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and tributary habitat. Between 1996 and 1999, steelhead smolt densities in the off-channel sites ranged from 0.7 to 4.35 smolts/100 m^2 and averaged 2.0 smolts/100 m^2, whereas densities in reaches 4 of the Coquitlam River ranged from 1.0 to 2.7 smolts/100 m^2 and averaged 1.8 smolts/100 m^2 (see Figure 1). In 1997, too few steelhead smolts were recovered in reach 3 to provide a population estimate. In 1999, estimated density in reach 3 was similar to that in reach 4 (2.6 smolts/100 m^2).

In 1999, an estimated 7% of steelhead smolts in the 12 km section overwintered in the off-channel sites (520 of 7,444 smolts). Given that off-channel areas represent 14% of available habitat, off-channel use by steelhead was low in proportion to availability. However, extrapolating smolt densities from the upper river mainstem to lower reaches likely resulted in an overestimate of smolt numbers; earlier studies found steelhead densities were lower in downstream reaches compared to reaches 3 and 4. As well, steelhead smolt output from reach 4 in 1999 was relatively high compared to six previous sample years. During 1996 and 1997, steelhead (smolts and parr) use of off-channel habitat in reach 4 was proportional to its availability. The Grant's Tomb and Or Creek sites, representing 45% of wetted area in reach 4, supported 34% of steelhead in 1996 and 67% in 1997.

Similar to results for coho, the construction of off-channel habitat did not appear to adversely affect steelhead smolt production in existing mainstem and tributary habitat. Mean smolt output from reach 4 averaged 362 for post-construction years (n = 4) compared to 207 for pre-construction years (n = 3). However, higher numbers in the mainstem in the post-construction period may have been influenced by increased flow releases from the dam.

Lessons Learned

The pond-channel design appears to be an effective approach to increasing coho smolt abundance through habitat restoration. The Coquitlam River pond-channel projects have been successful in part because they provide critical coho overwintering habitat in a system where natural overwintering habitat is scarce.

- Data for the combined pond-channel projects at Coquitlam River suggests that this type of off-channel habitat may also provide important over-wintering habitat for steelhead and cutthroat.
- The tendency for stable off-channel habitat to produce consistent smolt yields may be more important than its ability to augment production in any one year, particularly in a degraded watershed such as the Coquitlam.
- Fry recruitment may be an important factor, particularly in the case of larger off-channel sites with limited access to the stream's mainstem. During construction, effort should be made to enhance the attractiveness of outlet channels to migrating adults and juveniles through the addition of artificial log jams or other debris structures. If hatchery enhancement occurs in the watershed, consideration should also be given to releasing fry in off-channel sites. ▲

This information is compiled from reports (1996-1999) that were prepared for B.C. Hydro Power Facilities and the Department of Fisheries and Oceans' Resource Restoration Division, Vancouver, B.C. Funding for the restoration and assessment work was provided by B.C. Hydro, DFO, FRBC, and the Port Coquitlam Fish and Game Club.

Case Studies of Whole-stream Fertilization in British Columbia

P.A. Slaney, and K.I. Ashley.

Project Description

Whole-river fertilization experiments have been conducted in British Columbia on a series of oligotrophic coastal and interior streams that have been affected by past logging practices and/or hydroelectric development.. These experiments were designed to determine, under diverse conditions, the effects of inorganic nutrient addition on water chemistry, periphyton and invertebrate community composition and biomass, and fish growth and abundance. The treated systems include Keogh River, Salmon River, and Adam River, all located on the northern Vancouver Island; Big Silver Creek, located near Harrison Lake

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on the southern mainland; and the large Mesilinka River, located in northern British Columbia (280 km north of Prince George). The fertilization treatments and responses of these 5 streams represent a broad spectrum of stream types and fish communities in various regions of B.C.

Restoration Responses

Keogh River

Stream fertilization during the spring in 1984, 1985, and 1986 resulted in striking increases in the average weights of steelhead and coho salmon fry, in response to augmented periphyton and benthic insect communities. In 1981, inorganic fertilization increased geometric mean weights of salmon and trout fry respectively by 1.6-1.7 times and 1.9-2.1 times the control. During whole-river treatments from 1984 to 1986, larger sizes-at-age of steelhead parr were usually detected. In 1984, mean weight-at-age of parr did not differ statistically between the upper treated reach and the control. However, in the two other reaches in 1984, and within the three treated reaches in 1985 and 1986, age 1+ parr were 30-130% greater in geometric mean weight than parr in the upstream control section. The older age 2+ parr were 41-63 % larger in the treated reaches than in the control in 1985 and 1986. In 1981, mean salmonid biomass in the treated reach increased 1.8 times, from 35 kg/ha to 65 kg/ha, as compared to the control reach.

Steelhead smolts, as primary mainstem users, increased in production by 62% by brood year over pre-treatment years. Peak smolt output (1987) from the Keogh River was 2.5 times greater than the average for pre-fertilization years. Fertilization also shifted the age class structure of the smolts; age 3 smolts dominated pre-fertilization smolt yields, whereas age 2 smolts dominated the annual smolt production during fertilization, and age 1 smolts appeared for the first time in 1987 as a significant portion (12%) of the annual yield. However, fertilization had a minimal effect on average smolt size: mean smolt length in 1985, 1986, and 1987 was 175, 160, and 170 mm, respectively. Thus, smolt migrated at about the same size as pre-fertilization but one year earlier on average. Adult steelhead originating from smolt cohorts of fertilized years returned to the river from 1986 to 1990. Their numbers, and catch in the sport fishery, corresponded with the increased numbers and size-at-age of smolts, whereas the catch of wild steelhead at an untreated river nearby showed little change.

There was also a 21% increase in coho smolts, possibly as a result of fertilization. However, there are 16-19 untreated tributaries and 6 small lakes that produce an estimated 60% of coho outside the mainstem. Their presence confounded the analysis of treatment effects on mainstem coho production in the treated areas. Mean coho smolt length and age did not change significantly as a result of the treatment.

Fertilization of 30 km of the Keogh River resulted in about a 50% increase in adult steelhead, or an additional 15 adults per km.

Salmon River

Past logging-related instability made fertilization one of the few options in this bouldery stream. During 1990 and 1991, peak periphyton responses were similar to those recorded at the Keogh River during fertilization in 1984-86. In May to July of 1990 and 1991, chlorophyll *a* at the treated sites and downstream in the mainstem at the diversion, peaked at 5-10 times the level of the control section, 10 mg/m^2. By 1992, at the fertilized site in Grilse Creek and at the Salmon River diversion site (9 km downstream of the 4th nutrient dispenser), peak chlorophyll *a* was only moderately elevated to 42 and 37 mg/m^2 by late July, respectively. On the other hand, the peak in the control and 25 km downstream of the fertilizer dispenser in the Salmon River were low in July (6.4-9.0 and 6.3-7.5 mg/m^2). In 1993, more intensive sampling of chlorophyll *a* was conducted. Mean peak chlorophyll *a* biomass was moderate to low, except at the surcharged (10 mg P/L and 40 mg N/L) section at Norris Creek (80 mg/m^2). Peaks at the other seven sites ranged from 17-39 mg/m^2, somewhat higher than the two untreated sites, which ranged from 16-27 mg/m^2. Insect grazing apparently moderated initial algal responses to nutrient addition, which was confirmed elsewhere.

In 1992, the abundance and composition of insects within colonized baskets in Grilse Creek and the Salmon River (in which chlorophyll *a* levels were elevated by 3-4 times) was 2.5 times and 7 times higher than both the upstream control and the sampling site located 25 km downstream from the fourth fertilizer dispenser. The relative percentages of insects varied among the four sites. Mayflies dominated the control (52%) and the fertilized sites (50%) in the Salmon River, with slightly less at the lower Salmon site (40%) and still less in Grilse Creek (20%). Dipterans, which mainly consisted of chironomids, dominated the composition at the Grilse Creek site (75%) and were also evident at the other sites (29-36%). In the lower Salmon River 13-14% of the benthic insects were stoneflies and caddisflies; elsewhere these insects were generally sparse (<10%), although 14% of the insects at the Salmon diversion were caddisflies. In 1993, additional sampling sites facilitated a more rigorous comparison between the control (n=2) and treated (n=8) sites; the mean

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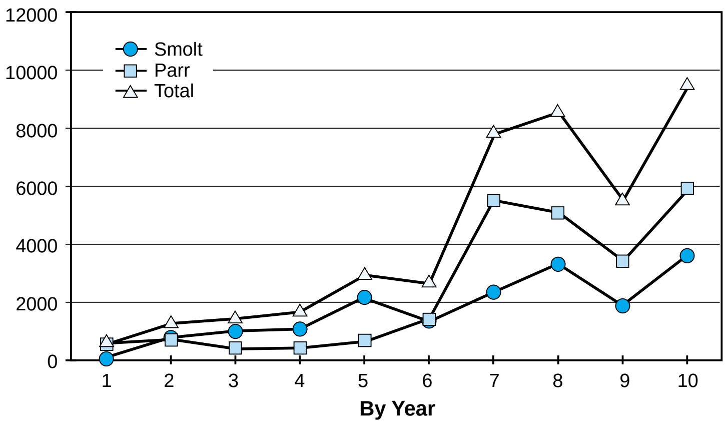
biomass of benthic insects from the fertilized sites was 3.7 times greater than the untreated control sites.

In 1990, the mean weights of trout fry were 3 times greater on average in sites associated with liquid fertilization than in the spatial control, in both Grilse Creek and the Salmon River. In 1992, without nitrate addition there was still a 2 times greater size of fry in fertilized reaches on average, and about 2 times larger than sites >35 km downstream where peak periphyton chlorophyll *a* was not elevated. In addition, mean weights of age 1+ parr were 2-3 times greater in 1990 and 1992 at the sites associated with fertilization.

A strong response to nutrient addition was evident in outputs of migrant steelhead parr and smolts, as enumerated each spring at a hydro-diversion bypass on the Salmon River (Figure 1).



Year	1988[1]	1989[2]	1990	1991	1992[1]	1993	1994	1995	1996	1998[2]
Smolts	150	902	1041	1128	2265	1379	2414	3446	1931	3718
Parr	500	763	447	490	718	1357	5593	5312	3403	6014
Total	650	1665	1488	1618	2983	2736	8023	8758	5334	9732

[1]Efficiency of smolt screen estimated at less than 50% .
[2] Trapping and enumeration later than usual.
**Fence not operated because hydro diversion canal was closed during 1997 and 1999.

Figure 1. Steelhead smolts and parr enumerated at the hydro-diversion bypass on the treated Salmon River.

Big Silver Creek

Big Silver Creek is a large coastal stream located 35 km north of Harrison Hot Springs, B.C. It originated from the Coast Mountains and flows for about 40 km in a southerly direction before emptying into the expansive and highly oligotrophic Harrison Lake. Pre-fertilization conditions were documented in 1992 and 1993 (Toth et al. 1993). It was fertilized in 1994 with 9.5 tonnes of 10-34-0 (ammonium polyphosphate) added in the Middle treatment zone (T1; 13 km upstream from Harrison Lake) and again in 1995 with 9.5 tonnes of 10-34-0. Nitrogen (i.e., 28-0-0) was not required because of the natural high background concentration of dissolved inorganic nitrogen in Big Silver. Approximately the same nutrient load (i.e., 9.5 tonnes of 10-34-0) was added in 1996 and 1997.

In 1995, peak periphyton biomass (measured as chlorophyll *a*) was 4-5 times greater in the Middle (T1, 6 to 13 km from Harrison Lake) but only slightly greater in the Lower treatment zones (T2, 1 to 6 km from Harrison Lake), compared to the control reach (13 to 15 km from Harrison Lake) and to pre-treatment years. Benthic invertebrate biomass increased 2-3 times in T1, and increased spectacularly in T2. Total number of rainbow trout >20 cm per ha was constant in the control. The number increased >3 times in the Middle reach, but only increased about 50% in the Lower reach. Electrofishing surveys indicated juvenile rainbow trout density was similar between the control and fertilized sections; however, the biomass of the juvenile rainbows in the fertilized reach was 20% greater than the biomass from the control reach of the mainstem. Mountain whitefish abundance (a species that only inhabits the lowest reach near the lake) increased > 2 times after fertilization. A P-induced nitrogen limitation probably limited the response of Big Silver to nutrient addition.

Adam River

The Adam River is an oligotrophic coastal trout stream located 80 km northwest of Campbell River on Vancouver Island. It was fertilized in 1994 with 2.3 tonnes of 10-34-0 (ammonium polyphosphate) and 1.03 tonnes of 28-0-0 (urea-ammonium nitrate), added in the lower treatment reach (T2; ~8 km). The river was fertilized again in 1995 with the same type and amount of fertilizer. About the same nutrient load (i.e., 2.3 tonnes of 10-34-0 and 1.03 tonnes of 28-0-0) was added in 1996 and 1997.

Peak periphyton chlorophyll *a* was almost 2 times higher in the post-fertilization period within the unfertilized control and T1, but T2 reach was >4 times higher than in pre-fertilization years. Confounding by forest fertilization may explain the elevated levels in untreated reaches C and T1. Benthic invertebrate biomass was sampled in both spring and summer; a strong increase was evident in summer but not in spring in the T2 fertilized reach. This indicates that it required several weeks to obtain an insect response to increased periphyton accrual. On average, underwater counts of total numbers per ha of rainbow, brown and cutthroat trout >20 cm did not increase in

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the fertilized reach compared to the other reaches until 1997. Also, electrofishing surveys indicated increased juvenile rainbow trout biomass in the fertilized reach compared to the untreated reaches. By 1996, there was evidence of straying of fish from T2 into T1, possibly in response to a food gradient and deep pool availability in low summer flows.

Mesilinka River

The Mesilinka River is a large cool river located in B.C.'s northern interior 280 km north of Prince George. The headwaters originate in the Omenica mountain range and flow for a distance of about 120 km prior to joining B.C.'s largest body of water, the Williston Reservoir. The external control in this project, the Nation River, is located about 100 km south of the Mesilinka River. Fertilization was selected as one of the few practical options for mitigating for loss of habitat in the lower Mesilinka and Omenica Rivers because large reaches of the Parship, Finlay and Peace rivers and their numerous tributaries, were flooded by impounding the Peace system as the expansive Williston Reservoir.

Peak periphyton biomass (measured as chlorophyll *a*) in 1994 was 10 times and 2 times higher in T1 and T2, respectively, than the control reach. By 1994, benthic invertebrate biomass increased 2 times in T1 but less so in T2. Adult fish densities were higher in T1 and T2 following the first year of nutrient treatment, mainly due to a response from mountain whitefish. By 1995-97, fish populations continued to increase in treatment reach T1, but less so in treatment reach T2. Increases in abundance ranged between 1.5 and 3 times, except for highly migrant bull trout in T2 which lagged until a marked increase in 1999. Large rainbow trout (> 30 cm) increased 3 times in both reaches. Given the cold climate and longevity of the target species in the Mesilinka (e.g., bull trout, Arctic grayling), several years of fertilization will likely be required before the overall response is confirmed.

Lessons Learned

- To date, the results of experimental stream fertilization inferred from the response of five streams strongly demonstrate that low-level seasonal addition of limiting nutrients can substantially increase the trophic productivity of oligotrophic streams. (methods including slow release are described in technical circular 9)
- The effective distance of fish growth resulting from nutrient additions was approximately 15 km on average (range 12-15 km) in the Salmon River.
- This technique is applicable to streams with depressed nutrient influxes (lacking salmon carcasses), as well as to increase fish survivals in disturbed watersheds, such as the Salmon River.

Based on : Slaney, P.A. and K.I. Ashley. 1998. Case Studies of Whole-stream Fertilization in British Columbia. Restoration of Fisheries by Enrichment of Aquatic Ecosystems. 1999. pp. 83-98, In: J.G. Stockner and G. Milbrink (Eds.). Proceedings of the International Workshop at Uppsala University, March 30 to April 1, 1998, Uppsala, Sweden. 219 pp.

Update

Conferences

Technologies for New Millenium Forestry, Demo 2000 International. Sept. 11-16, Kelowna, B.C. For updated information, consult the following websites: www.cwfcof.org or www.forestindustry.com. This event is organized every four years, so don't miss it. Approximately 8,000 - 10,000 registrants are expected from over 30 countries.

International Conference on Ecology and Management of Wood in World Rivers. Oct. 23 – 27, 2000. Corvallis, Oregon. Call for papers: abstracts must be received by April 1, 2000. Further information on abstract formatting and registration are available at the conference website at http://riverwood.orst.edu.

Workshops

Watershed Assessment in the Southern Interior of B.C. March 9 and 10, 2000. Penticton Lakeside Resort. Penticton, B.C. The objectives of the workshop are to present recent hydrologic research to assist in watershed analysis in the interior of B.C., to present research on the four main topics included in watershed analysis to enable better watershed assessments, and to present research about topics related to watershed analysis. For registration information, contact April Anderson tel: 250-226-7641.

2000 Interior Forest Site Rehabilitation Workshop in Kamloops on April 12th & 13th, 2000 at the Best Western Towne Lodge. The IFSR will again be an interesting two-day event based around this year's theme "*Results and Accomplishments - toward better forests, stabilized channels and cleaner water*." The emphasis will be on lessons learned over the last 5 years and various projects of the WRP program – what techniques and measures have stood