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Restoring Stream Productivity with Nutri-Stones

Ken Ashley and Sarah Mouldey

Introduction

A recent review of anadromous salmon and trout in B.C. and the Yukon indicated 624 stocks were at high risk, 78 were at moderate risk, 230 were of special concern, and 142 stocks had been extirpated in this century (Slaney et al. 1996). In addition, 43 % (4,172) of the stocks were unable to be classified due to an absence of reliable data. Thus, in the time span of approximately 100 years, wild salmonid stocks in British Columbia and the Yukon have gone from a relatively pristine state to one of numerous stock extinctions and moderate to high risk status for nearly one thousand individual stocks. Although a variety of well documented human impacts have been identified (e.g., habitat degradation associated with logging, hydropower and urbanization were responsible for most of the 142 documented stock extinctions), a poorly understood interactive effect of large scale forest harvesting in concert with industrialized fishing has likely played a key role in the decline of these stocks. The mechanism responsible for the decline is subtle and insidious: a “negative feedback loop” of decreased habitat capability and quality and reduced salmon escapement. This results in further reductions in the influx of salmon carcass-bound nutrients and carbon resulting in further reductions in freshwater productivity and survival of juvenile salmonids. Simply put, anadromous salmon are “nutrient pumps” which transport nutrients from the oceans to the streams, and fewer fish means fewer nutrients, which decreases the ability of the stream to produce salmon and trout. This process, now over a century in progress, is likely increasing in significance as the abundance of wild stocks continues to decline (Larkin and Slaney 1996). An exception to this rule would be watersheds that have received additional spawners due to “enhancement” activities (i.e., hatcheries or spawning channels). This “oligotrophication” threat, although considerably more subtle than the well known negative environmental and fisheries impacts caused by excessive nutrient loading (i.e., cultural eutrophication), is equally threatening to freshwater fish stocks and should be taken seriously (Stockner and MacIsaac 1996).

Fortunately, aquatic scientists in the Pacific Northwest have long speculated on the importance of marine-derived nutrients in maintaining the productivity of oligotrophic lakes and streams. Pioneering whole-lake fertilization experiments were conducted in Alaska in the 1950’s to test the hypothesis that commercial overharvesting of returning salmon could decrease the productivity of sockeye nursery lakes due to interception of the carcass-bound phosphorus supply (Nelson and Edmondson 1955). Similarly, pioneering whole-stream fertilization experiments in British Columbia demonstrated the importance of inorganic nutrients in controlling the growth and survival of juvenile steelhead trout and coho salmon (Slaney et al. 1986). Stable isotope evidence (^{15}N and ^{13}C) has recently confirmed the importance of marine-derived nitrogen and carbon, and by inference phosphorus, in riverine food webs as returning salmon spawners were found to contribute up to 30-40% of the nitrogen and carbon content of juvenile salmonids in small headwater streams (Bilby et al. 1996). In addition, studies in the Olympic peninsula have indicated that large and small

Anderson			Clear			Shovelnose		
Date	%N	%P	Date	%N	%P	Date	%N	%P
28/06	6.7	17.74	21/06	6.7	17.74	22/06	6.7	17.74
13/07	5.18	14.47	04/07	5.19	14.58	06/07	5.28	14.91
25/07	4.96	14.00	18/07	4.87	14.05	19/07	4.85	14.16
11/08	4.88	13.89	02/08	4.73	13.91	01/08	4.93	14.30
22/08	4.88	13.85	16/08	4.68	13.58	17/08	4.77	14.04
08/09	4.89	13.89	01/09	4.68	13.55	30/08	4.71	13.88
22/09	4.83	13.91	12/09	4.67	13.65	13/09	4.76	13.99
05/10	4.79	13.97	27/09	4.68	13.97	26/09	4.67	13.90
Mean	5.14	14.47	Mean	5.02	14.38	Mean	5.08	14.62

Table 1. Percent composition of nitrogen and phosphorus in Nutri-stones over time for Anderson Creek, Clear Creek and Shovelnose Creek for the 1995 field season.

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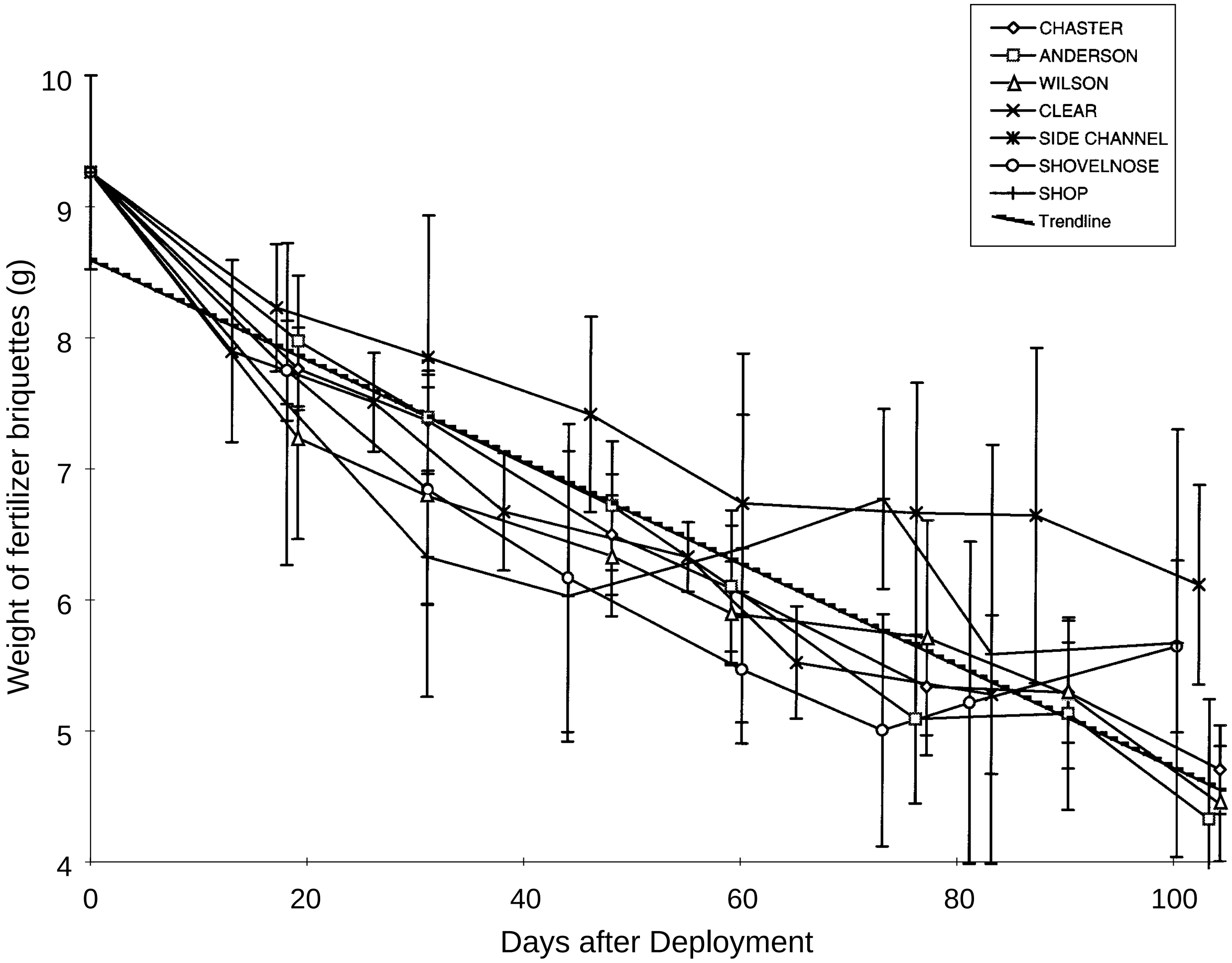

Figure 1. The rate of dissolution of the fertilizer briquettes is demonstrated; the reduction of weight over time is approximately 0.5% per day.

organic debris are the most important instream element for retaining salmonid carcasses, thus allowing decomposition, nutrient recycling, and direct feeding by juvenile salmonids and invertebrates to occur (Cederholm et al. 1988). Therefore, watershed restoration activities should include replacement of instream habitat complexity and nutrients in order to successfully and rapidly rebuild salmonid stocks in watersheds that are nutrient-limited and which have become nutrient depleted due to a historical combination of overfishing and habitat degradation.

Nutri-Stones

In order to restore stream nutrients, B.C. Environment and IMC Vigoro Inc. have cooperatively developed and field tested a solid, slow release fertilizer briquette for use in small streams (i.e., < 10 $m^3 \cdot s^{-1}$ mean summer flows). The idea was simple: to create a fertilizer product that simulated the slow decomposition of decaying salmonids, but contained as much nutrients, mainly phosphorus, as possible. The nutrient content of salmon carcasses is approximately 0.325% P and 3.0% N (wet weight), whereas the 8 gram Nutri-Stone briquettes developed by IMC Vigoro are initially 17.7% P and 6.7% N by weight i.e., approx. 55 times higher P content. The briquettes consist of a magnesium-ammonium phosphate fertilizer with a proprietary binder matrix of unpolymerized saran. This formulation was designed to obtain the highest possible proportion of P yet still slowly release the nutrients over time. The selection of this formulation builds upon previous experience using slow release fertilizers at the Keogh River, B.C. (Slaney et al. 1986). Slow release fertilizer for use in N limited rivers or streams will likely require additional nitrogen content, which is quite feasible. The high P content of the Nutri-Stones significantly reduces the weight of fertilizer required to restore depleted P content in streams as compared to nutrient replacement via salmon carcasses. For example, 500 kg of Nutri-Stones was applied to Shovelnose Creek (B.C.) in 1995 to achieve a P load of 87.4 kg. The equivalent P load of

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salmon carcasses would have been approximately 27 tonnes. In situations where stream access is by air only, inorganic nutrients are the only cost-effective nutrient replacement option. For example, three tonnes of slow release fertilizer was recently applied to the very infertile Cruickshank River and tributaries (near Comox Lake, B.C.) in three hours by helicopter, to obtain a P load of 524 kg P. The equivalent P load in salmon carcasses would have been approximately 164 tonnes, and with a helicopter lift capacity of 500 kgs (e.g., A-Star), the treatment would have taken 328 trips over several days and would not have been an economically or logistically feasible option. This is not to imply that salmon carcasses are not a valuable source of nutrients. We are currently exploring techniques for applying salmon carcasses to streams when available, within the constraints mandated by the Federal-Provincial Transplant Committee to ensure potential salmonid diseases are not transferred between watersheds.

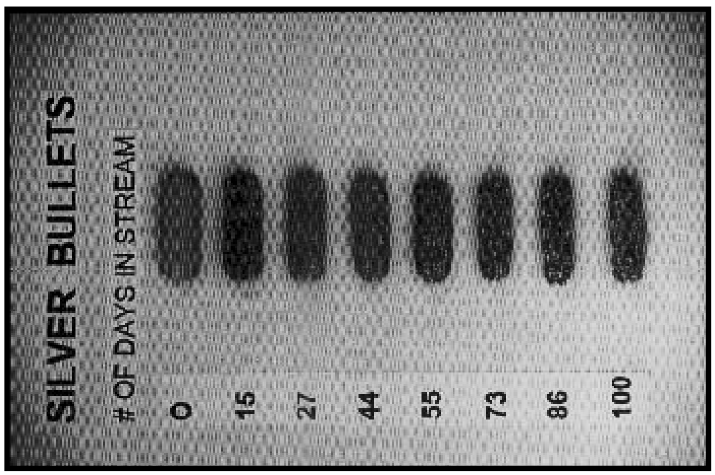

Figure 2. Appearance of slow release fertilizer briquettes from Day 0 to Day 100 in a stream.

Philosophy of Nutrient Replacement

The underlying philosophy of stream fertilization is to provide an interim supply of nutrients until the ecosystem recovers to its historical state. Therefore, a successful fertilization project is one in which external nutrient additions can eventually be reduced or discontinued altogether as natural nutrient inputs from riparian vegetation and anadromous salmonids gradually recover. Ecosystem recovery, from a watershed perspective, requires restoration of several interrelated components: (1) stabilization of upslope erosion and/or reduction in sediment inputs from hillslopes, gullies and roads; (2) stabilization of river channel(s); (3) restoration of large woody debris in the channel in the short term (4) regrowth of a riparian mix of deciduous and mature coniferous trees in the long term to supply new large woody debris into the stream/river channel and (5) rebuilding of wild stock escapements (Slaney and Martin 1997). The degree to which nutrient additions can be reduced is also dependent on some key external factors, namely variation in ocean productivity and sustainable management of the commercial fishery to allow sufficient escapement of spawners. Therefore, fertilization should be viewed as an interim measure which is most effective if all components of ecosystem recovery and key external factors are achieved in a coordinated fashion. A detailed description on the use of Nutri-Stones is included in Chapter 13 of Slaney and Zaldokas (1997).

Field Testing

This unique product has been subjected to a variety of laboratory tests to determine the effect of pH, alkalinity, hardness, iron, humics, water velocity and temperature on the release rates of N and P (Sterling 1997). An extensive series of field trials indicate the briquettes dissolve at approximately $0.5\% \cdot day^{-1}$ (Figure 1), a rate which is relatively independent of stream characteristics. The briquettes retain their shape and consistency even after 100 days in the stream (Figure 2), and their chemical composition remains relatively constant over time. This ensures that the release rates and target nutrient concentrations do not vary due to unequal loss rates of phosphorus or nitrogen (Table 1). Preliminary trials in 1995 resulted in under-application of briquettes due to lower than anticipated release rates, so target concentrations were only 32% of the target concentration of 3 $\mu g \cdot L^{-1}$ P (or 3 parts per billion). Regardless, several streams responded with 27% of streams showing a significant increase in soluble reactive phosphate and 53% showing increased periphyton biomass (Figure 3; Figure 4) (Mouldey and Ashley 1996). The field trials were repeated in 1996 with re-calculated amounts of briquettes to achieve a target loading of 3 $\mu g \cdot L^{-1}$ P, and the results are being analyzed.

Bioassay Testing

As a safeguard, we conducted bioassay tests to determine the toxicity of the IMC Vigoro 7-40-0 Magnaphos fertilizer to rainbow trout and a series of planktonic and benthic organisms (EVS 1997). The lab tests indicate the toxicity of the product was primarily related to the ammonia content of the briquette, which was not unexpected. The stock solution the lab used contained approximately 1 $g \cdot L^{-1}$ of 7-40-0 Magnaphos, and most of the tests

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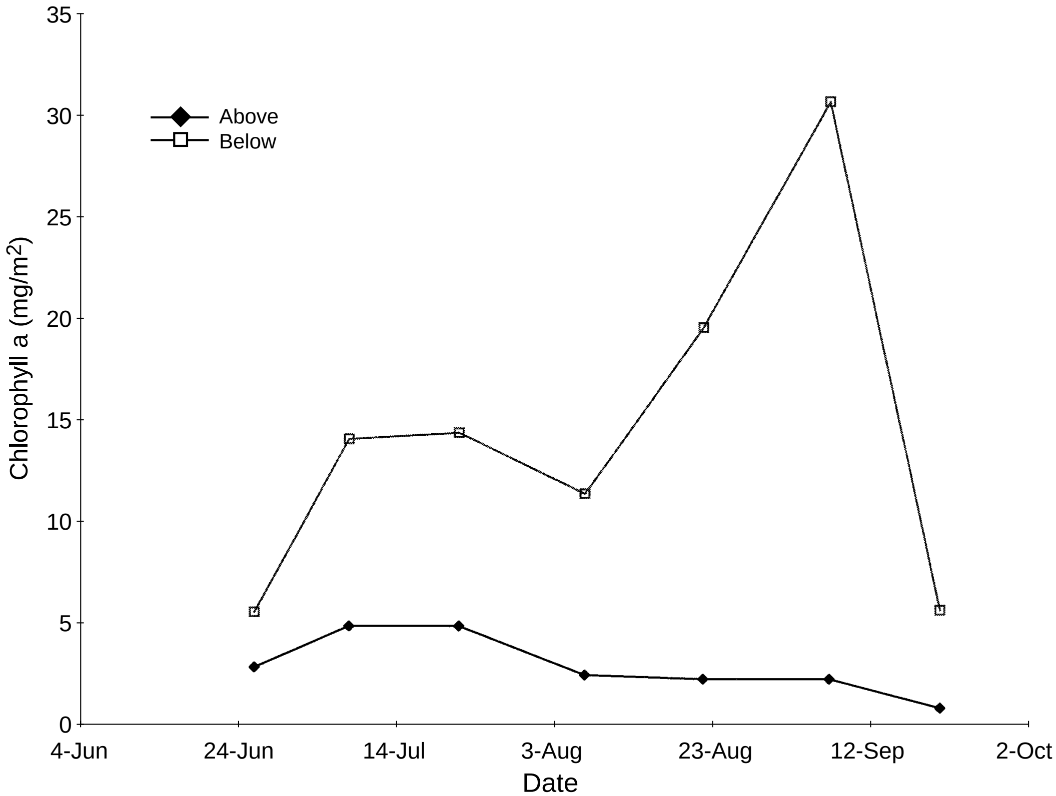

Figure 3. Periphyton biomass responded with a significant increase when briquettes were applied in Shop Creek in 1996 (measured by a chlorophyll a method).

were non-toxic at a dilution of 12.5 %, or 125 mg.L^{-1}. Because all applications will be in the range of 3-5 µg.L^{-1} (i.e., 3-5 ppb), the resultant concentrations in the water will be several orders of magnitude lower, thus toxicity will never be a concern.

Further Developments

Research plans for the upcoming 1997 field season involve developing and field testing a high nitrogen briquette for use in N-limited streams, and developing spreader systems for manual and helicopter application. If additional research funding is secured, experiments will also begin to determine if Nutri-Stones can be used to fertilize riparian zones to increase the regrowth of riparian vegetation and thus reduce the time required for logging-impacted riparian zones to recruit large woody debris into the stream channel. Ideally, through an integrated strategy of salmon harvest management, watershed restoration, and stewardship, depressed wild salmonid stocks can be rebuilt to their historical levels of abundance.

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Technical Tips

Figure 4. Rocks from above the fertilizer site are barren of algae, while those below are coated in diatoms.

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Securing Instream Structures: Epoxy Attachment Method

The Importance of LWD for Fish Habitat

Large woody debris (LWD) in a stream channel can function hydraulically in two ways. Streamflows accelerate around the LWD, creating localized scour and pockets of deeper water near to it. (A similar process occurs with boulders within a stream channel.) As a weir or “mini-dam”, LWD can impound water upstream (causing substrate build-up, or aggradation) and create a deep plunge pool immediately downstream as the water cascades over it. In either case, fish habitat may be improved through the creation of locations where fish can hold their position or hide from predators, and through the potential build-up of spawning gravels. Additional functions of LWD include:

- Stabilization of streambanks by armoring
- Provision of overhead cover from predators
- Storage and supply of detritus and leaf-litter for food-chains
- Retention of spawner carcasses (sources of nutrients and food)
- Provision of substrate for growth of fungi, bacteria and algae, important links in fish food-chains

Keogh River Watershed Restoration Project, Vancouver Island

Caroline Melville

In the summer of 1996, 119 large wood and boulder structures were constructed on the Keogh River. These structures replace large woody debris (LWD) that are naturally present in old growth and recently logged watersheds, but noticeably absent from streams in watersheds logged over 20 years ago. On the first pass of restoration of LWD, risk of loss or damage to structures is reduced by some form of anchoring (*see pg. 10 of Streamline Vol.1 #1*).

To anchor the LWD, it was attached to large boulders (>.6 m diameter) by galvanized cable (1/2 inch). The cable was passed through the drilled holes in the logs and glued to the boulders using a Hilti HIT-MD2000 kit with HY 150 epoxy (Hilti Canada Ltd. 7860 Venture St. Burnaby, B.C V5A-1V3). The attachment was durable through several freshet events

Figure 1. Boulders must be cleaned thoroughly using a wire brush and fluid sucker until the water runs clear.