Salmon River Stream Productivity Monitoring

2011-2013

Report Prepared for the Campbell River Salmon Foundation

By

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Table of Contents

List of Figures

List of Tables

Introduction

Nutrient enrichment has been conducted on several key Vancouver Island rivers in an attempt to offset low marine survival, losses of freshwater rearing habitat from human activities, and reduced inputs of marine derived nutrients from low salmon escapements. By stimulating stream productivity at the lowest point (primary production) the growth of algae, insects, and fish is increased. Larger juveniles experience higher over winter survival and smolt at a younger age resulting in a higher ratio of smolts per spawner. Increased smolt production offsets low adult returns and other watershed impacts, thereby improving steelhead population resilience.

Sections of the Salmon River and tributaries have been enriched with different combinations of fertilizers and application locations for over 20 years. A review of nutrient enrichment of the Salmon River watershed was recently conducted by Pellett (2011 (a)) which included a comprehensive summary of treatment and monitoring data. The review was commissioned by members of the BC Hydro Fish and Wildlife Compensation Program (FWCP)-Technical Review Committee (TRC) as a tool for better understanding the effects of nutrient treatments to the Salmon River as well as to guide future enrichment activities.

The review provided several key findings that were common to most treatment years including:

- Periphyton biomass was greater in reaches downstream of nutrient treatment.
- Water chemistry was altered as a result of nutrient addition, consistent with program objectives and loading rates.
- Steelhead fry in treated reaches were significantly larger at the end of the growing season.
- The magnitude of the growth response in fry was positively correlated to the quantity of nutrients added and negatively correlated to flow.
- Treatments that began earlier in the year often resulted in a larger growth response by steelhead fry.
- The formulation (chemical) or state (solid vs liquid) did not appear to influence the effectiveness of treatments.
- Steelhead smolts sampled at the diversion dam consisted of approximately 70- 90% two-year-olds during enriched years, consistent with the Keogh River enrichment program.
- The size of two-year-old smolts captured at the diversion dam was positively correlated with the quantity of nutrients added to Grilse Greek two years prior.
- The distribution and magnitude of the adult steelhead population has increased in recent years to reaches above the diversion dam.

Although the review was useful in determining the effect of nutrient addition under varying environmental conditions, monitoring of background stream productivity at the watershed level had not been conducted. Preliminary findings/conclusions could be better supported through the collection of monitoring data during years where no treatments were conducted.

The recommended approach was to monitor three consecutive years of background productivity followed by three years of nutrient addition. The first non-treatment year was 2011 but dedicated funding to properly evaluate background productivity was not available until 2012 and was able to be carried into 2013. This report summarizes results from 2011-2013 although only 2012 and 2013 were funded by the CRSF.

Methods

The summer of 2012 and 2013 marked the second and third consecutive years without nutrient enrichment in the Salmon River watershed since 1989 (see Appendix A for history). Although no nutrients were added, monitoring of background biological productivity as well as physical parameters including water chemistry were continued. The collection of biological data was consistent with recent nutrient treatment programs and include algal biomass and steelhead fry growth. Other data sets that have been used in the evaluation of past treatments include biological sampling of steelhead smolts and adult steelhead snorkel counts. Given equipment and budgetary constraints only adult returns are discussed.

Water Chemistry

Low level nutrient concentrations were monitored across the Salmon River watershed by conducting regular water sampling at seven locations (Table 1, Figure 1). Site descriptions remained consistent with treatment years (i.e control/treated) in order to minimize sampling error and allow for easy interpretation of results. Samples were collected in plastic bottles by field staff during monthly site visits. The potential for sample contamination was reduced by using nitrile gloves to collect all water samples. The samples were shipped on ice to the lab (Environment Canada[1] in 2012 and Maxxam Analytics[2] in 2013) on the day of collection in order to preserve sample integrity. Specific low level nutrients which were requested for analysis including minimum detection levels were: total phosphorus (0.002 mg/l), orthophosphate (0.001 mg/l) and nitrate/nitrite (0.002 mg/l). Nutrient concentrations may be described in different units where 0.001 mg/l = 1.0 ug/L ; 1.0 mg/l = 1.0 ppm and 1.0 ug/l = 1.0 ppb.

Table 1. Location of seven water sampling locations in the Salmon River watershed, 2011-2013

	Stream	**Site**
1	Salmon River	Smolt Screen
2	Salmon River	Washout Control
3	Salmon River	Bigtree Mainline Bridge
4	Grilse Creek	Grilse Control
5	Grilse Creek	Grilse Treated
6	Memekay River	Memekay Control
7	Memekay River	Memekay treated

Periphyton Monitoring

The biological monitoring component of the study began with primary productivity. Consistent with previous years, algal growth on artificial substrate (florist foam) was measured at the seven monitoring sites (Table 1, Figure 1). The periphyton collector plates consisted of a concrete block with a sheet of black plexi-glass which the florist's foam was secured to (Appendix B, photos 1&6). Two circular punches of the foam block were collected at monthly intervals and sent to the lab for chlorophyll *a* analysis. This testing was used as a surrogate for algal growth as it is difficult to properly sample algae

[1] Pacific Environmental Science Center, 2645 Dollarton Highway, North Vancouver, V7H 1B1

[2] Maxxam Analytics, 4606 Canada Way, Burnaby, British Columbia V5G 1K5

quantitatively in the field. Chlorophyll *a* concentrations may be expressed as ug/cm^2 or mg/m^2 where 1.0 ug/cm^2 = 10 mg/m^2.

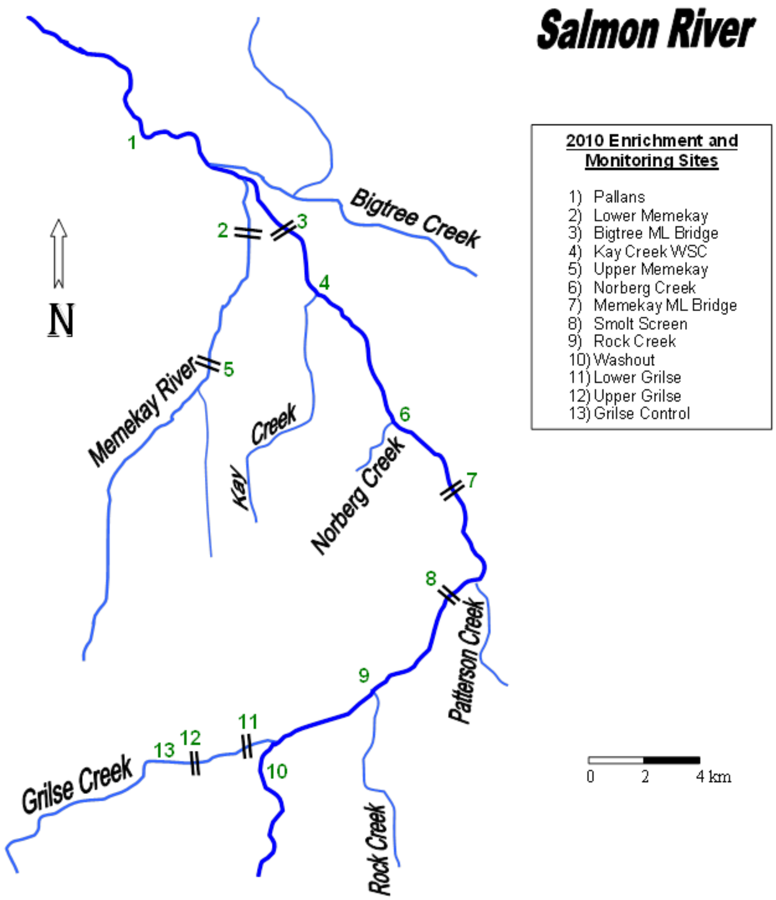

Figure 1. Map of the Salmon River watershed of monitoring locations which were consistent with the last year of stream enrichment in 2010 (as in Pellett 2011 (b)).

Electrofishing

Closed-site electrofishing[3] was conducted at ten sites which have been repeated annually since 1998 on the Salmon River mainstem, Grilse Creek and the Memekay River (Figure 1). Approximately 100 m^2 of suitable steelhead fry habitat was enclosed at each site with small mesh stop nets, and fish removed using the standard 2-pass removal method (deLeeuw 1981). Fork lengths and weights were measured to compare fish growth in treated versus control reaches (reaches remained consistent but were not treated during background monitoring 2011-2013). A minimum of 50 samples were obtained in Grilse Creek sites where a more intensive study on fish growth has been condiuted. A depth/velocity profile across a representative transect within the site was also recorded. Population estimates were derived and depth/velocity adjusted using MoE Fisheries Branch habitat suitability index curves (see Pellett (2013) for details).

[3,4] All electrofishing and snorkel survey activities were funded by BC Hydro and did not require CRSF financial support.

Snorkel Surveys

Adult snorkel surveys[4] have been regularly conducted from Kay Creek to Pallans (11.5 km) since 1999. Additional surveys have been completed from the diversion dam to Norberg Creek (11.5 km) as well as from Rock Creek to the diversion dam (6.7 km) in recent years. Steelhead abundance and distribution is best determined through a series of surveys in April that include these key reaches. Survey conditions (flow, visibility, timing) are critical to effectively evaluating populations and were within the preferred range (5-8 m effective visibility and <10 cms above diversion).

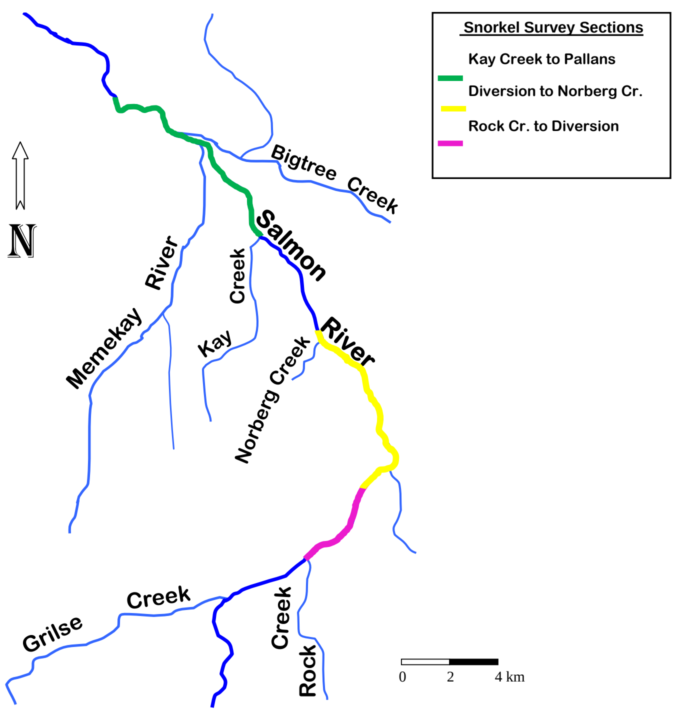

Figure 2. Adult steelhead snorkel survey sections in the Salmon River, 2011-2013.

Results

Water Chemistry

Water sampling occurred over three consecutive years of non-treatment monitoring in order to investigate background productivity in the Salmon River watershed. Only one sampling date occurred in 2011 when funding was limited (August 16) but was conducted monthly in 2012 (July 19, August 7, September 5) and 2013 (July 11, August 20, September 18). Data were compared to treatment years (2006-2010) in order to determine what effect nutrient enrichment has on low level nutrient concentrations in the Salmon River watershed.

Grilse Creek

Two main monitoring sites on Grilse Creek were sampled in treatment and non-treatment years. The upper control site did not receive any nutrient treatments at any time. Orthophosphate concentrations were found to be higher in each month at the treated site in enriched years while only trace levels were documented in September during non-treatment years (Figure 3). Levels at the control site were very low in treatment and non-treatment years with highest levels in September. Control and treated sites also showed similar levels in the absence of enrichment as expected. Nitrate/nitrite concentrations decreased during treatments and increased in the absence of nutrient addition at both control and treated sites. Levels in the treated site were slightly lower in enriched years and slightly higher in the absence of nutrients.

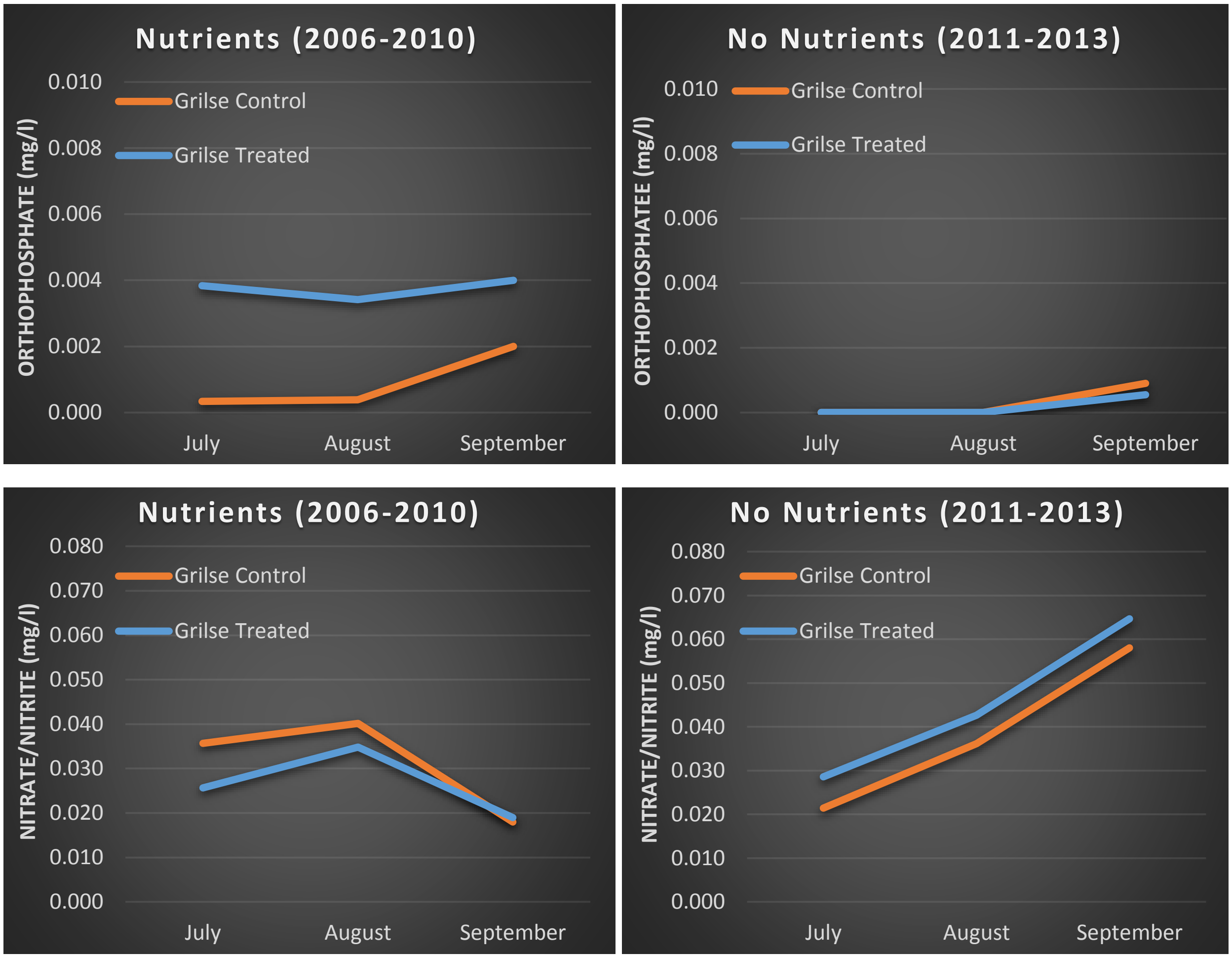

Figure 3. Low level nutrient concentrations by month at two sites in Grilse Creek during treatment (2006-2010) and non-treatment (2011-2013) years.

Memekay River

Similar to Grilse Creek, a control and treated site were monitored in the Memekay River during and after nutrient treatments. Orthophosphate levels were nearly identical in the control site in both treatment and non-treatment years while concentrations in the treated site were higher in July and August during treated years (Figure 4). In non-treatment years, phosphorus concentrations were very low in control and treated sites. Nitrate/nitrite concentrations decreased in both the control and treated sites during enriched years with higher concentrations upstream of nutrient treatments. In the absence of nutrient treatments, nitrogen levels increased steadily at both locations at nearly the same rate.

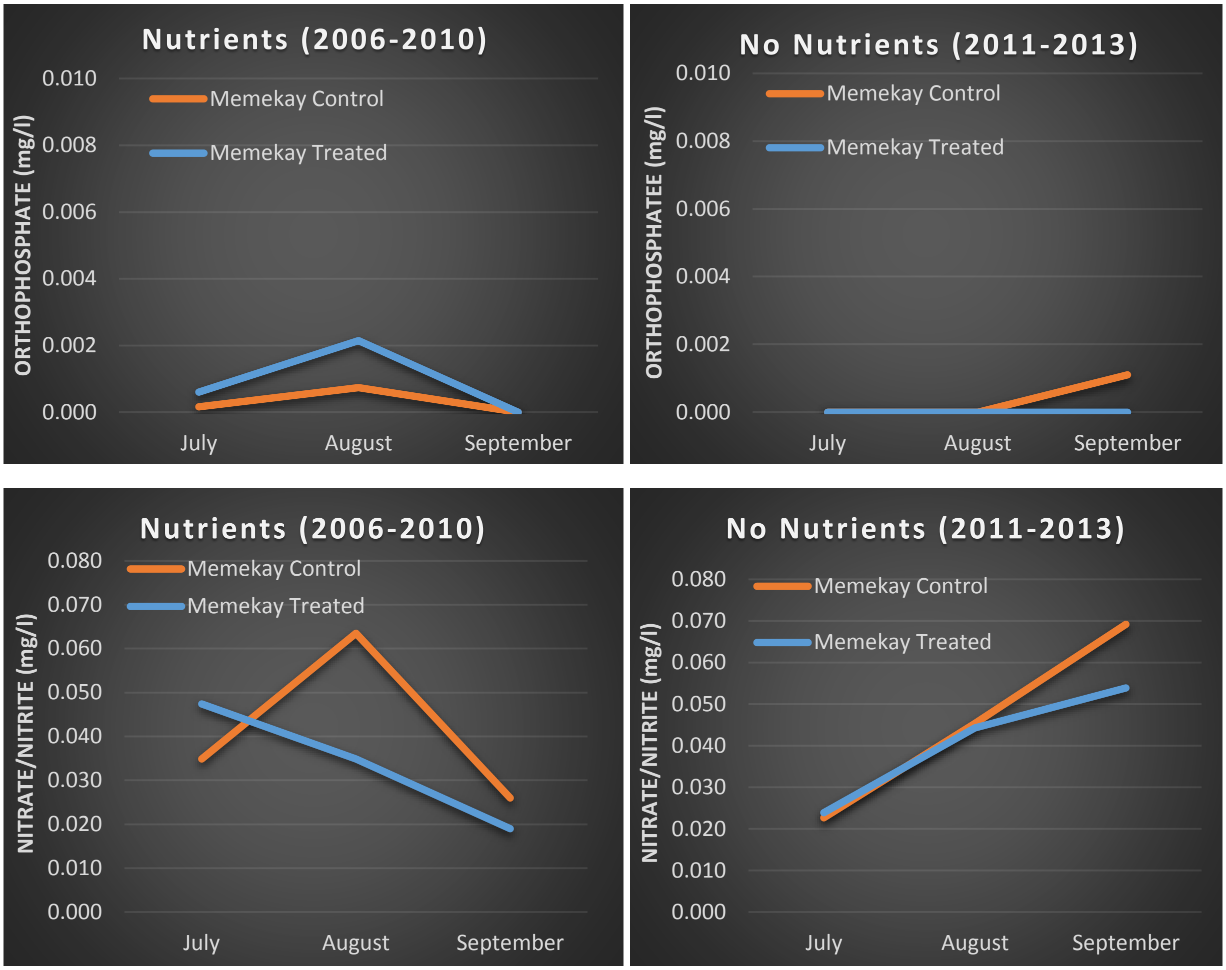

Figure 4. Low level nutrient concentrations by month at two sites in Memekay River during treatment (2006-2010) and non-treatment (2011-2013) years.

Salmon River

Three water sampling sites were monitored on the Salmon River mainstem in treatment and non-treatment years. Orthophosphate and nitrogen concentrations were found to be very similar in all years at the control site suggesting little influence from enrichment as expected (Figure 5). Progressing downstream, nitrogen concentrations at the Smolt Screen and Bigtree Mainline Bridge decreased over the season during treatments and increased at both sites when no nutrients were applied. Orthophosphate concentrations at the Smolt Screen and Bigtree Mainline Bridge were found to be elevated in all months when treatments were occurring. In the absence of nutrients, only trace amounts of orthophosphate were detected at the Smolt Screen in September while undetectable levels (<0.001 mg/l) were present at the Bigtree Mainline Bridge throughout the season.

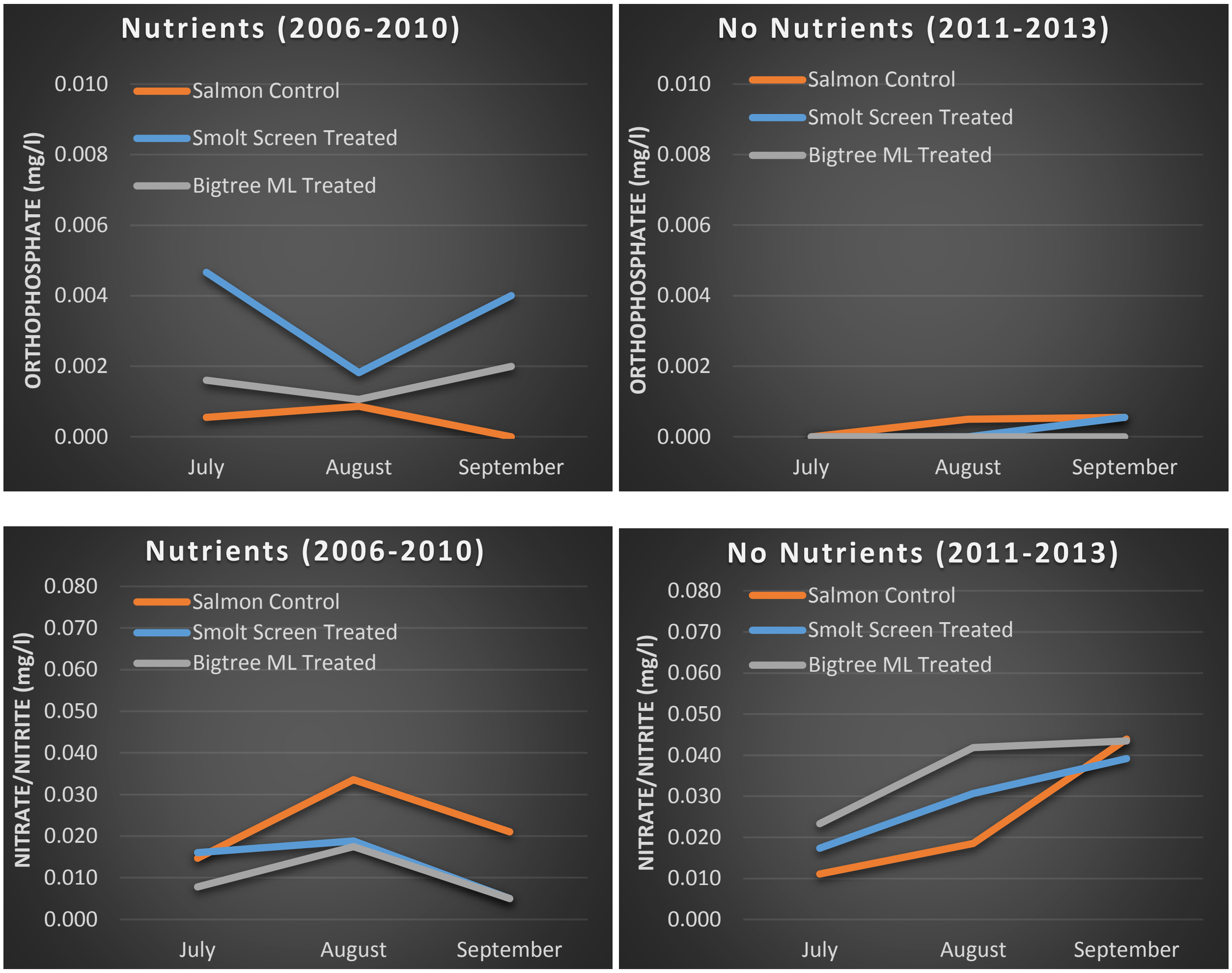

Figure 5. Low level nutrient concentrations by month at three sites in the Salmon River during treatment (2006-2010) and non-treatment (2011-2013) years.

Periphyton Monitoring

Periphyton growth was monitored at seven sites in nutrient enriched (2006-2010) and non-enriched (2012-2013) years. No data was collected in 2011 while regular sampling occurred in 2012 (July 19, August 7, September 5) and 2013 (July 11, August 20, September 18). Control and treated sites were compared during nutrient enriched and unenriched years in order to determine the effect of nutrient enrichment on periphyton growth.

Grilse Creek

Periphyton growth in Grilse Creek is typically higher at the treated site during nutrient enriched years (Figure 6). The difference between the upstream control (no nutrients) and downstream treated (below nutrients) sites increased throughout the treatment period. The same sites were monitored under background productivity levels (i.e. no nutrients) and found to have similar growth throughout the summer. However, growth in the non-treatment years was higher at the control site compared to treatment years while the treated site was nearly identical during both periods. This suggests that unenriched growing conditions in the two non-treatment years may have been more favorable compared to the treatment period. However, the relative response (treatment vs. control) appears to be stronger in enriched years.

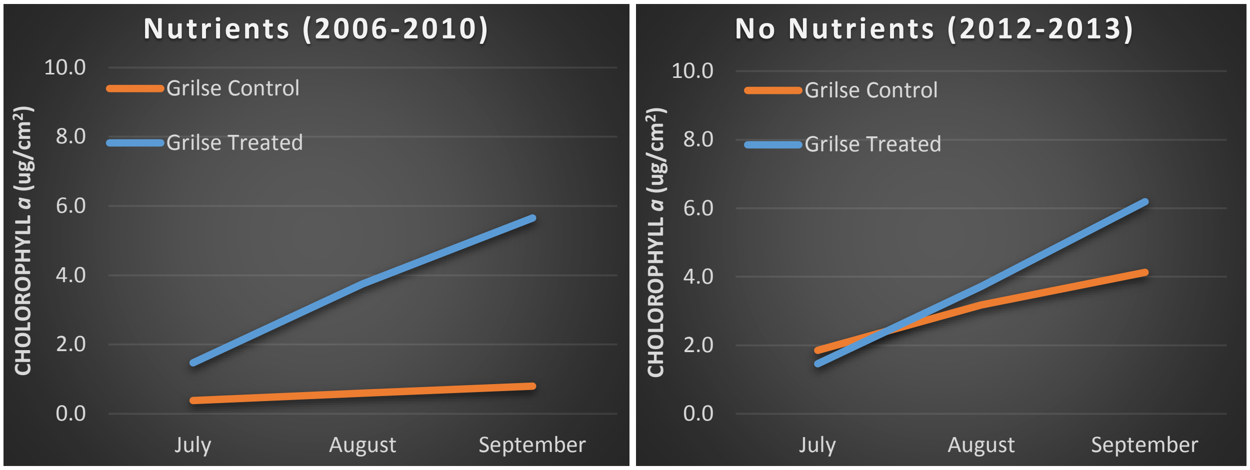

Figure 6). Monthly periphyton growth at control and treated locations within Grilse Creek during treatment (2006-2010) and non-treatment (2012-2013) years.

Memekay River

Periphyton growth in the Memekay River was monitored similarly to Grilse Creek. The response to nutrient treatments (2006-2010) was found to be modest (Figure 7) while little difference was found between the two sites during unenriched years. It was also apparent that growing conditions in 2012 and 2013 were more favorable than 2006-2010 as the control site showed stronger growth under unenriched conditions. Growth at the treated site was found to be nearly identical over the entire study period, similar to Grilse Creek.

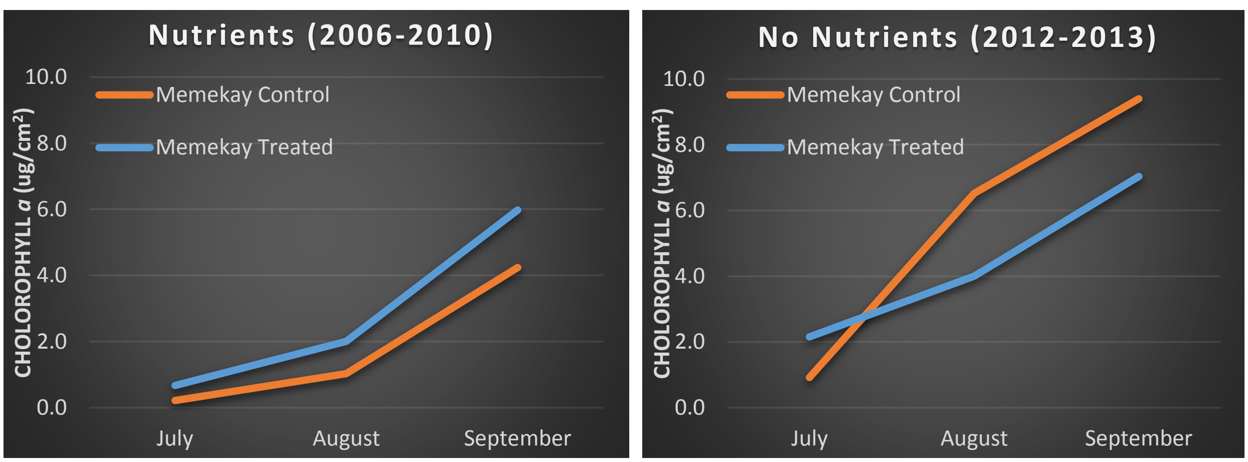

Figure 7. Monthly periphyton growth at control and treated locations within Memekay River during treatment (2006-2010) and non-treatment (2012-2013) years.

Salmon River

Periphyton growth in the Salmon River mainstem was found to be improved at both downstream treated locations with the addition of nutrients (Figure 8). The response typically peaked in August and maintained through September. Sampling under background productivity levels (2012-2013) revealed that there was no difference in growth between control and treated sites in the absence of nutrient enrichment. Similar to Grilse Creek and Memekay River, growth was found to be stronger in the control site during non-treatment years while growth in the downstream treated sites was lower than enriched years.

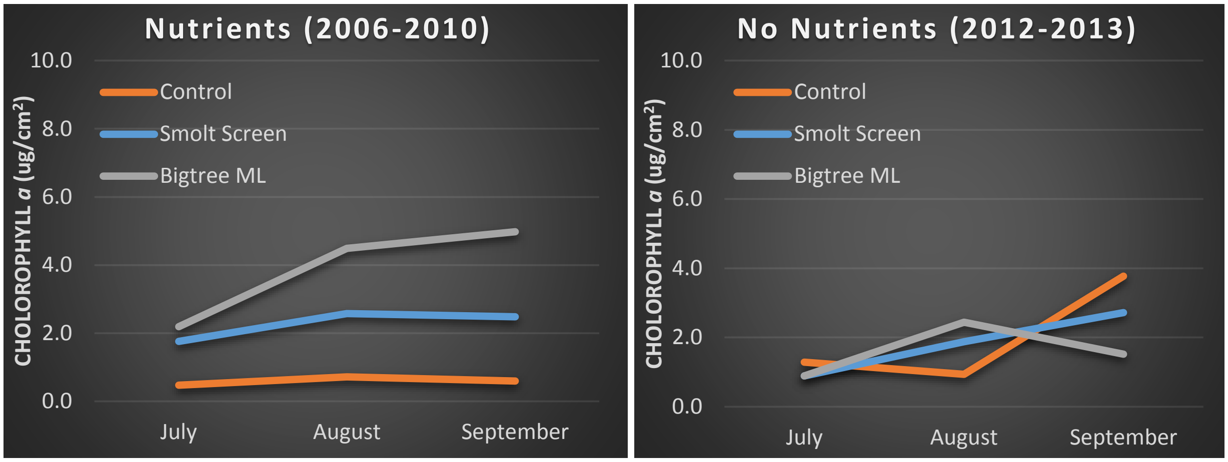

Figure 8. Monthly periphyton growth at control and treated locations within the Salmon River mainstem during treatment (2006-2010)) and non-treatment (2012-2013) years.

Juvenile Fish Sampling

Steelhead fry were captured within the Salmon River watershed by electrofishing at ten sites annually since 1998. Grilse Creek was chosen as a focus for investigating nutrient effects on fry growth as three of the ten sites are located in this sub basin including one upstream and two downstream of nutrient additions. Fry growth at two sites downstream of treatments (treated, T+0.5 km and T+3.5 km) was compared to the site upstream (control, C-0.5 km) in order to determine the response to nutrient enrichment each year. Three distinct periods of treatment were able to be compared based on target loading rates of 5.0 ug/L (1998-2006), 2.5 ug/L (2007-2010), and 0.0 ug/L (2011-2013).

Fry growth at all nutrient levels was not significantly different at the two downstream treated sites despite a separation of 3.0 km (Figure 9). Both treated sites were found to be significantly different from the upstream control site in all years when phosphorus loading rates were high (1998-2006), 2 out of 4 years when loading was moderate (2007-2010), and 0 out of 3 years when no nutrients were applied (2011-2013). Growth was significantly lower at the control site in the absence of nutrient enrichment (0.91 g) when compared to both treatment levels while there was no difference when comparing treatment years (1.59 g vs. 1.58 g, Figure 10). All sites were found to be insignificantly different in the absence of nutrient enrichment.

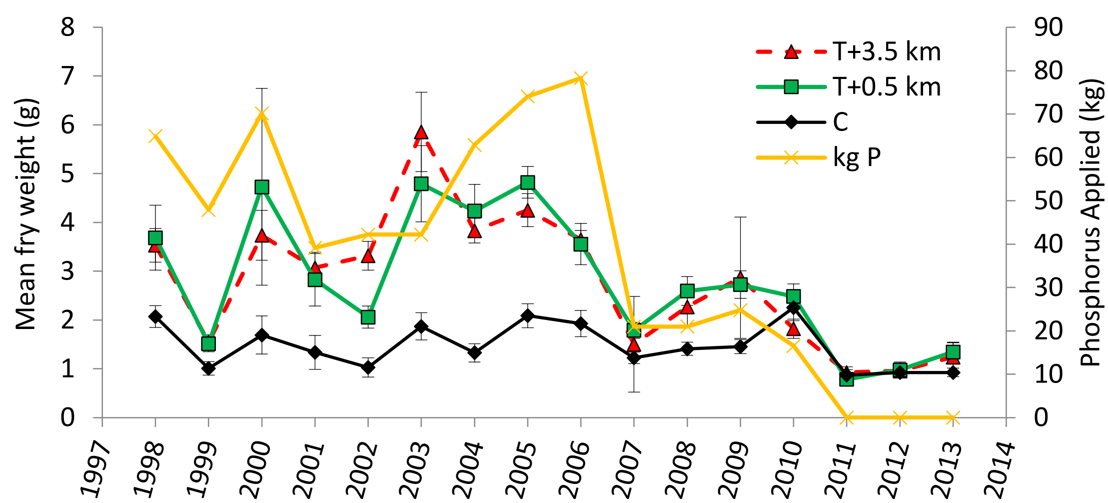

Figure 9. Average Steelhead fry weights at three sites within Grilse Creek compared to the amount of phosphorus added during nutrient treatments, 1998-2013. Note: error bars represent 95% confidence intervals.

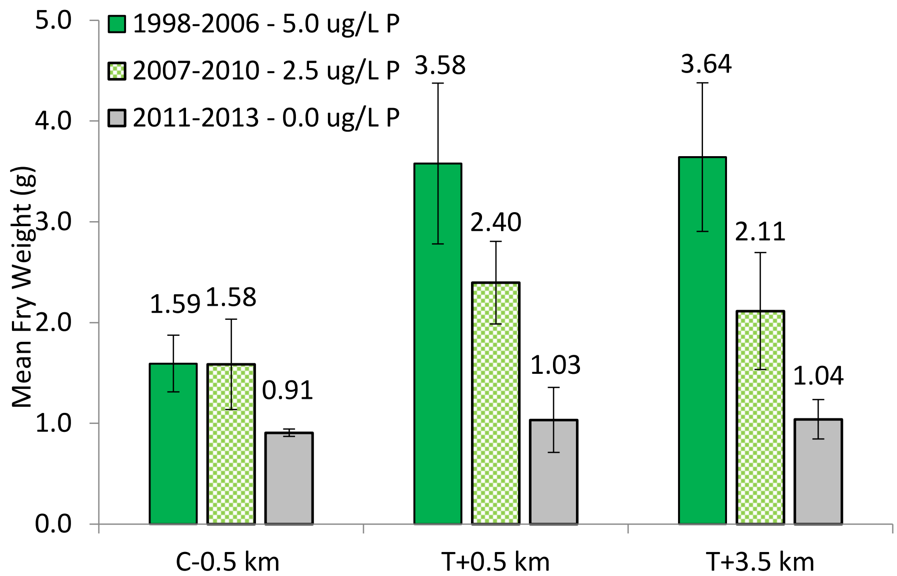

Figure 10. Average Steelhead fry weight at three sites within Grilse Creek at two levels of phosphorus loading and under background productivity levels in the absence of enrichment. Note: error bars represent 95% confidence intervals.

Snorkel Surveys

Adult Steelhead response to changing freshwater rearing conditions is difficult to determine with certainty. However, age structures from previous work on the Salmon River (Hooton et al. 1987) were used to forecast what the expected response would be to altered freshwater productivity (i.e. cessation or reinstatement of a nutrient enrichment program). Snorkel surveys have been regularly conducted in reaches of the Salmon River mainstem in order to index adult returns. Based on the model, it is expected that a significant adult response to the cessation of enrichment between 2011 and 2013 will occur in 2015-2017. Current snorkel survey results are therefore indicative of past treatments and will provide a baseline to compare the future response.

Table 2. Theoretical response of Salmon River Steelhead smolts and adults to a three year cessation of nutrient treatments (2011-2013). Note: this model does not take into account changes in marine conditions and assumes the effects of nutrient treatments are equal in each freshwater year.

Year	**Treatment**	**Smolt response**				**Adult response**				**Total Adult**
		Age 1.	***Age 2.***	***Age 3.***	***Age 4.***	***Age .1***	***Age .2***	***Age .3***	***Age .4***	**Response**
2009	yes	100%	100%	100%	100%	100%	100%	100%	100%	100.0%
2010	yes	100%	100%	100%	100%	100%	100%	100%	100%	100.0%
2011	no	100%	100%	100%	100%	100%	100%	100%	100%	100.0%
2012	no	0%	50%	66%	75%	100%	100%	100%	100%	100.0%
2013	no	0%	0%	33%	50%	52%	100%	100%	100%	98.2%
2014	Yes	0%	0%	0%	25%	6%	52%	100%	100%	75.9%
2015	yes	100%	50%	33%	25%	0%	6%	52%	100%	32.8%
2016	yes	100%	100%	66%	50%	48%	0%	6%	52%	7.3%
2017	yes	100%	100%	100%	75%	94%	48%	0%	6%	24.3%
2018	Yes	100%	100%	100%	100%	100%	94%	48%	0%	67.0%
2019	yes	100%	100%	100%	100%	100%	100%	94%	48%	94.3%
2020	Yes	100%	100%	100%	100%	100%	100%	100%	94%	99.6%
2021	yes	100%	100%	100%	100%	100%	100%	100%	100%	100.0%

Salmon River Steelhead Adults - ocean age

Age 1	Age 2	Age 3	Age 4
3.7%	43.0%	47.8%	5.5%

Salmon River Steelhead Smolts - FW age, enriched

Age 1	Age 2	Age 3	Age 4
1.1%	82.3%	16.4%	0.3%

Two main snorkel index reaches have been developed on the Salmon River. The lower river index from Kay Creek to Pallans has the longest period of record with regular surveys since 1999 (Pellett 2013). An upper index section from the BC Hydro Diversion Dam to Norberg Creek (11.5 km) was recently established in 2008 and provides an indication of up-river distribution and total abundance. In general, counts in both index sections have been quite good relative to other Vancouver Island Steelhead rivers. Regular counts in March and April provide a benchmark to evaluate future returns which will continue be monitored through BC Hydro WUP studies. Figure 11 provides an outline as to how the theoretical response in Table 2 can be compared to measured adult abundance from snorkel counts. Marine survival can also drive adult abundance and should be factored in if possible. However, this should provide a starting point for a cursory investigation into the effects of nutrient enrichment.

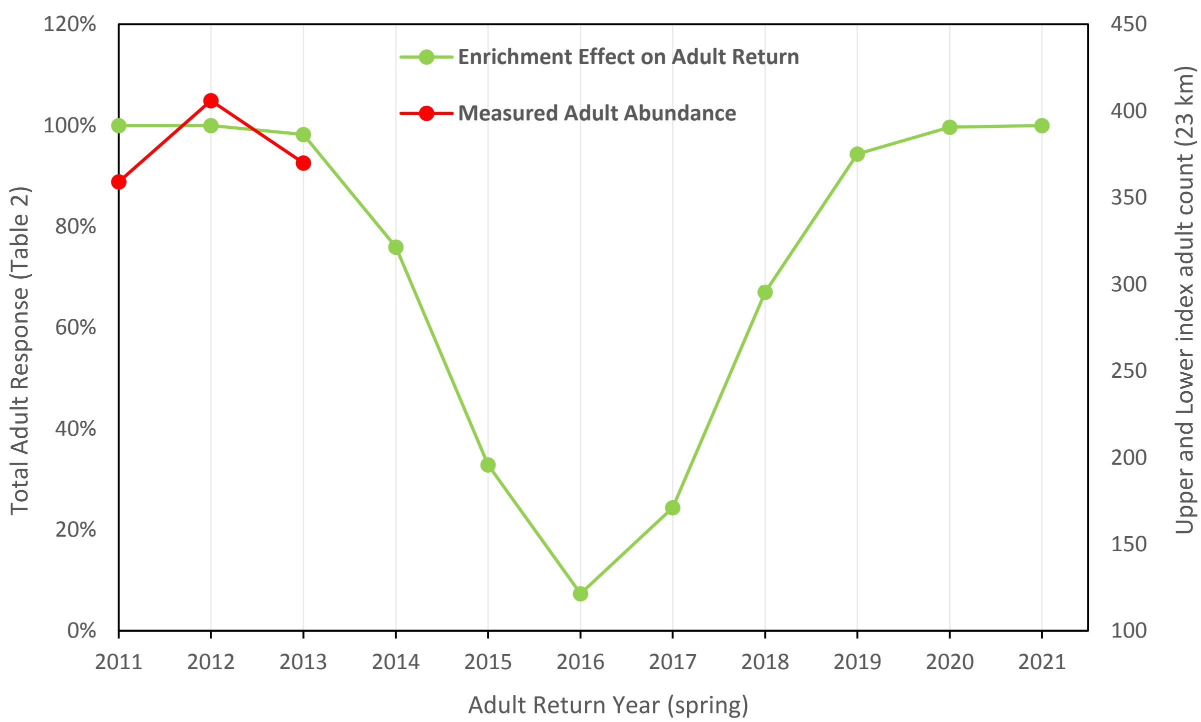

Figure 11. Example of a potential method to evaluate enrichment effect on adult abundance using data from Table 2 (total adult response) and annual snorkel survey data from upper and lower index surveys. Note: this model does not take into account variations in marine survival.

Discussion

Background productivity monitoring in the Salmon River watershed provided valuable insights into the effects of previous nutrient treatments. Water chemistry results indicate that phosphorus is limiting in the absence of nutrient enrichment while past treatments have clearly increased concentrations during the summer growing season. The majority of phosphorus detections under background monitoring occurred in September when the lowest flows of the season were realized. In most treatment years (1998-2006), nitrogen levels decreased throughout the summer while in non-treatment years (2012-2013) nitrogen concentrations increased steadily through September. Phosphorus concentrations were higher during treatment years at treated sites while control sites were similar in treated and non-treated years.

Differences in nitrogen and phosphorus levels can be associated with the increase in primary production as a result of stream enrichment. Elevated orthophosphate concentrations in treated sites from fertilizer resulted in increased primary productivity which required both phosphorus and nitrogen. As primary productivity increased in enriched years the concentration of nitrogen decreased. In the absence of enrichment, nitrogen levels increased throughout the summer as a result of reduced primary productivity which was limited by the absence of phosphorus.

Periphyton results indicated that differences observed between control and treated sites during nutrient enriched years were associated with phosphorus additions. Recent monitoring under background productivity levels indicated that no differences were observed between upstream and downstream sites. However, the magnitude of the growth between the treated (2006-2010) and non-treated (2012-2013) periods was similar in Grilse Creek/Memekay River and higher in the mainstem during treatments. This is likely due to the favourable growing conditions observed during the non-treatment monitoring (low flow, sun) as suggested by the water chemistry data. Periphyton data suggest that algal growth is similar in an average treatment period under moderate nutrient loading to favourable natural conditions and no nutrient addition.

Juvenile fish sampling showed the clearest response to changing nutrient concentrations. The growth response of Steelhead fry to nutrient treatments was found to be largest when phosphorus target loading rates were high. Moderate loading rates produced a moderate growth response while growth at all sites was lower in the absence of nutrient treatments. All three sites were found to be similar under background productivity conditions which indicates that enrichment was responsible for the increase in growth observed during past treatments. This also validates previous assumptions that no other factors significantly influence growth between the sites.

Unexpectedly, fry growth in the control site was not comparable between treated and non-enriched years. A small but significant difference was detected suggesting growing conditions were not as favourable in the non-treated years in a site which should not have been influenced by nutrient addition in any year. The most likely explanation is density dependent growth where available rearing space and food becomes limiting to growth as density increases. In nutrient enriched years (prior to 2011), fry density upstream of the Diversion Dam averaged 24 fry/100m^2 (range 5-40). An increase in adult Steelhead abundance and passage at the Diversion (2011-2013) resulted in a significant increase to 76 fry/100m^2 on average (range 66-82). Other possible explanations include a series of cooler than average springs which may have increased incubation time and delayed spawning and/or emergence. Cooler water temperatures can also affect the rate of growth. However; three consecutive years were monitored and reduced growth was apparent in all years.

Adult Steelhead returns were found to be relatively healthy in non-treatment years. Although the peak of the response (negative or positive) to the cessation of nutrient treatments is not expected until 2015, this suggests the available Steelhead habitat in the Salmon River watershed will be adequately seeded with fry which will rear in unenriched conditions. Continued collection of juvenile and adult density information will be critical to understanding the effects of nutrient enrichment at varying abundances.

There is a considerable amount of data on file from fish collected at the smolt screen at the Diversion Dam. Data collection in recent years has been limited by the operations of the Diversion in the spring which BC Hydro has not used due to a variety of reasons. If the diversion is operated in future smolt migration periods the opportunity to collect biological data (age, length, weight) from Steelhead smolts produced during unenriched years should not be overlooked.

Recommendations

The three year cessation of nutrient treatments in the Salmon River watershed has met objectives by providing data on background productivity including fish production. One of the key tests will be monitoring the abundance and distribution of adults returning in 2015 and 2016 of which the majority will be the first non-treated cohort. As per the proposal submitted to the Campbell River Salmon Foundation in 2012, the recommended approach is to reinstate enrichment for three years and re-evaluate the program after the adult response to cessation is investigated (spring 2016). This is consistent with the direction set in 2012 (see excerpt from proposal below) and should also show a renewed juvenile response to enrichment in the fall of 2014.

"The recommended approach would be to monitor three consecutive years of background productivity followed by three years of nutrient addition. This will provide sufficient data to compare to past treatments as well as a reinstatement of the treatment program prior to evaluating adult returns. If returns are found to be negatively impacted by the pause in nutrient addition during years four through six the program will already be in place to avoid further losses. Also, the analysis of juvenile size at age will have been completed providing early indications of any reduction in freshwater productivity. A the end of the six year period a decision regarding the future of nutrient addition on the Salmon River can be made with increased confidence and data gaps will have been largely filled in."

In order to maximize the juvenile response to enrichment, it is recommended that the phosphorus loading rate for future treatments be increased to 5.0 ug/l. Unless additional nitrogen is added, this will decrease the number of sites which are able to be enriched on the Salmon River mainstem as background nitrogen levels will eventually become limiting. Future program planning should take this into consideration when selecting enrichment sites. Monitoring as per previous years should be continued with the reinstatement of an enrichment program. The collection of juvenile and adult data is scheduled to continue through BC Hydro WUP process while fish passage improvements at the Diversion Dam are in cue. This data will become increasingly valuable to the investigation of nutrient treatments and steelhead production in the watershed and the collection should be considered mandatory in the next six years.

References

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APPENDIX A

Chronology of Salmon River Stream Enrichment

Chronology of Salmon River Nutrient Enrichment Treatments, 1988 – 2009.

<u>Pre-fertilization Sampling</u>
Agencies: MELP, NANAIMO. Contractor: Limnotek Research and Development Inc.
Water chemistry samples: ✔ Five sample sets from 2 sites.
Periphyton samples: ✔ Two series of 3 sample sets over 21 days- from 2 sites.
Taxonomy samples: Algae. ✔
References: Perrin (1989).

<u>Fertilization and Sampling</u>
1989 **Agencies:** MELP, NANAIMO. Contractor: Limnotek Research and Development Inc. Funding from the B.C. Habitat Conservation Fund.
Fertilizer Applied: prill (solid) form – 34-0-0 and 12-51-0 blend.
Period of Application: June 2 – August 26, 1989.
Sites: Norris Creek, Grilse Creek (upper bridge site).
Water chemistry samples: 10 sample sets from 3 sample sites.
Periphyton samples: ✔ Two series of 35 and 40 days- from 3 sites.
Taxonomy samples: Algae ✔ Three sample sites.
References: Perrin (1990).

1990 **Agencies:** MELP, NANAIMO. Contractor: Limnotek Research and Development Inc. Funding from the B.C. Habitat Conservation Fund.
Fertilizer Applied: Liquid- 32-0-0 (Norris Creek only) and 10-34-0.
Period of Application: May 12 – July 29, 1990.
Sites: Norris Creek, Grilse Creek (upper), Grilse Creek (lower bridge site).
Water chemistry samples: ✔ Seven sample sets from 5 sites.
Periphyton samples : ✔ One series (7 samples over 51 days) from 4 sites.
Taxonomy samples: ✔ One set from 4 sites; one replicate from 2 sites.
References: Perrin (1991b).

1991 **Agencies:** MELP, NANAIMO. Contractor: Limnotek Research and Development Inc. Funding from the B.C. Habitat Conservation Fund.
Fertilizer Applied: Liquid- 32-0-0 (Norris Creek only) and 10-34-0.
Period of Application: May 18 – July 31, 1991.
Sites: Norris Creek, Grilse Creek (upper) and Grilse Creek (lower bridge site).
Water chemistry samples: ✔ Four sample sets from six sites.
Periphyton samples: ✔ Eight sample sets from five sites (one series over 57 days).
Taxonomy samples: Algae ✔ One sample set from 5 sites.
References: Perrin (1991a).

1992 **Agencies:** MELP, NANAIMO. (Administered by B.C. Conservation Foundation (BCCF). Funding from the Habitat Conservation Fund).
Fertilizer Applied: Liquid- 32-0-0 (Norris Creek only) and 10-34-0.
Period of Application: May 15 – July 28, 1992.
Sites: Norris Creek, Grilse Creek (upper bridge), Grilse Creek (lower bridge).
Water chemistry samples: ✔ Three sample sets from six sites.
Periphyton samples: No.
Taxonomy samples: No.
References: Carswell (1992).

1993 **Agencies:** MELP, NANAIMO. (Admin. by BCCF. Funding from the B.C. Habitat Conservation Fund and fertilizer purchased by the Campbell River Chapter of the Steelhead Society of B.C.).
Fertilizer Applied: Liquid- 32-0-0 (Norris Ck. only) and 10-34-0.
Period of Application: May 25 – August 8, 1993.
Sites: Norris Creek, Grilse Creek (upper bridge), Salmon River- Rock Creek ML bridge crossing, Memekay ML bridge crossing.
Water chemistry samples: ✔
Periphyton samples: ✔
Taxonomy samples: unknown (see Comments).
References: Carswell (1993).

Comments: Water, periphyton and insect sampling were conducted by Daiva Zaldokas, MELP, Vancouver, Fisheries Research and Development Section.

1994 **Agencies:** MELP, NANAIMO. (Admin. by BCCF. Funding from the B.C. Habitat Conservation Fund, liquid fertilizer purchased by the Campbell R. Chapter of the Steelhead Society of B.C.).
Fertilizer Applied: Liquid- 32-0-0 (Norris Creek only) and 10-34-0.
Period of Application: May 19 – August 14, 1994.
Sites: Norris Creek, Grilse Creek (upper bridge), Salmon River- Rock Creek ML bridge crossing, Memekay ML bridge crossing.
Water chemistry samples: Two sample sets from ten sites.
Periphyton samples: No.
Taxonomy samples: No.
References: Hansen (1994).

1995 **Agencies:** MELP, NANAIMO. (Admin. by BCCF. Funding from Habitat Conservation Fund, liquid fertilizer purchased by the Campbell R. Chapter of the Steelhead Society of B.C.).MELP, Vancouver, Fisheries Research and Development Section monitored slow-release briquettes (pucks) in Norris Creek and Grilse Creek.
Fertilizer Applied: Briquettes in Norris Creek and Grilse Creek and liquid 10-34-0 in the mainstem Salmon River.
Period of Application: May 25 – August 25, 1995.
Sites: Norris Creek, Grilse Creek (upper bridge), Salmon River- Rock Creek ML bridge crossing, Memekay ML bridge crossing.
Water chemistry samples: ✔ Two sample sets from five sites on the mainstem Salmon River. Seven sample sets from five sample sites on Norris Creek and Grilse Creek (MELP, Vancouver).
Periphyton samples: ✔ (MELP, Vancouver).

Taxonomy samples: ✓ (MELP, Vancouver).
References: Hansen (1995). Mouldey Ewing, Ashley (1998).

Comments: An in-depth study of the slow-release fertilizer was conducted by the MELP Fisheries Research and Development Section, Vancouver, from 1995 to 1997 inclusive. Three reports are cited in **REFERENCES** (Mouldey Ewing, et al. 1996, 1998, 1998).

1996 Agencies: MELP, NANAIMO. (Admin. by BCCF. Funding from the B.C. Habitat Conservation Fund, liquid fertilizer paid for by the Campbell River Chapter of the Steelhead Society of B.C.) .
MELP, Vancouver, Fisheries Research and Development Section, monitored slow-release briquettes in Norris Creek and Grilse Creek.
Fertilizer Applied: Briquettes- Norris Creek and Grilse Creek. Liquid 10-34-0- Salmon River mainstem.
Period of Application: June 1 – September 5.
Sites: Briquettes- Norris Creek, Grilse Creek (upper bridge). Liquid- (Salmon River)- Rock Creek ML bridge crossing, fish screen, and Memekay ML bridge crossing.
Water chemistry samples: ✓ Two sample sets from six sites on the mainstem Salmon River. Nine sample sets of five sites on Norris Creek (2 sites) and Grilse Creek (3 sites).
Periphyton samples: ✓ Nine sample sets from five sites on Norris Creek (2 sites) and Grilse Creek (3 sites).
Taxonomy samples: algae.
Benthic invertebrate biomass measured: ✓
References: Hansen (1999b). Mouldey Ewing and Ashley (1998).

Comments: Fertilizer toxicology testing was conducted by EVS Environmental Consultants (1997) for rainbow trout, chironomids, amphipods and daphnids.

1997 Agencies: MELP, NANAIMO. (Admin. by BCCF. Funding by BC Hydro and the Campbell River Chapter of the Steelhead Society of B.C.).
MELP, Vancouver. Fisheries Research and Development Section.
Fertilizer Applied: Briquettes (7-40-0) (Norris Creek and Grilse Creek) and liquid 10-34-0 (mainstem Salmon River).
Period of Application: June 12 – October 6.
Sites: Norris Creek (briquettes), Grilse Creek (upper bridge) (briquettes), Salmon River- Rock Creek ML bridge crossing (liquid), fish screen (liquid), and Memekay ML bridge crossing (liquid).
Water chemistry samples: ✓ Every two weeks (eight sample sets) from nine sample sites throughout 40 km of the river treatment area.
Periphyton samples: ✓ Eight sample sets from nine sample sites.
Taxonomy samples: algae. ✓
Benthic invertebrate biomass measured: ✓
References: Hansen (1999a). Mouldey, Ashley & Wilson (1998).

Comments: In addition to treatment of the upper Salmon River and tributaries, the Memekay River and Cooper Creek were treated with briquettes (7-40-0): 60 kg to Cooper Creek and 599 kg to each of two sites on the Memekay River (total – 1,198 kg).
Water chemistry samples: ✓ Two sample sets. **Periphyton:** none. **Taxonomy:** none.

1998 Agencies: MELP, NANAIMO. (Admin. by BCCF. Funding - BC Hydro).
Fertilizer Applied: Briquettes - 7-40-0 (Norris Creek) and liquid 10-34-0.

Period of Application: June 10 – August 19.
Sites: Norris Creek, Grilse Creek (upper bridge), Salmon River- above Rock Creek ML bridge crossing, fish screen and Memekay ML bridge crossing.
Water chemistry samples: No.
Periphyton samples: No.
Taxonomy samples: No.
References: Hansen (1999c).

Comments: In addition to the mainstem Salmon River and upper Salmon tributaries, the Memekay River and Cooper Creek were also treated. Sixty kilograms of briquettes were added to the upper end of Cooper Creek and liquid 10-34-0 was applied by drip station to the Memekay River just below the ML bridge.

1999 **Agencies:** MELP, NANAIMO. (Admin. by BCCF. Funding BC Hydro).
Fertilizer Applied: liquid 10-34-0.
Period of Application: August 9 – September 28.
Sites: Grilse Creek (upper bridge), Salmon River- above Rock Creek ML bridge crossing, fish screen and Memekay ML bridge crossing.
Water chemistry samples: No.
Periphyton samples: No.
Taxonomy samples: No.
References: Hansen (1999d).

Comments: In addition, a liquid drip station (10-34-0) was maintained on the Memekay River just below the Memekay ML bridge. Due to extremely high flows from a record high snow-pack, discharge in the Salmon River and tributaries was too high in June and July for practical delivery of a fertilizer drip-rate. Fertilization did not start until early August when flows had moderated, and was continued later than in previous years.

2000 **Agencies:** MELP, NANAIMO. (Admin. by BCCF. Funding BC Hydro)
Fertilizer Applied: liquid 10-34-0 and briquettes (new formula).
Period of Application: June 19 – September 12.
Sites: Briquettes- Grilse Creek just upstream of the falls, Liquid- Grilse Creek (upper bridge), Salmon River- above Rock Creek ML bridge crossing, fish screen and Memekay ML bridge crossing.
Water chemistry samples: No.
Periphyton samples: No.
Taxonomy samples: No.
References: Hansen (2001).

Comments: Briquettes were placed in Cooper Creek, 7 km upstream of the confluence with the Memekay River. A liquid drip station (10-34-0) was maintained on the Memekay River just below the Memekay ML bridge.

2001 **Agencies:** MWLAP, NANAIMO. (Admin. by BCCF. Funding by Weyerhaeuser (FRBC) & BC Hydro, Bridge Coastal Restoration Program).
Fertilizer Applied: liquid 10-34-0.
Period of Application: July 5 – August 24.

Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper bridge), Salmon River- upstream of Rock Creek ML bridge crossing (deactivated), fish screen and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: Yes.
Taxonomy samples: No.
References: Hansen, (2002).

2002 **Agencies:** MWLAP, NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program).
Fertilizer Applied: liquid 10-34-0.
Period of Application: June 18 – August 19.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper bridge), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), fish screen and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: Yes.
Taxonomy samples: No.
References: Hansen, (2003)

Comments: An experimental, slow-release fertilizer product was applied to the upper Salmon River just below the Jessie Creek confluence on July 29, 2002. The fertilizer was a struvite-coated urea granule (18-6-0) produced by PSP Enterprises of Urbana, Ohio.

2003 **Agencies:** MWLAP, NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program and Weyerhaeuser Canada Ltd., Renewal Investment Corp.).
Fertilizer Applied: liquid 10-34-0.
Period of Application: June 17 – Sept 6.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper bridge), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), Salmon River bridge near the diversion and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: No.
Taxonomy samples: No.
References: Hansen & Wright, (2003)

Comments: A new product providing organic instream nutrients was tested in Paterson Creek in 2003. The product was made from organic fish meal (Alaskan pollock) pressed into 4 kg logs.

2004 **Agencies:** MWLAP, NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program.and Weyerhaeuser Canada Ltd.
Fertilizer Applied: liquid 10-34-0.
Period of Application: June 8 – September 17.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper bridge), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), fish screen and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: No.
Taxonomy samples: No.
References: Hansen, (2004)

Comments: An experimental, organic fishmeal product (pollock) was applied to the upper Salmon River just below the Jessie Creek confluence on June 17 and July 22, 2004.

2005 Agencies: MWLAP, NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program) and Weyerhaeuser Canada Ltd.
Fertilizer Applied: liquid 10-34-0.
Period of Application: June 18 – August 19.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper bridge), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), fish screen and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: No.
Taxonomy samples: No.
References: Manley, Hansen & Wright (2006)

Comments: An experimental, organic fishmeal product (pollock) was applied to the upper Salmon River just below the Jessie Creek confluence on June 22, 2005.

2006 Agencies: MoE., NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program) Cascadia Canada Ltd.
Fertilizer Applied: liquid 10-34-0.
Period of Application: June 14 – September 5.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper bridge), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), fish screen and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: Yes
Taxonomy samples: No.
References: Hansen & Wright (2006)

Comments: An experimental, organic fishmeal product (500 kg of pollock) was applied to the upper Salmon River just below the Jessie Creek confluence on June 29, 2006.

2007 Agencies: MoE., NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program) Western Forest Products Ltd., and Georgia Basin Living Rivers
Fertilizer Applied: 16-40-0. (Nutricote T40)
Period of Application: July 4 – September 30.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper and lower bridges), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), smolt screen and Memekay ML bridge crossing.
Water chemistry samples: Yes.
Periphyton samples: Yes
Taxonomy samples: No.
References: Pellett (2007)

Comments: Solid Nutricote T40 fertilizer replaced liquid as the source of nutrients for stream enrichment. Product was tested at PESC again in June of 2007 to confirm it is safe for stream applications. No pollock or liquid fertilizer was used this year.

2008 **Agencies:** MoE., NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program) Western Forest Products Ltd., and Georgia Basin Living Rivers
Fertilizer Applied: 16-40-0. (Nutricote T40)
Period of Application: June 24 (White) and June 26 (Salmon) – September 30.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper and lower bridges), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), smolt screen, Memekay ML bridge crossing, Bigtree ML Bridge, White River at Stewart ML, 6.5 km d/s Stewart ML, Consort Creek at Stewart Lake outlet and Consort at 2.5 km d/s of Stewart Lake.
Water chemistry samples: Yes.
Periphyton samples: Yes
Taxonomy samples: No.
References: Pellett (2008)

Comments: Solid Nutricote T40 fertilizer replaced liquid as the source of nutrients for stream enrichment. Product was tested at PESC again in June of 2007 to confirm it is safe for stream applications. Addition of Bigtree ML Bridge site and White River system to FIA project funds.

2009 **Agencies:** MoE., NANAIMO. (Admin. by BCCF. Funding by BC Hydro, Bridge Coastal Restoration Program) Campbell River Salmon Foundation, and Georgia Basin Living Rivers
Fertilizer Applied: 16-40-0. (Nutricote T40), 5-27-0 (Crystal Green)
Period of Application: June 17 (Salmon) and June 24 (White) – September 30.
Sites: Memekay River at the ML bridge crossing, Grilse Creek (upper and lower bridges), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), Menzies ML bridge, Memekay ML bridge crossing, Bigtree ML Bridge, White River at Stewart ML, 6.5 km d/s Stewart ML, Consort Creek at Stewart Lake outlet and Consort at 2.5 km d/s of Stewart Lake.
Water chemistry samples: Yes.
Periphyton samples: Yes
Taxonomy samples: No.
References: Pellett (2010)

Comments: Solid Nutricote T40 fertilizer replaced by Crystal Green as the source of nutrients for stream enrichment on the Salmon, Grilse and Memekay. Product was tested at PESC to confirm it is safe for stream applications. White River drainage treated with remaining Nutricote T40. Campbell River Salmon Foundation provided partnership funding in absence of FIA support for areas below diversion and the White River/Consort Creek.

2010 **Agencies:** MoE., NANAIMO. (Admin. by BCCF. Funding by Campbell River Salmon Foundation and Georgia Basin Living Rivers
Fertilizer Applied: 5-27-0 (Crystal Green)
Period of Application: June 30 (Salmon) and July 14 (White) – September 25.
Sites: Memekay River at the 2 lower bridge crossings, Grilse Creek (upper and lower bridges), Salmon River upstream of Rock Creek ML bridge crossing (deactivated), Menzies ML bridge, Memekay ML bridge crossing, Kay Creek (in lieu of Bigtree ML Bridge), White River at Stewart ML, 6.5 km d/s Stewart ML, Consort Creek at Stewart Lake outlet and Consort at 2.5 km d/s of Stewart Lake.
Water chemistry samples: Yes.
Periphyton samples: Yes
Taxonomy samples: No.
References: Pellett (2011)

Comments: Campbell River Salmon Foundation provided partnership funding in absence of BCRP and FIA support for areas below diversion and the White River/Consort Creek. Georgia Basin Living Rivers – Vancouver Island provided financial support for activities that CRSF funds not able to cover. No significant growth response by steelhead fry in 2010 due possibly to high flows.

2011 Agencies: MoE., NANAIMO. (Admin. by BCCF. Funding by Georgia Basin Living Rivers
Fertilizer Applied: None (first non-treatment year)
Period of Application: N/A
Sites: No fertilizer in entire watershed including White River
Water chemistry samples: Yes – one round only – August
Periphyton samples: No.
Taxonomy samples: No.
References: To be summarized

Comments: Increased scrutiny regarding program benefits prompted a review of 20 years of enrichment. One of the recommendations in the review was to stop enrichment for a period of 3 years in order to investigate background productivity levels. Fish growth, fry density and adult counts continued through BC Hydro WUP funding. Limited monitoring was conducted with Living Rivers funds and alternate funding sources to support continued water and periphyton monitoring are being investigated.

2012 Agencies: MoE., NANAIMO. Funding from The Campbell River Salmon Foundation (CRSF) and Georgia Basin Living Rivers (GBLR; Admin. by BCCF)
Fertilizer Applied: None (second non-treatment year)
Period of Application: N/A
Sites: No fertilizer in entire watershed including White River
Water chemistry samples: Yes
Periphyton samples: Yes
Taxonomy samples: No.
References: To be summarized

Comments: Funding to continue with monitoring only was secured from the Campbell River Salmon Foundation (CRSF). Steelhead monitoring indicated very small fry in former treated sites and no difference between upstream and downstream locations.

2013 Agencies: MoE., NANAIMO. Funding from The Campbell River Salmon Foundation (CRSF) and Georgia Basin Living Rivers (GBLR; Admin. by BCCF)
Fertilizer Applied: None (third non-treatment year)
Period of Application: N/A
Sites: No fertilizer in entire watershed including White River
Water chemistry samples: Yes
Periphyton samples: Yes
Taxonomy samples: No.
References: Pellett (2014)

Comments: CRSF funds were used to continue sampling. Results were similar in all three non-treatment years and will be summarized in a final report to CRSF. Future program direction has been suggested to reinstate the enrichment program and continue monitoring. The influence of the non-treatment on adult returns is expected to be the largest in spring 2015 and 2016.

APPENDIX B

Photographic Record

1. Periphyton collector plate in the former treated site at Grilse Creek, July 19, 2012.

2. Lower Memekay River, June 27, 2013.

3. Absence of algal growth in Grilse Creek, August 20, 2013

4. Looking upstream off the Menzies Mainline Bridge, August 20, 2013.

5. Underwater photo of stream substrates at Rock Creek, July 19, 2012. Note the lack of algal growth.

6. Looking downstream at a periphyton collector plate at the Bigtree Mainline Bridge, July 19, 2012

7. Closed site electrofishing on Grilse Creek, September 20, 2011.

8. Steelhead fry captured in Grilse Creek averaged less than 40 mm in the absence of nutrient enrichment.

APPENDIX C

Budget Expenditures

Name of Project: CRSF Salmon River Background Productivity Monitoring

Labour — **Budget**

Wages & Salaries

Position	# of persons	# of work days	hrs per day	rate per hour	total cost
Labour	1	5	8	43.75	1,750
Person Days (# of crew x work days)		6		**sub total**	**1,750.00**

Site / Project Costs

Item	details	# of units	unit cost	total cost
Vehicle - Mileage	per km	580	0.50	290
Per Diems	meals	2	23.75	48
Lab - w ater chemistry analysis	per sample	49	32.84	1,609
Lab - periphyton analysis	per sample	42	28.57	1,200
Shipping	lump	2	26.69	53
			Total Site / Project Costs	3,199.87

Administrative Costs

Other overhead costs (give details)	- BCCF Administration 0% on labour plus site/project costs	-
	Total Administrative Costs	-
	Project Total Costs	4,949.87

Budget Summary

Total Labour Costs	1,750.00
Total Site / Project Costs	3,199.87
Total Administration Costs	-
Project Total	4,949.87