seton Dam nearing completion about 1955 (from Roos 1991). Lower: Bird's-eye view of power canal and by-pass structures. Louver line was tested as a means to prevent entrainment but found to be ineffective. From RL&L (1999).

Groves and Higgins (1995) identified the spillways, fish water release gate, and the fish ladder as “bypass facilities” wherein reasonably safe fish passage occurs. During their study, flows were approximately 102 m^3/s, 0.85 m^3/s, and 5.7 m^3/s in the power canal, the fish ladder and fishwater release, respectively (Groves and Higgins 1995). If one assumes that smolts are routed through the Seton facility in proportion with discharge, this implies that 94% of the fish were entrained into the power canal and exposed to turbine mortality at the time of their study.

Following power canal entrainment, sockeye smolt mortality rate is estimated as 17%. This mortality rate estimate is based on previous IPSFC studies carried out at the Ruskin plant on the Stave River as well as within the Seton facility (Groves and Higgins 1995). The 17% estimate includes direct mortalities as well as latent mortality from injuries, cumulative stresses, disease and predation. While many different methods have been tested to mitigate smolt mortality, operational flow modifications appear to have the greatest potential to provide the most effective method (Groves and Higgins 1995). The approach involves scheduling annual or daily turbine shutdowns to overlap with the greatest densities of migrant smolts, thereby minimizing smolt entrainment into the power canal.

3.0 Methods

The methods adopted during the present study were identical to those previously adopted since the program began in 2006. Monitoring and enumeration of sockeye smolts relied on an Inclined Plane Trap (IPT) that was fished in the Seton River during spring time periods in April-May when the smolts are emigrating (Figure 3). The Safety Plan followed during the present study is shown in Appendix 1.

Mark-recapture tests using dyed smolts were undertaken in the Seton River using the same procedures as those developed since 2006. In order to differentiate the mark groups, Neutral Red was used for the marks released below the dam and Bismarck Brown Y for the marks released above the dam. Tests were undertaken to estimate trap efficiency and to estimate the number of downstream migrants exiting via the river.

Appendix 1 provides a complete description of the field methods utilized during the study.

Figure 3. Inclined plane trap situated in the Seton River at a location that was consistently monitored throughout the sockeye smolt migration period during 2012.

As in 2011, two sets of mark groups (released above or below the dam) were used for informing the population and mortality estimation procedures in 2012. The recapture results for mark groups released below the dam were used to generate capture efficiency estimates for the IPT during day and night periods. The intent of the releases above the dam was to enable testing of the smolt routing proportions when the plant was operational versus when it was shutdown. In 2012, the extended 24-hour outage period (until May 9) followed by a period of consistent plant operation including shorter duration shutdowns, enabled the linkage of smolt routing results with specific plant operations for this year.

The routing proportions were calculated by applying the appropriate IPT capture efficiency value (11.3% at night; 9.6% during day) to the number of marked smolts released above the dam that were recaptured during subsequent trap sets. The results represented the total number of marked smolts released above the dam that migrated through the dam and into the river. These values were then translated into a proportion. The remaining proportion of marked smolts that were unaccounted for were assumed to have migrated down the power canal. These relative proportions were considered to be reflective of the general smolt routing patterns for each operation being tested. The routing proportions for the 2012 migration represented by these calculations were:

- 69% of the smolts migrated down the river when the plant was shutdown;
- 31% of the smolts migrated down the power canal when the plant was shutdown (assumed that these fish remained in the approach channel or were held up in the power canal until operation of the plant resumed);
- 31% of the smolts migrated down the river when the plant was operating (at ca. 110 cms);
- 69% of the smolts migrated down the power canal when the plant was operating (at ca. 110 cms).

Therefore, the number of smolts that migrated down the canal was estimated by multiplying the hourly estimates for the river by the appropriate power canal proportion according to plant operation (above) and then dividing by the river proportion. The total smolt population estimate is the sum of the Seton River Day + Seton River Night + Power Canal Day + Power Canal Night estimates.

The annual smolt mortality estimate is produced by applying a fixed mortality rate (17%) directly to the estimated number of smolts that migrated down the power canal. This value is then divided by the total smolt population estimate to determine the overall smolt mortality percentage. For the purposes of the estimate, it was assumed that no mortality is associated with passage through Seton Dam into the river.

4.0 Results

4.1 Physical Characteristics

4.1.1 Discharge

Discharge through the mid-April to late May smolt migration was relatively stable and slightly less than 30 cms over the sampling period. The uniformity of flow in 2012 obviated the need for making adjustments to trap catchability during the smolt migration, as was also the case in 2011 (Sneep et al. 2012).

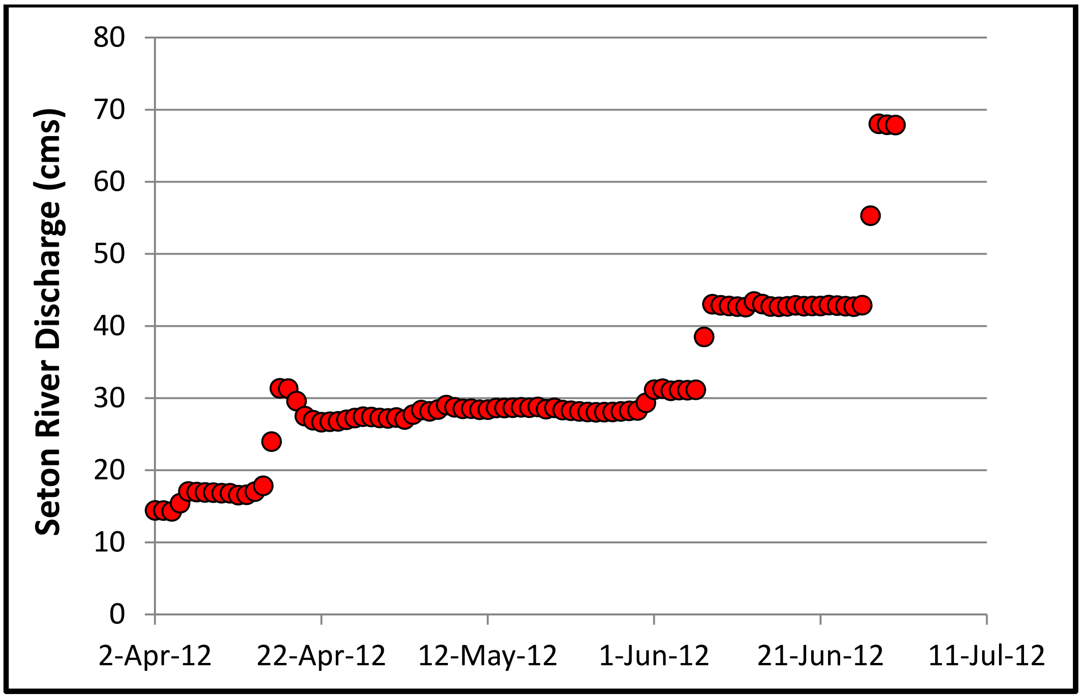


Figure 4. Seton River discharges during the 2012 smolt migration period.

There was a seasonal maintenance outage that took the generator off-line between April 14 – May 9 (Figure 5). Thereafter 5-hour duration nightly shutdowns took place between May 9 – May 20. Based on previous data collected over 6 years, the combined seasonal and nightly outages in 2012 that overlapped the average smolt migration timing pattern observed since 2006 would be expected to result in high smolt protection benefits.

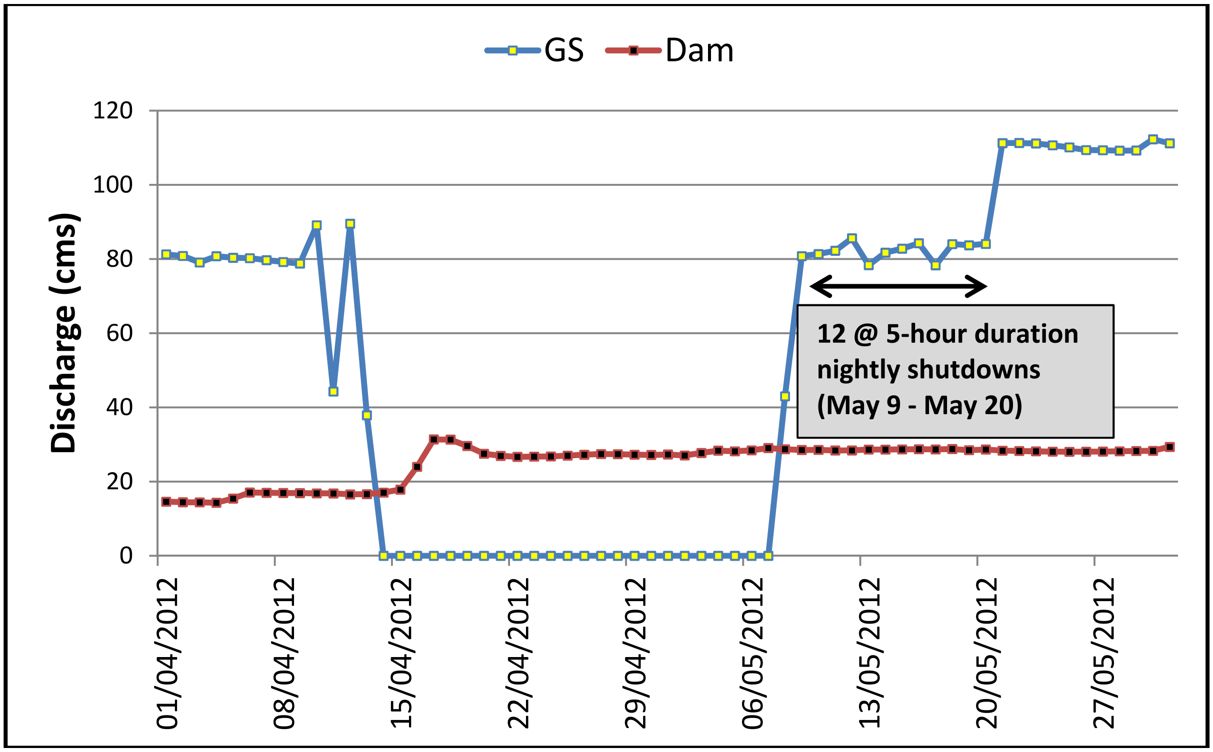


Figure 5. Water flows though the generating station and the Seton Dam showing the timing of a maintenance outage (April 14 - May 8) nighttime shutdowns (May 9-20).

4.1.2 Temperature

Both hourly and daily (Figure 6) temperature conditions were similar to those observed in previous years. It is likely that a temperature of 5^{0}C serves as a migration cue for sockeye smolts (Sneep et al. 2012) and this temperature was surpassed on April 12 prior to a brief duration cooling trend below the threshold between May 16-19. Water temperatures in the Seton River generally follow air temperatures, however in 2012 this relationship didn't hold between mid-May and early-June when water temperatures rose independently of the air temperatures. This may have been associated with Seton Lake temperatures conditions following spring turnover.

These observations require verification to determine whether the river temperature is similar to the Seton lake temperature at this time of the year. Simultaneous measurements from Seton Lake and River during the smolt emigration period are recommended to permit this comparison.

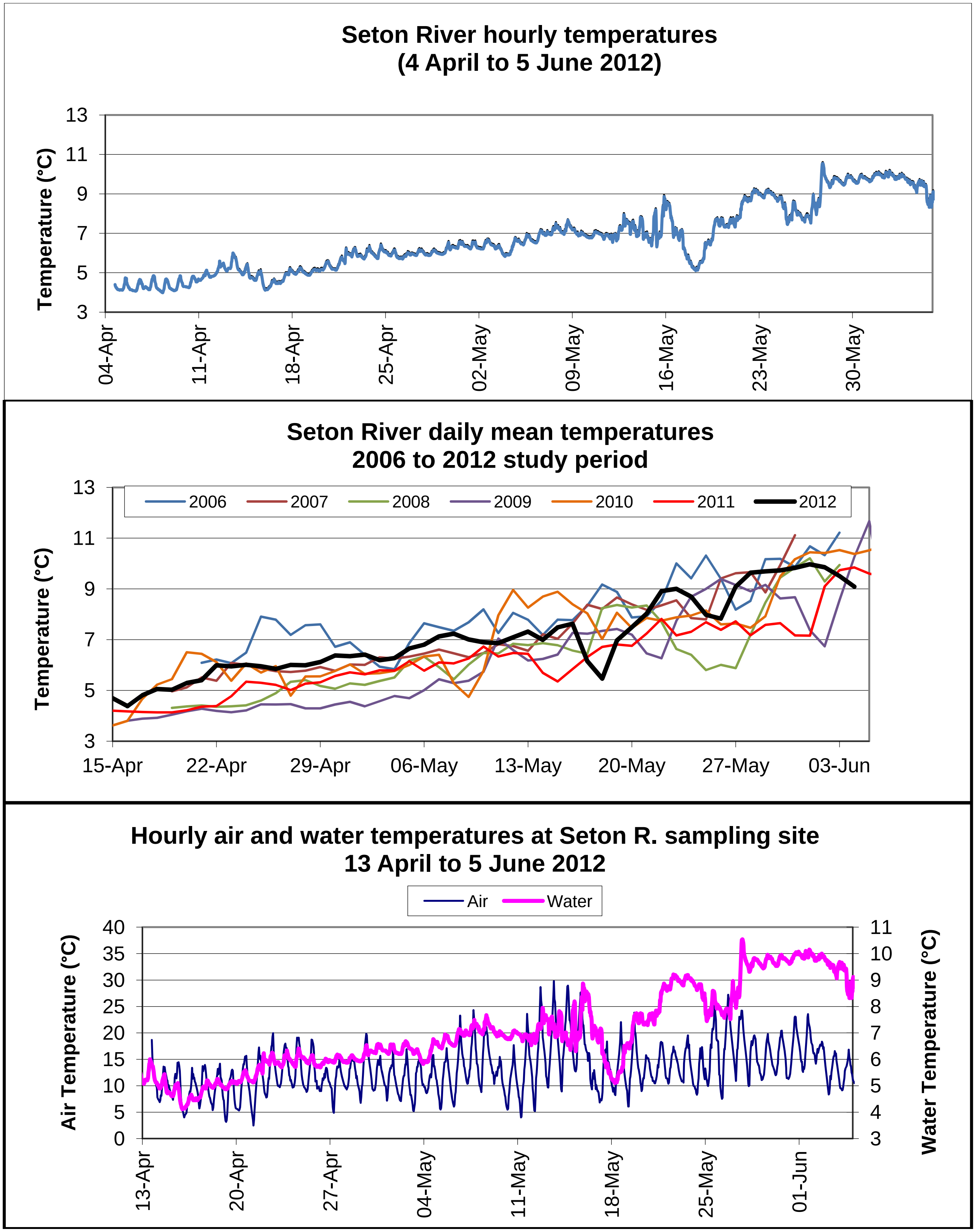
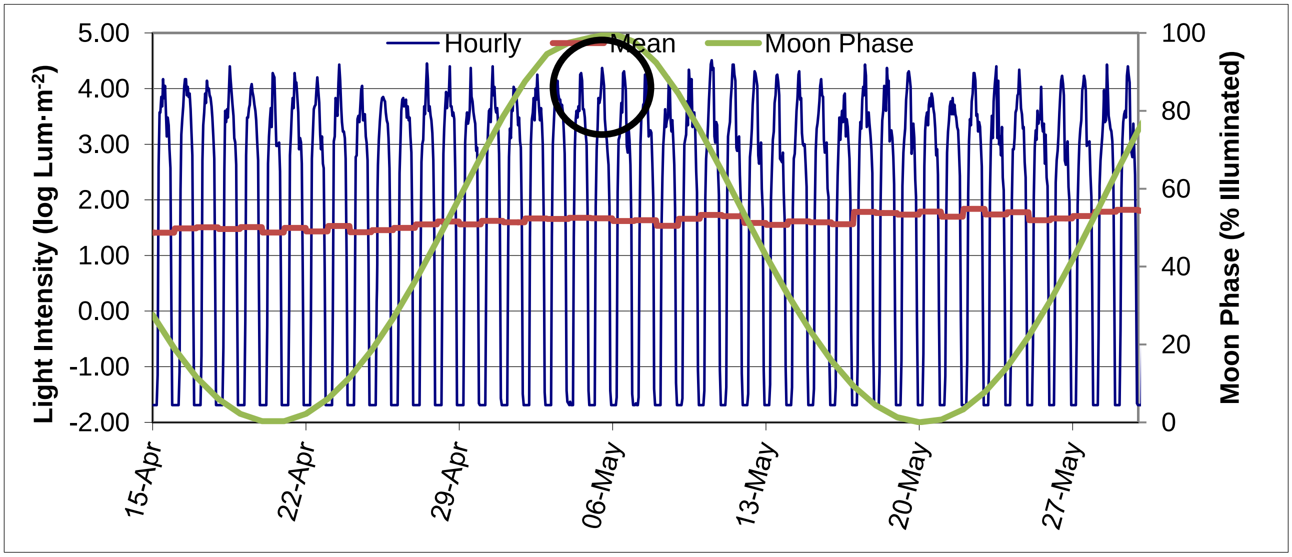


Figure 6. Top to bottom: hourly air temperatures, daily temperatures, and hourly air/water temperatures.

4.1.3 Light Intensity

There was a gradual increase in mean light intensity between mid-April to the end of May (Figure 7; note log axes). This is also reflected by the photoperiod which showed a measurable increase between mid-April and the end of May.



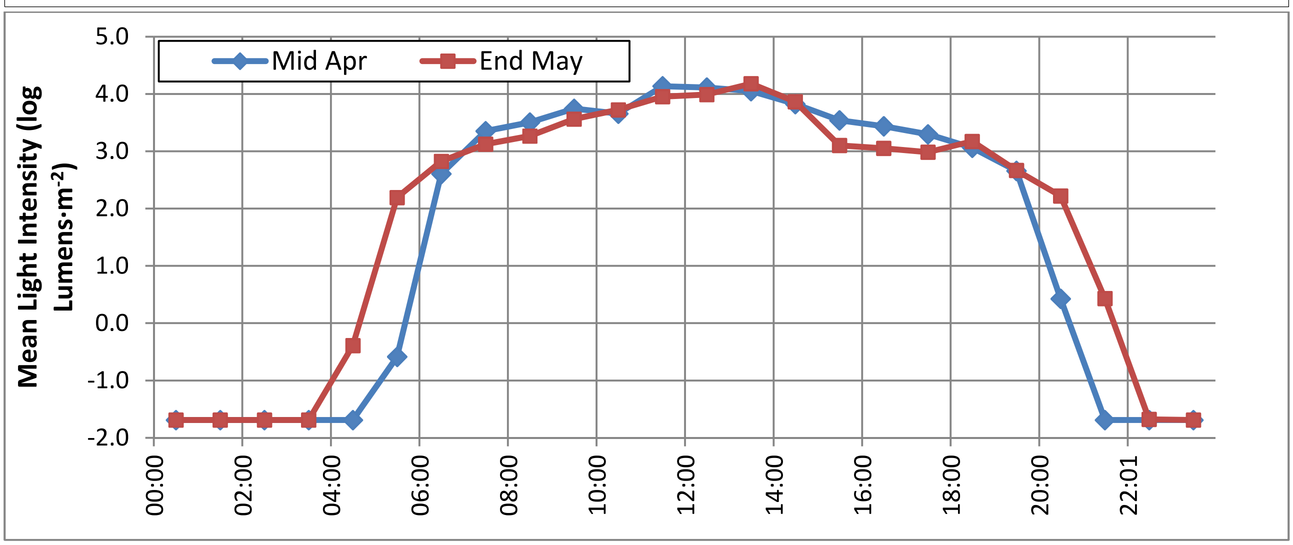


Figure 7. Light conditions at the Seton River sampling site.

4.2 Sockeye Smolt Monitoring Data

4.2.1 Inclined Plane Trap Catch Data

Compared with 2006-2011 IPT results, catches in 2012 were extremely high compared with the 7-year sampling series. Table 1 provides the total annual catches, broken out by daytime and nighttime sampling periods, as well as the maximum daily or nightly catch results. Catches in 2012 surpassed all of the other years and daytime catches were similar in magnitude to nighttime catches, reflecting huge numbers of daytime migrators. In 2012, the maximum daily daytime catch was 45,817 smolts, higher than the total seasonal smolt catch for all years between 2006 - 2010. This pattern is puzzling since 2012 smolts were the offspring of smolts that outmigrated in 2008 which had the lowest numbers on record (Table 1). It is evident that the offspring of the 2010 parental brood (smolts which emigrated in 2012) survived at much higher rates than in the other years that were monitored.

Table 1. Total and maximum daily catches of sockeye smolts between 2006-2012.

	Total Catch	Total nighttime Catch	Total daytime Catch	Nighttime - Daytime ratio	Maximum 1-day catch (nighttime)	Maximum 1-day catch (daytime)
2006	34,143	34,143	---------	---------	6,705	---------
2007	43,450	43,450	---------	---------	7,059	---------
2008	8,694	7,026	1,668	0.19	632	731
2009	18,048	13,486	4,562	0.25	1,641	717
2010	27,335	20,532	6,803	0.25	3,096	2,167
2011	144,128	136,388	7,740	0.05	12,177	1,561
2012	249,979	129,153	120,826	0.48	40,574	45,817

To date, the maximum catch dates haven't been correlated with environmental cues (e.g. light conditions and/or temperature) or operational practices (e.g. discharge) and such comparisons will be made in future years.

4.2.2 Seasonal Migration Timing

As in previous years, the smolt outmigration spanned the period between mid-April through the termination of sampling at the end of May. Given that sizeable numbers of smolts were still being captured by day and night crews right up to the end of May, the smolt migration period likely extended beyond the end of the seasonal sampling period in 2012.Figure 8 shows the nighttime and daytime smolt catch results plotted on a logarithmic axis to effectively display the data which cover 4 orders of magnitude. Seasonal catches in 2012 surpassed all of the other years that were monitored, consistent with the total catch and maximum 1-day catch data (Table 1).

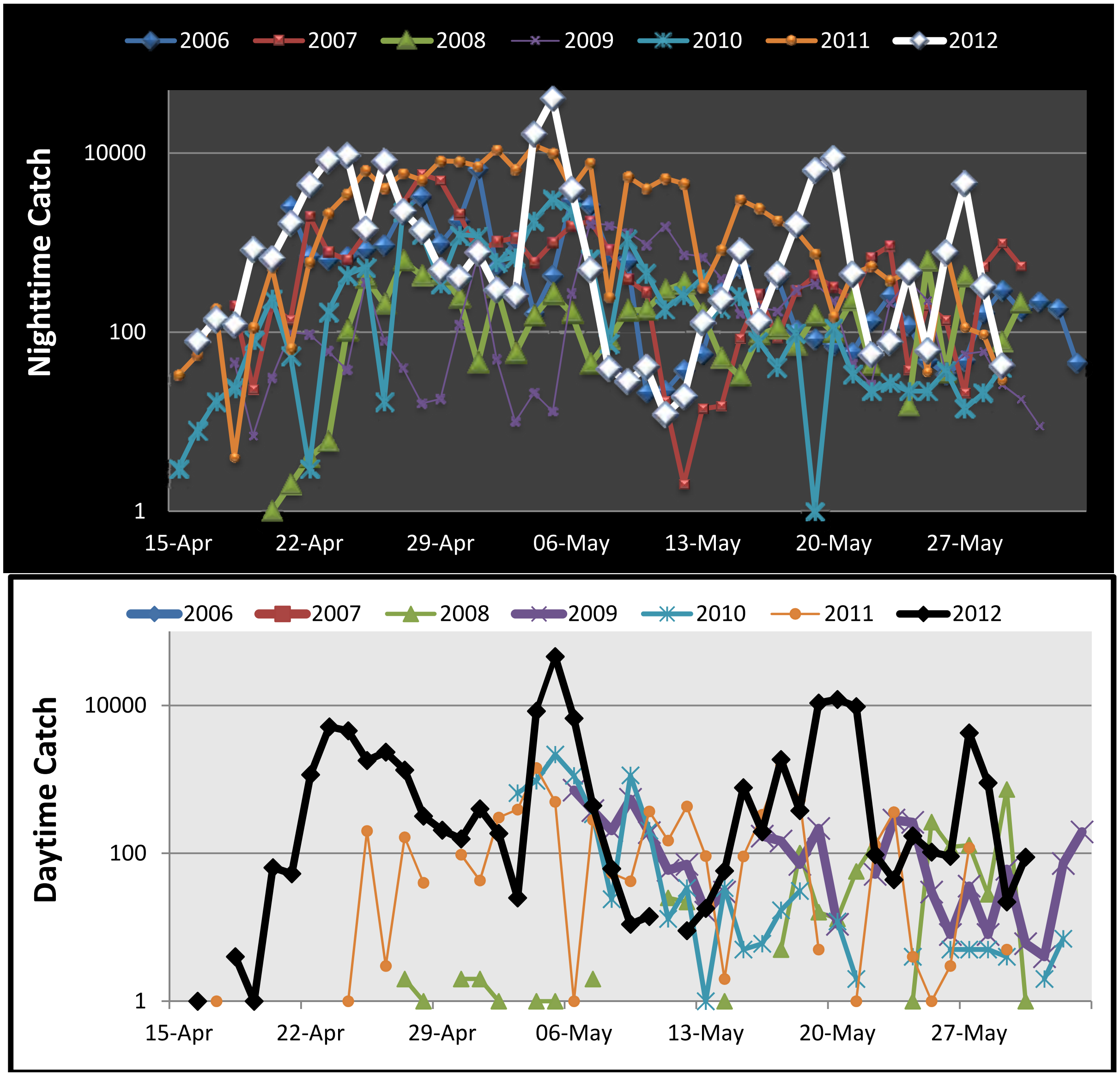


Figure 8. Nighttime vs. daytime catches plotted with a logarithmic axis.

Comparison of the mean proportion of smolt catches over the migration period (Figure 9) indicated different patterns between nighttime and daytime. Whereas the nighttime proportions were fairly uniformly distributed, there was a higher proportion of daytime migrators from May onwards at the tail end of the migration with only low proportions occurring during April.[1] The data have been plotted on a log scale due to the large variation (5 orders of magnitude) in the catch records when plotted as a proportion of the annual smolt run.

[1] There was no daytime sampling in April during 2009 and 2010. Daytime sampling during those years commenced in early May so sampling could be extended into June in an attempt to account for the later season daytime migrators (as observed in 2008).

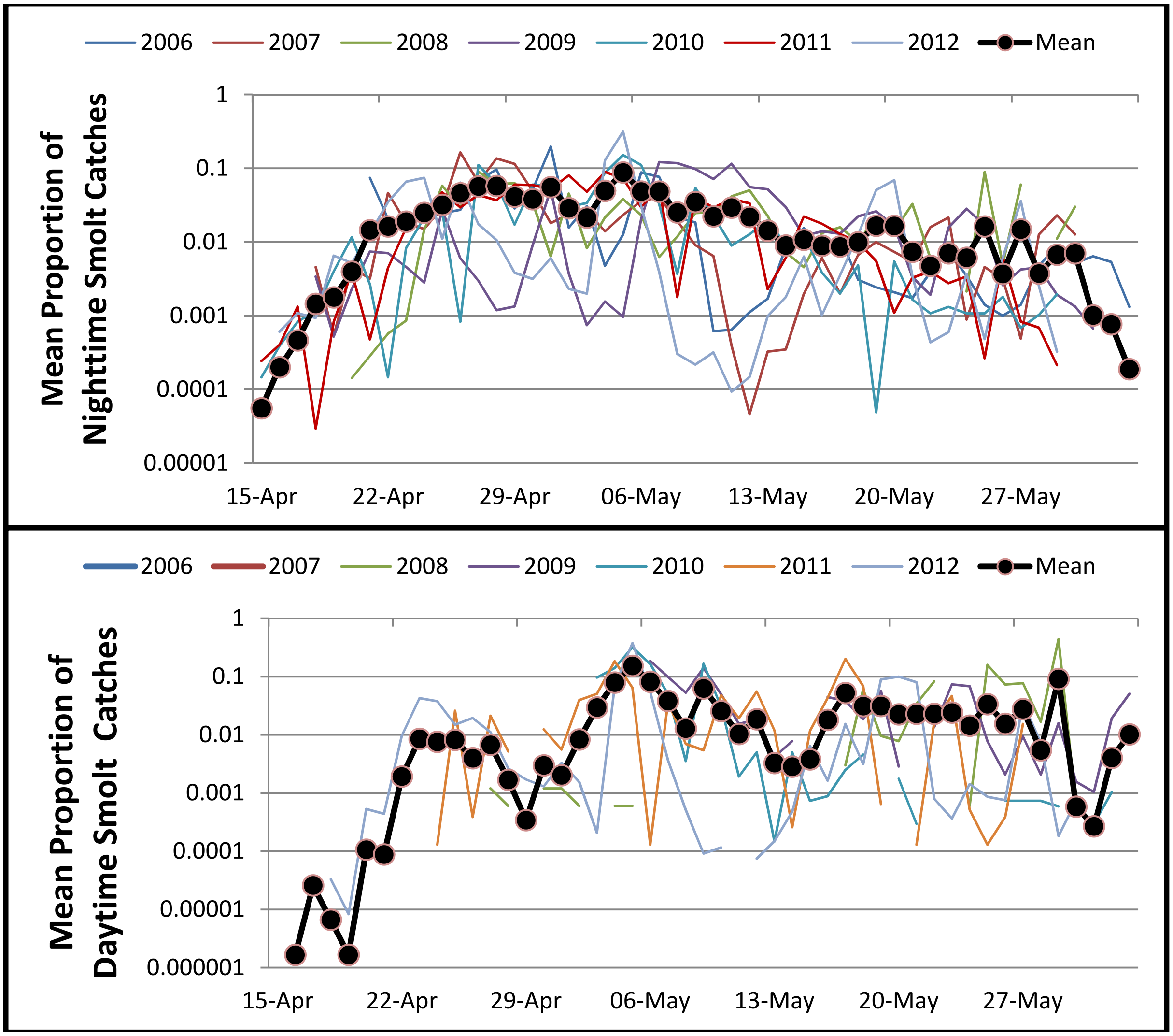


Figure 9. Seasonal proportions of daytime and nighttime smolt catches plotted with a logarithmic axis.

As in previous years, the catch data were transformed into time-density plots to measure the median migration dates and to compare migration patterns between years (Figure 10). The median migration dates in 2012 were May 5 and May 12 for nighttime and daytime migrations respectively. Mean outmigration timing across all of the 7 years (Figure 10; lower panel) shows that daytime migrations on average occur later in the outmigration period, by about 6 days. Median migration dates are May 5 and May 11 for the consolidated data set, very similar to the 2012 values.

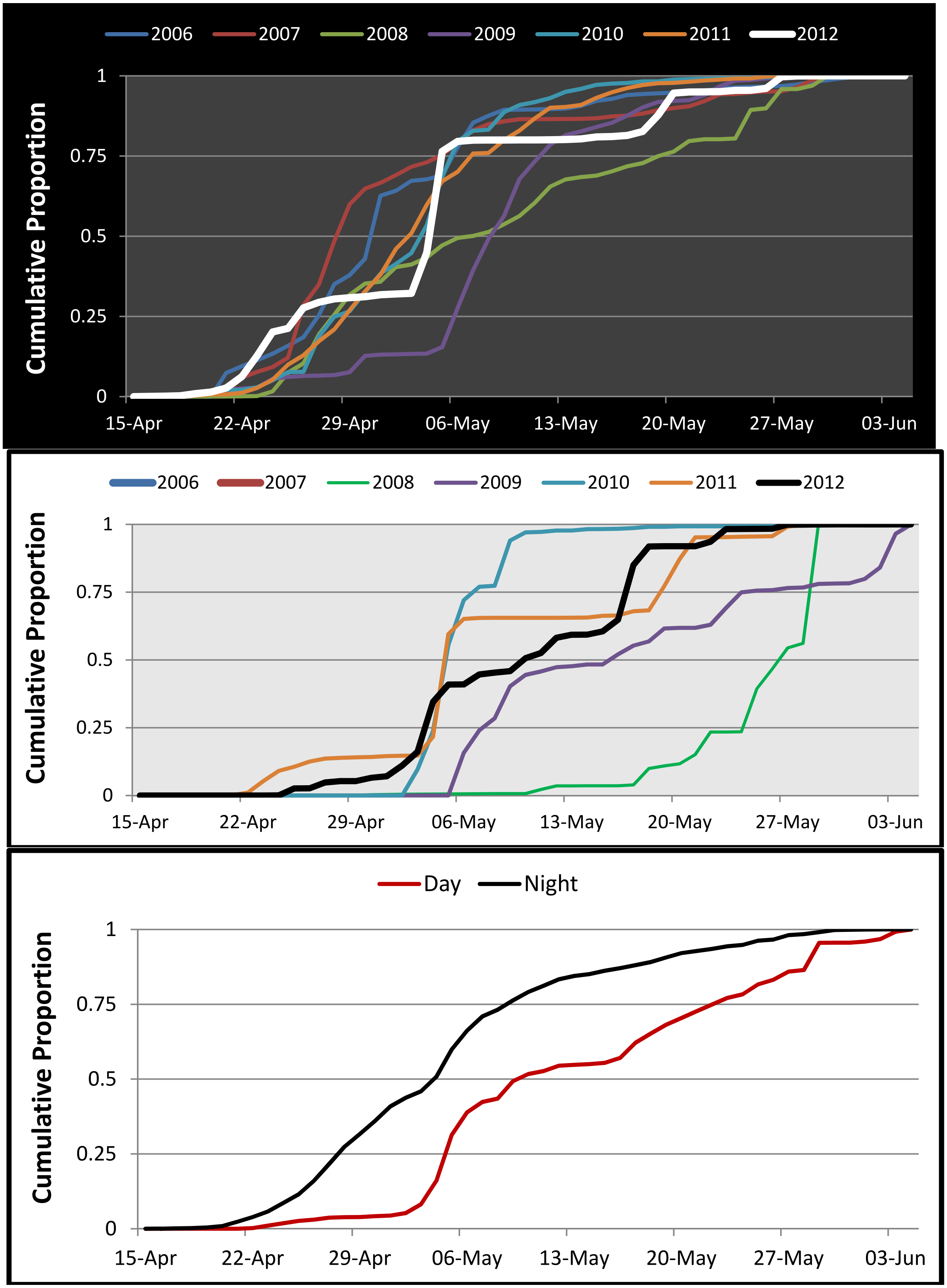


Figure 10. Time-density plots for (top to bottom) nighttime, daytime and average proportional catches for the 7 years of observations.

Seasonal timing together with day-night catch comparisons were also evaluated by plotting day and night catch histograms (Figure 11). Patterns varied between years with some years (nightime - 2011) being unimodal, others being skewed (nighttime - 2008 and 2010) and others being pulsed (2012 both daytime and nighttime).

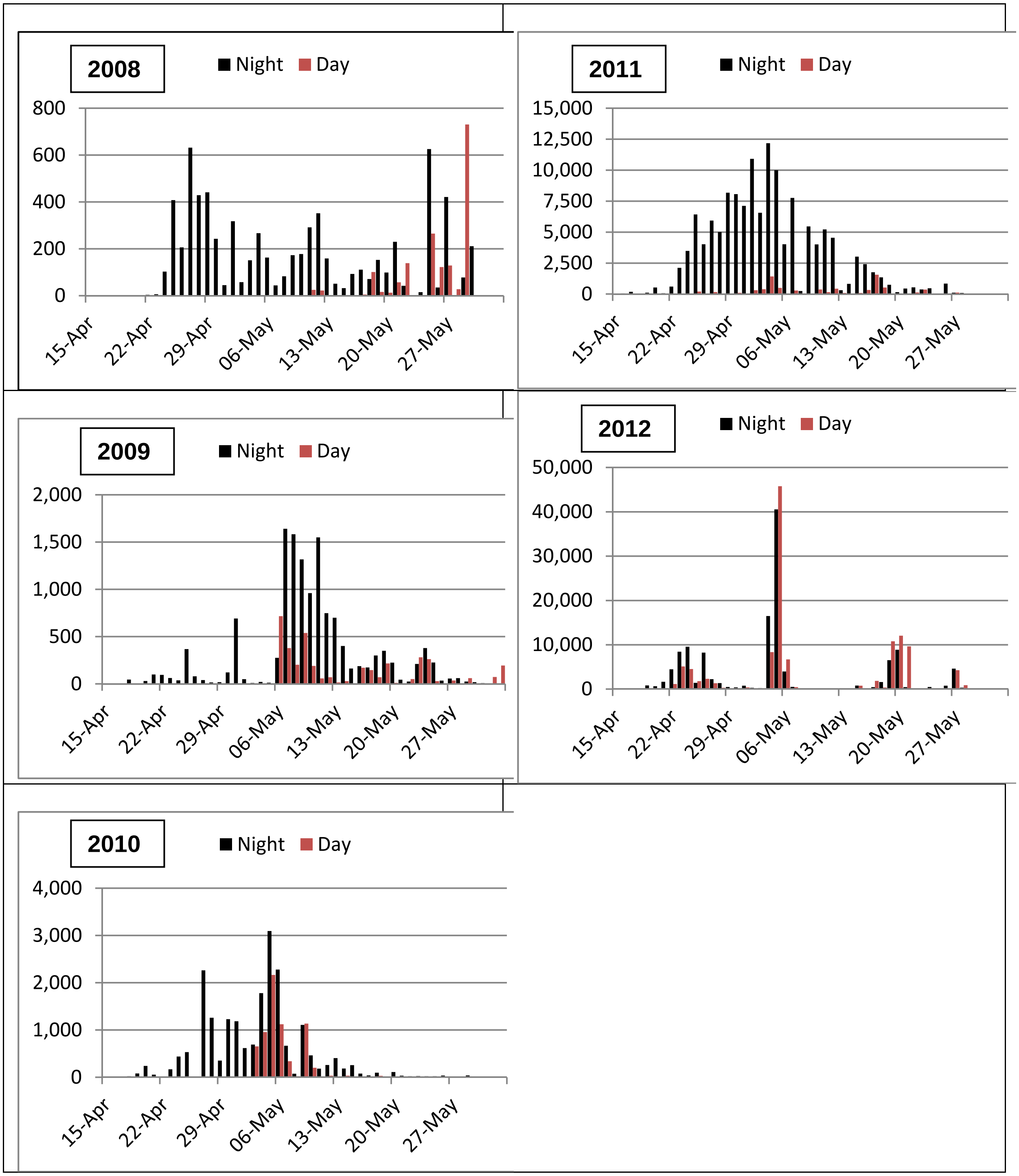


Figure 11. Day and night catch histograms for 2008 - 2012 when daytime and nighttime periods were consistently sampled.

4.2.3 Diel Timing

Understanding of smolt diel timing patterns is essential for scheduling 6-h shutdowns so as to maximize the mortality mitigation benefits. In 2006 it was determined that a 6-h period between 20:00 and 02:00 would be the optimal timing for 6-hr duration shutdowns and that has been followed annually. In every year including 2012 this was the case (Figure 12). During 2012, 82% of the nightly migration occurred between 20:00 - 02:00 justifying the diel scheduling of the 6-hr shutdowns. In previous years, catches generally increased from early morning through to early evening[2].

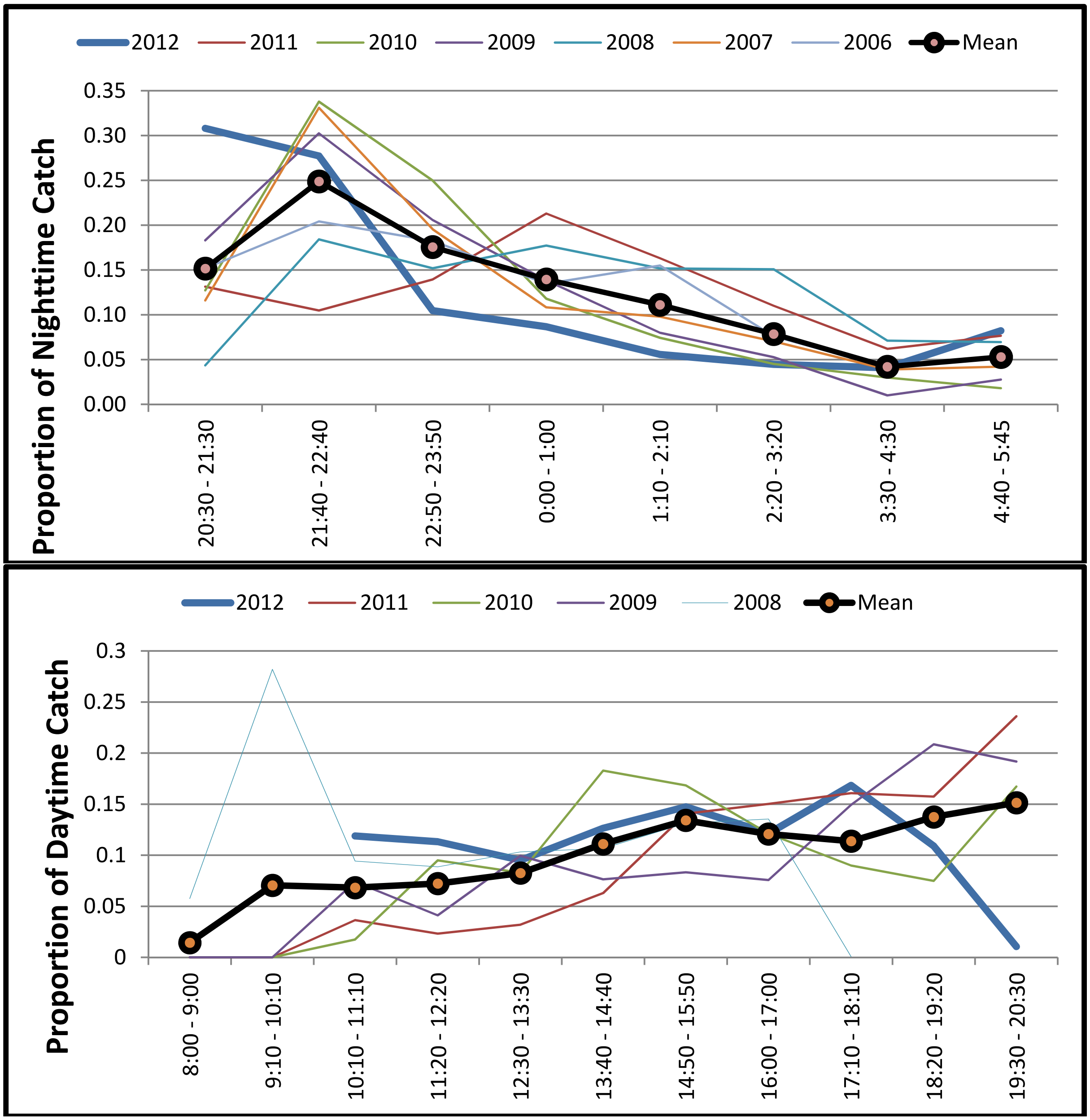


Figure 12. Hourly variation in the proportion of nighttime and daytime catches.

[2] Sampling did not occur between 06:00 - 10:00 in order to optimize the available personpower within the available budget envelope.

4.2.4 Smolt Size Characteristics

Sockeye smolts in the Seton River showed large interannual differences in fork length distribution (Figure 13, Table 2). Largest smolts were captured in 2009 (mean = 109 mm) and smallest smolts occurred in 2012 (mean = 77 mm). This large variation in body size suggests annual variability in Seton and Anderson Lake rearing conditions for sockeye juveniles, although the mechanism involved is presently unknown. Section 4.2.5 evaluates density-dependent relationships between smolt abundance and body size.

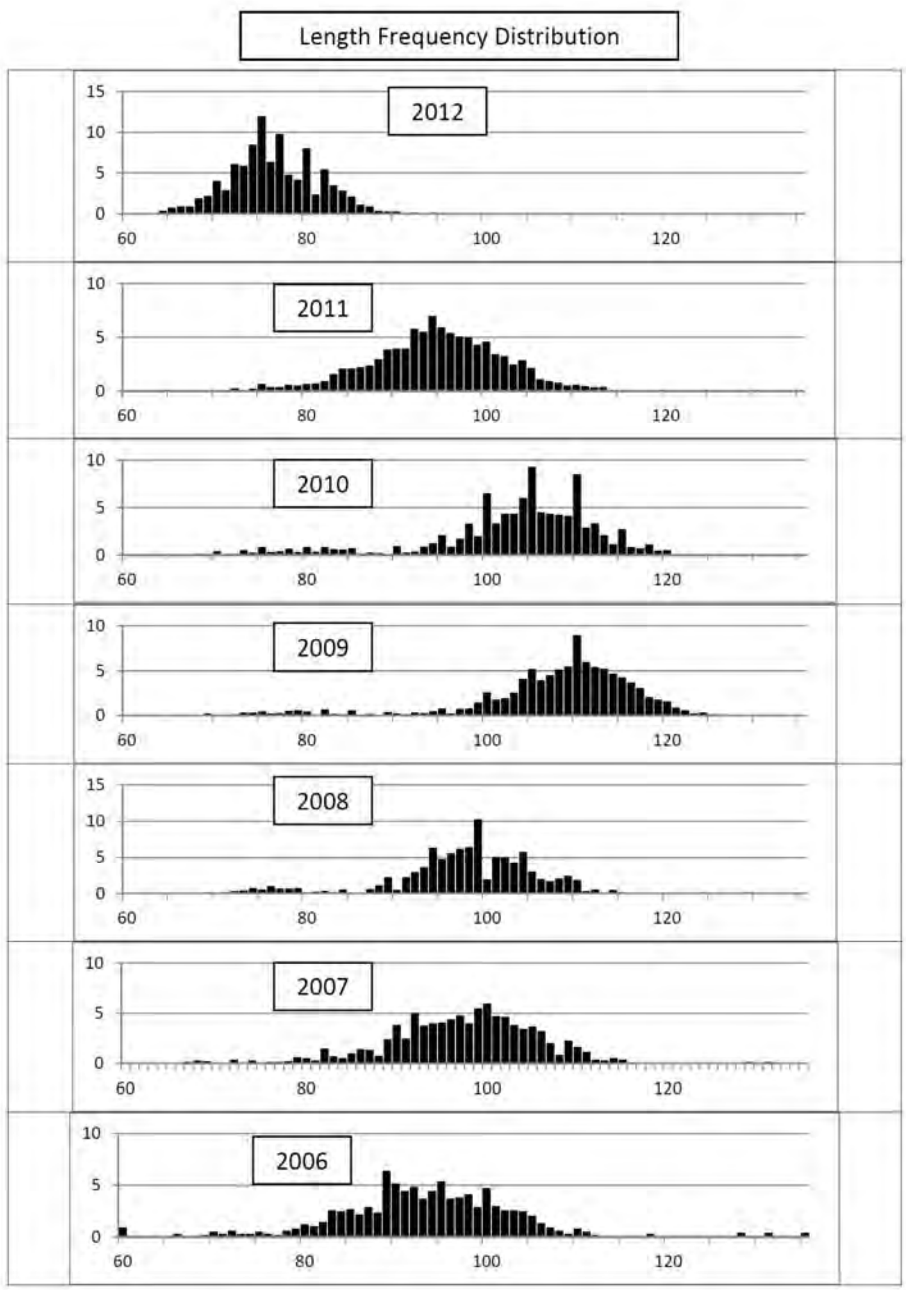


Figure 13. Smolt length frequency histograms for the 7 study years.

Table 2. Mean forklengths of age-1 sockeye smolts captured in the Seton River, by study year.

	Night Sampling			Day Sampling			All Periods		
	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
2006	93	9	1239	-	-	-	-	-	-
2007	98	7	1183	-[a]	-	-	-	-	-
2008	99	6	1049	102	6	394	100	6	1443
2009	109	6	1003	110	6	873	109	6	1876
2010	105	6	1246	106	6	464	105	6	1710
2011	94	7	1555	95	8	921	94	7	2476
2012	77	6	1499	78	6	1414	77	6	2913

[a] Daytime sampling was sporadic and opportunistic in 2006 and 2007.

4.2.5 Smolt Abundance

Smolt abundance was determined by the Peterson mark-recapture method (see Krebs 1978 for discussion of methodological assumptions) . The equation that estimates population size is:

$$N = MC/R$$

where N = population size
M = number smolts marked
C = number smolts captured in the sample
R = number of recaptures

Tables 3 and 4 show the mark recapture statistics for 2006 - 2012 during nighttime and daytime releases respectively. See Appendix 1 for information describing marking and release strategies associated with these measurements. The dye experiments are run somewhat opportunistically depending on the availability of smolts from previous IPT catches. Experience has shown that dye-marked fish disperse out of the Seton River within several hours so each batch of dyed fish don't comingle with previous marked batches.

Table 3. Summary of nighttime mark-recapture experiment results (stratified by discharge) from the Seton River IPT, 2006 to 2012. 2012 data reflect trials of marked smolts released below the dam.

Study Year	Seton River Q ($m^3 \cdot s^{-1}$)	# of Trials	# of Marks Released	# of Marks Recaptured	% Recapture
2006	25 to 30	1	311	22	7.07
2007	25 to 30	1	416	26	6.25
	50+	3	1049	60	5.72
2008	25 to 30	3	1034	82	7.93
	31 to 35	1	660	38	5.76
2009	25 to 30	4	2310	212	9.18
2010	25 to 30	3	1012	105	10.38
2011	31 to 35	7	1517	90	5.93

2012	25 to 30	5	602	68	11.3

Table 4 Summary of daytime mark-recapture experiment results (stratified by discharge) from the Seton River IPT, 2006 to 2012. 2012 data reflect trials of marked smolts released below the dam.

Study Year	Seton River Q ($m^3 \cdot s^{-1}$)	# of Trials	# of Marks Released	# of Marks Recaptured	% Recapture Rate
2008	31 to 35	2	590	58	9.83
2009	25 to 30	2	1048	54	5.15
2010	25 to 30	1	386	25	6.48
	31 to 35	1	383	23	6.01
2011	31 to 35	5	748	62	8.29
2012	25 to 30	5	492	47	9.55

There were 10 mark-recapture trials below the dam in 2012 (5 nighttime and 5 daytime) which yielded similar recapture rates: 11.13% during nighttime and 9.55% during daytime.

Mark-recapture experiments in 2011 and 2012 relied on Bismarck Brown Y dye for marked smolts released above the dam and Neutral Red dye for marks released below the dam allowing the 2 release groups to be analyzed separately. Separate experiments were run during the day and night with dyed fish released above and below the dam under 2 operating conditions: 1) generator off during nightly and 24-hour shutdowns, and 2) generator running normally for periods outside of the closures.

The primary purpose of the above dam/below dam comparison was to estimate diversion rate into the powercanal based on relative recaptures of dyed smolts. During 2011 this method was followed and estimated that 34% of the smolt population migrated downstream via the powercanal vs. 66% down the Seton River under the operating conditions observed during the smolt migration period in that year (i.e., nightly shutdowns on 43 nights out of 45; no maintenance outage). In 2008 when an IPT was fished in the powercanal and mark-recapture experiments were conducted, 84% of the smolts were estimated to migrate via the powercanal when the power canal discharge was ca. 80 cms. Previously, it was assumed that smolt entrainment is proportional to the flow routing (Groves and Higgins 1995), which in 2012 was roughly 73% into the powercanal after May 8 when the maintenance outage ended and the nightly shutdowns started (Figure 5). Table 5 provides the annual time series of population estimates; 2012 was by far the largest population which was calculated as 6.1 million smolts. By contrast, 2008 yielded only 543,000 smolts, an 11-fold difference.

Table 5. Total Population Estimates for Seton-Anderson Sockeye Smolts, including Seton River (day + night) and Power Canal proportions, 2006 to 2012.

Year	Seton River Night Pop. Est.	Seton River Day Pop. Est.[a]	Power Canal Pop. Est. (Day + Night)	Total Smolt Pop
2006	618,500	ca.160,000	ca. 990,000	1.8 M
2007	889,900	ca. 220,000	ca.1.070,000	2.2 M
2008	106,500	19,000	417,700	543,000
2009	166,500	99,700	46,100	312,000
2010	237,300	117,500	54,800	410,000
2011	3,074,000	102,700	1,656,100	4.8 M
2012	**1,550,000**	**1,662,000**	**2,851,000**	**6.1 M**

[a] Daytime sampling was not systematic in 2006 and 2007. Therefore the daytime proportions in those years were based on the mean day:night catch ratio from 2008 to 2010. Different assumptions were utilized in 2011 based on the relative recapture rate of marked smolts both above and below the dam (Sneep et al. 2012). The 2012 estimate was based on the 2012 mark-recapture data that suggested smolt diversion rates of 69% into the Seton River when the power canal was shutdown, and 31% when the powercanal was operating (typical pc discharge was ca. 110 cms in 2012). The population estimates also assume that no migration occurs outside the seasonal sampling window.

Comparison of the smolt population estimates with the smolt size data demonstrated a density-dependent effect of population size on smolt growth (Figure 14). Similar density dependence has been demonstrated for sockeye smolts in numerous sockeye lakes including Quesnel and Shuswap (DFO unpublished), Babine (Johnson 1958), Owikeno (Ruggles 1966) and various Alaskan lakes (Kyle et al. 1997).

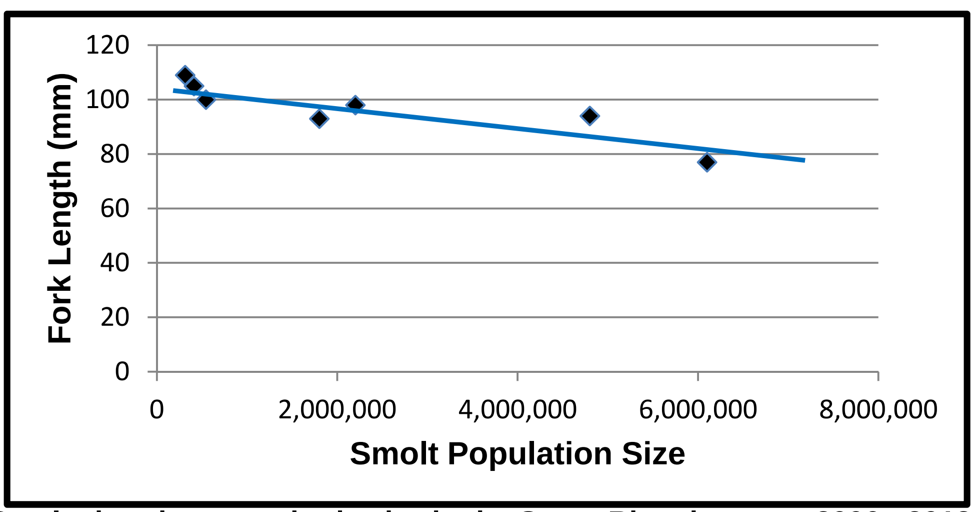


Figure 14. Smolt abundance vs. body size in the Seton River between 2006 - 2012. Line fitted by eye.

4.2.6 Smolt Mortality

In 2011, the method for calculating smolt mortality estimates was revised to reduce the dependency on some of the assumptions. Under this revised method, the annual estimate was produced by applying the fixed mortality rates directly to the proportions of smolts that migrated into the river, or went down the power canal from the hourly catch data. Assumptions for the mortality rate calculations included:

- for the study years 2006 to 2010: 84% of the smolts migrated down the canal and 16% passed through the dam whenever the plant was running (based on the 2008 power canal sampling data); 100% of the smolts migrated through the dam when the plant was shutdown;

- for the 2011 data: 66% of the total run were estimated to have migrated out via the Seton River and 34% migrated out via the power canal. These results were based on the recapture percentages for mark groups released above the dam during the 2011 sample period;

- mortality associated with passage through the turbine is 17%, with no incremental mortality associated with passage through the dam;

- and, the study period covered 100% of the smolt migration window.

In 2011 a correction factor of 2% mortality was added to the Seton River smolt migrants for mortality associated with passage through the dam (Groves and Higgins). This assumption was relaxed in 2012 since there are only very few injured smolts captured in the Seton River IPT and few dead smolts. In 2012, the mortality rate estimate was 8.0% (Table 6).

Table 6. Summary of estimated mortality rates for Seton-Anderson sockeye smolts, 2006 to 2012.

Study Year	Daytime (%)	Nighttime (%)	Mean (%)
2006	-	9.2	-
2007	-	8.5	-
2008	14.4	13.3	13.5[1]
2009	5.5	3.3	4.2
2010	4.2	3.9	4.0
2011	-	-	7.1
2012	**8**	**7.2**	**8.0**

[1] Power canal sampling in 2008 precluded some plant shutdowns, contributing to a higher mortality estimate for that year.

The information described above demonstrates that mortality rate estimates are sensitive to the calculation methodology: mark-recapture versus assumed routing percentages. The sensitivity of the estimates will be tested in 2013 by independently calculating the rates according to the 2 methodologies.

5.0 Discussion and Recommendations

Sockeye smolt catches and population estimates were dramatically higher in 2012 than in any of the previous years. During 2008, the smolt year that matured into adults in 2010, the abundance was extremely low: 6.1 million in 2012 vs. 543,000 in 2008 (Table 5). There are no obvious reasons for the extreme discrepancy other than the logical conclusion that the underlying mechanism is likely located in Anderson and/or Seton Lakes. While 7 years between 2006-2012 is a major time and resource commitment, this is still a modest data set for elucidating the underlying biological mechanisms These trends will be re-visited annually to gain better understanding of the inter-annual variability and the implications for the smolt mitigation strategy.

The smolt mortality rate in 2012 was 8.0%. A large surprise during 2012 was the alteration in the daytime:nighttime migration ratio whereby nearly equal numbers of smolts were trapped during daytime as at night (121,000 vs. 129,000). The high daytime catch reflected the highest 1-day trap catch that was enumerated in the 7 years of monitoring: ca. 46,000 on May 5. Given the high abundance, this shift may reflect a density-dependent response that leads to a strong daytime migration. Both in the daytime and the nighttime in 2012, most of the fish migrated during 3 major pulses (Figure 11) on, or close to, April 24, May 6 and May 27. In other years the proportion of daytime migrators has increased as the migration period progresses. This may reflect a physiological "urge" for the smolts to leave freshwater and to embark on their marine migration which gets more pronounced over time.

In terms of scheduling shutdowns, in 2012 82% of the nocturnal catch occurred between 20:00 and 02:00 making this scheduling optimal from a smolt protection standpoint. The high number of daytime migrants wasn't predicted and the high numbers were unprecedented. Daytime:nighttime catch ratios (Table 1) were 0.56 for 2012 compared to 0.03 - 0.41 in previous years:

	Daytime: Nighttime migration ratio
2006	--
2007	--
2008	0.20
2009	0.41
2010	0.34
2011	0.03
2012	**0.56**

There is no immediate requirement to re-visit the nightly shutdown schedule unless the 2012 patterns are repeated which is unexpected in view of the 2008-2011 results. It is expected that smolt behavior in 2013 will revert back to primarily a nocturnal migration.

The demonstration of density-dependent growth (Figure 14) for sockeye smolts in the Seton-Anderson system strongly suggests a within-lake growth and survival mechanism. In view of the prevailing fry migration pattern involving the rapid dispersal of Gates Creek fry into Seton Lake, this would be the likely habitat where mortality and growth mechanisms would likely occur. This question will be further addressed by BRGMON 6 during 2014. Marine survival of sockeye is related to smolt size: larger smolts survive better. During 2012, there was a huge number of relatively small smolts while in other years e.g. 2009 there was a relatively small number of very large smolts (Figure 13). The marine survival consequences of the density-dependent growth patterns are unknown.

The population and mortality rate estimates hinge critically on knowing the diversion rate of sockeye smolts into the power canal. Large differences in diversion rate estimates using mark-recapture results (2011 and 2012) and direct measurements (2008) were observed. Power canal sampling is impractical since the flow discharge needs to be maintained to fish an IPT thereby undermining the utility of the nightly shutdown strategy. The mark-recapture approach is easily carried out but the low diversion estimates, in relation to the powercanal:Seton River flow split, creates uncertainty. In future it would be informative to acoustically tag smolts and to track their behavior within the forebay of the dam. Safety considerations preclude using a boat in this area, but it may be feasible to install shore-based receivers to generate a realistic estimate.

The management questions that guide this monitoring project are:

1. What proportion of total sockeye outmigrants from Seton Lake will pass through Seton Dam when the powerhouse is shutdown each night (2000 – 0200) between April 20 and May 20?
2. How is this proportion affected by total release from the Seton dam and the configuration of dam discharge facilities used to release water?
3. Are there refinements to the seasonal timing or daily timing of powerhouse shutdowns to improve?

Question 1 can be answered in relation to the seasonal migration information coupled with migration routing which is determined via mark-recapture, as described above. Additional mark trials that sequentially release marked fish above and below the dam can generate this information, as was done in 2012. Question 2 hasn't yet been addressed since there hasn't been an attempt to manipulate the bypass flow release structures and to measure the impact as determined by IPT catches. For Question 3, the seasonal migration timing doesn't vary substantially from year-to-year making the April 20 - May 20 shutdown window optimal. During 2012, the diel behavior shifted with most migrants emigrating during daytime in sharp contrast with previous years. It is premature to evaluate whether a 6-hour daytime shutdown would provide greater survival benefits than a a nighttime shutdown, but it seems unlikely that daytime migrations will be consistently higher magnitude than nighttime migrations. This question will be re-visited in future years.

6.0 References

Groves, K.L., and P.S. Higgins. 1995. Seton Project: Overview study of downstream fish passage. BC Hydro Report No. H2768. WPR-259.

Johnson, W.E. 1958. Density and distribution of young sockeye salmon *(Oncorhynchus nerka)* throughout a multibasin lake system. J. Fish. Res. Board Can. 15: 961-982.

Krebs, C.J. 1978. Ecology: the Experimental Analysis of Distribution and Abundance. Second Edition. Harper and Row. 678p.

Kyle, G.B., J.P. Koenings and J.A. Edmundson. 1997. An overview of Alaska lake-rearing salmon enhancement strategy: nutrient enrichment and juvenile stocking. Freshwaters of Alaska. Ecol. Studies 119: 205-227.

Levy, D.A., J. Sneep and S. Hall. 2008. Effectiveness of Seton Powerhouse shutdowns for reducing entrainment mortality of sockeye salmon smolts during 2008. Prepared for BC Hydro, Burnaby, BC.

Mundy, P.R. 1982. Computation of migratory timing statistics for adult Chinook salmon in the Yukon River, Alaska, and their relevance to fisheries management. N.Am.J.Fish.Mgmt. 4:359-370.

RL&L Environmental Services Ltd. 1999. Seton Dam fish diversion project, 1999 investigations and testing. Prepared for BC Hydro, Kamloops, BC.

Roos, J.F. 1991. Restoring Fraser River Salmon – a history of the International Pacific Salmon Fisheries Commission 1937-1985. Pacific Salmon Commission, Vancouver. 438p.

Ruggles, C.P. 1966. Juvenile sockeye studies in Owikeno Lake, British Columbia. Can. Fish Cult. 36: 3-22.

Sneep, J., S. Hall and LIllooet Tribal Council. 2012 (draft). Seton River sockeye smolt monitoring program: 2011 sampling results. Prep. for BC Hydro.

Appendix 1: Detailed Methods

As in the previous study years, inclined plane traps (IPT) were the sampling gear employed for capturing sockeye smolts during the 2012 monitoring program (Figure 17). The primary sampling location was in the Seton River ca. 500 meters downstream of Seton Dam. At this location, the IPT was operated for a 6-week sample period between mid-April and the end-of-May. The trap was tethered to a cable that was suspended across the river and anchored to a stack of concrete lock blocks (north shore) and the base of a mature ponderosa pine tree (south shore). Two bridle cables were used to attach the trap to the main cable. Due to variation in flow volumes in the Seton River between study years, the positioning of the trap across the channel width has differed somewhat from year-to-year to target the most appropriate conditions for fishing the trap and to ensure the safety of the crew and sampling equipment. Under most flow conditions, trap positioning was selected to capture the thalweg. Water depths at the trap have varied between ca. 0.6 to 1.5 m, depending upon discharge levels; mean width was approximately 30 m and also varied with flow.

Figure 17. Inclined plane trap fishing in the Seton River, 2006.

Construction of the IPT consisted of two main sections: the trap and live box (Figure 18). The trap was built with perforated aluminum sheets and aluminum angle bars welded into a frame. The front opening of the trap was 107 cm high and 152 cm wide. The back opening was 23 cm high and 91 cm wide. Longitudinal V-shaped corrugations on the bottom plate increased the filtering area and strength of the plate (Figure 18). The live box (122 cm long, 91 cm wide, and 61 cm deep) was also constructed of perforated aluminum sheets and aluminum angle bars welded into a frame. Plywood dividers were used to baffle the flow and separate the live box into three separate compartments. The trap and live box were supported on four plastic pontoon floats.

To maintain sampling efficiency and consistency, and to enable comparison of inter-annual trends in the data, the standardized protocols developed for fishing the trap during 2012 were maintained during the previous (since 2006) monitoring activities. All sampling was conducted by a 3-member crew; two technicians working the trap, and one stationed on shore recording data and monitoring the safety of the other crew members. At the start of every sampling shift, the trap and live box were lowered into the river until the bottom edge of the trap mouth was submerged to a depth of ca. 0.90 m. Under certain flow conditions, this target sampling depth was adjusted to ca. 0.60 m to account for higher flow velocities or limited river depth. As a result, the total sampling area has varied from ca. 0.9 to 1.4 m^2 during the previous years to-date.

Water velocities at the trap opening were measured using a calibrated Swoffer Model 2100 current velocity meter. These data enabled the estimation of the total volume of water filtered by the trap for each sample event. In addition to a focus on optimizing the sampling efficiency of the trap, all efforts were made to minimize injury to captured fish by adjusting the trap angle and live box depth such that plunge distance and velocity forces in the trap box were minimized.

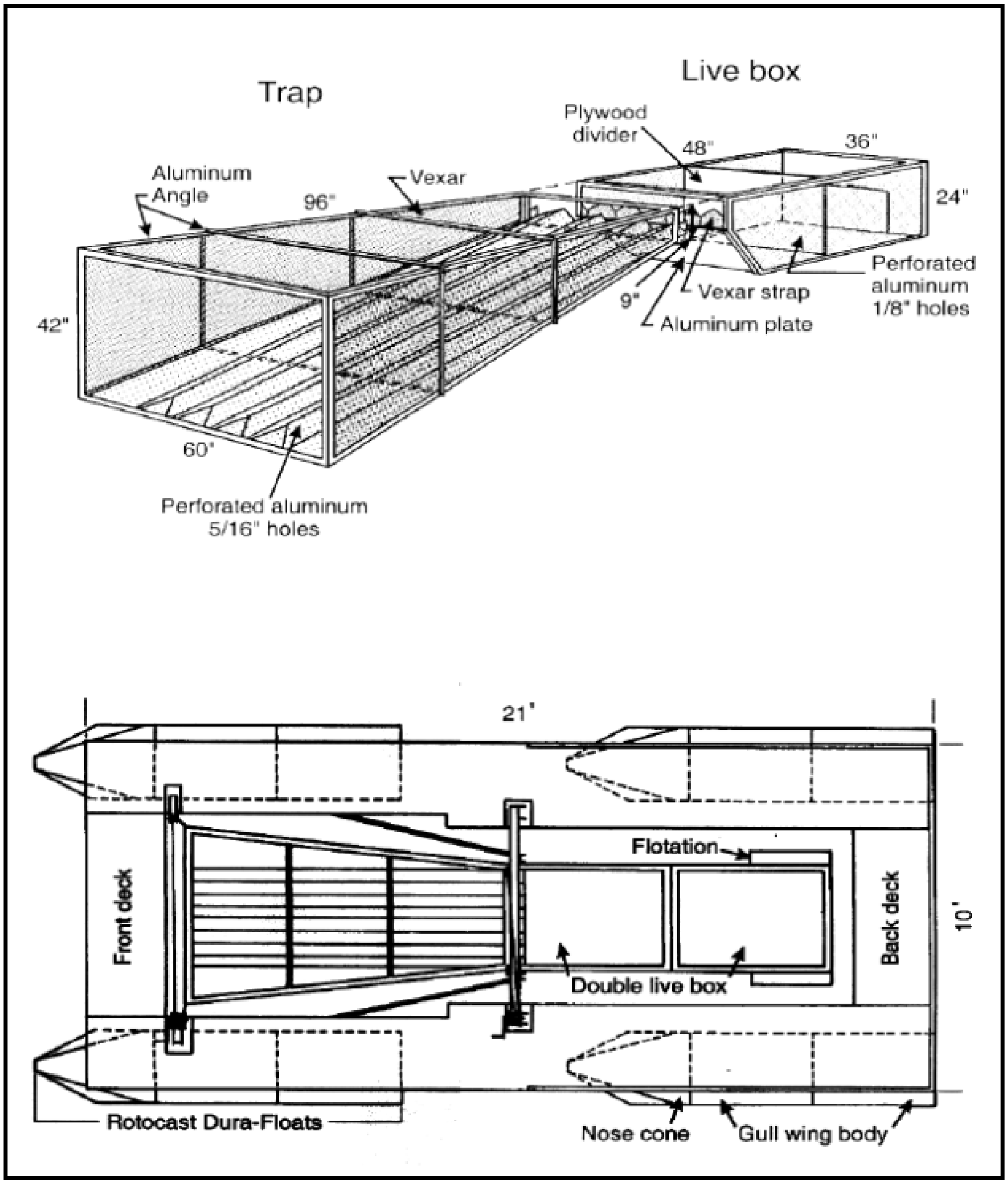


Figure 18. Side view and top view of IPT used in this monitoring program.

During each study year sampling was conducted at night to coincide with the outmigration timing of the majority of sockeye smolts as determined by previous studies on the Seton River (Fretwell 1979; R.L.&L. 2001). Sampling commenced shortly after 2000h each night and concluded between 0530h and 0600h. However, daytime periods were also sampled at the Seton River site during 2008 and 2009, at the same intensity as nighttime periods by a second field crew (0800h to 1800h in 2008; 1000h to 2000h in 2009). The purpose of the daytime sampling was to collect data on the diel nature of smolt migration patterns. The sampling protocols employed were identical to those employed during the night shifts.

In general, the traps were checked and redeployed hourly during each shift. However, due to much lower debris accumulation, the canal trap was occasionally fished for up to 3 or 4 hours between checks. At each check, captured fish were removed from the live box, identified, enumerated, and released back into the water behind the IPT; handling of the captured fish was minimized to minimize stress. Any accumulated algae and debris were routinely cleaned from the trap and live box. Fork lengths from a sample of captured sockeye smolts (up to 40 fish per night) were measured to enable analysis of length frequencies, mean size and standard deviation, and estimation of the size breaks between age classes.

Standardized data sheets were used to ensure consistent collection of data. Recorded parameters included: date; crew; time of trap deployment and retrieval; counts of captured sockeye by age class (i.e., fry, Age-1, Age-2) and trap set; % cloud cover; weather conditions; depth and velocity measurements at the trap mouth; sockeye size data (fork length to the nearest mm) from a subset of captured fish; and comments related to the sampling efficiency of the IPT.

Mark-recapture experiments were undertaken to estimate the capture efficiency of each IPT under the range of discharge conditions from Seton Dam during the study period. Multiple trials were conducted for the Seton River trap, during both day and night periods, and the canal trap. For each experiment, a known number of marked smolts were released upstream of the trap location and the recaptured individuals were subsequently enumerated in the live box to estimate a recovery rate.

Fish marking was conducted according to an adapted version of the procedure described in R.L. & L. (2001). Captured smolts were held in a flow-through holding tank in the river until a sufficient number for a mark-recapture trial had been collected (target = 500 smolts). The fish were then transferred into a set of 20 L buckets (up to 100 smolts maximum per bucket), each equipped with an air bubbler and partially submerged at the river's edge to maintain the water temperature. A measured dose (i.e., 0.8 g) of either Neutral Red or Bismarck Brown Y dye was added to each bucket and carefully mixed into the water. The fish were retained in the dye mixture for 20 minutes with a constant airflow from the bubblers. Immediately following the dyeing period, the marked fish were transferred back into the fresh water of the flow-through holding tank. After a minimum 12-hour recovery period, dead and moribund fish were removed and all fish that appeared robust were transferred to buckets for release. The release location for the Seton River trap was the right bank immediately below the fishway at Seton Dam ca. 500 m upstream of the trap location. Marked smolts for the canal trap were released into the power canal ca. 500 m upstream of the trap location. All fish subsequently captured in the traps were inspected for marks; separate counts were recorded for marked and unmarked fish. A sample of sockeye smolts marked with Bismarck Brown dye is shown in Figure 19.

Figure 19. Seton sockeye smolts marked with Bismarck Brown dye.

Water and air temperatures were recorded using Tidbit™ data loggers manufactured by Onset Computer Corporation. The logger for monitoring water temperature was deployed at the Seton River sampling site about 25 m upstream of the trap location. The logger was anchored to the substrate in a continuously wetted and flowing portion of the river channel and recorded data every 30 minutes. Air temperature was monitored by suspending the logger from the railing at the back of the IPT and recording data once every hour.

Ambient light intensity was recorded by a light intensity logger (model HLI manufactured by Onset Computer Corporation). The logger was sealed in a clear case and mounted to the top of the Water Survey of Canada gauging station tower, which is located immediately downstream of the trap site on river right. Light data were recorded once every hour. All data loggers were deployed prior to the start of sampling and retrieved on the final day of field sampling.