White Paper No. 6[1]

Nutrient Enhancement of Freshwater Streams to Increase Production of Pacific Salmon

1 Introduction

The purpose of this paper is to inform resource managers about the use of stream nutrient enhancement as a tool for increasing survival of juvenile salmonids. Nutrient enhancement is widely recognized as a benefit to natural salmonid stocks. Lack of sufficient stream nutrients can be a limiting factor in the recovery of salmonid populations. In-stream nutrients are usually derived from the disintegration of spawned-out salmon carcasses. In the absence of sufficient naturally occurring carcasses, additional nutrification may be needed. The HSRG advocates nutrient enhancement of streams while recognizing that some methods, such as the use of salmon carcasses, carries the risk of disease transmission. This paper contains a review of existing literature on the development, use, and evaluation of stream nutrient enhancement. Recommendations based on the literature review are presented.

2 Background

Pacific salmon and steelhead once contributed large amounts of marine-derived carbon, nitrogen, and phosphorus to freshwater ecosystems in the Pacific Northwest. These nutrients are no longer available in the historic quantities because fewer adult fish are returning to freshwater systems.

To compensate for reduced nutrient load and resultant lowered stream productivity, recent mitigation efforts have focused on addition of nutrients to freshwater systems. The two methods for adding nutrients are 1) allocation of larger fish escapements and 2) artificial nutrient enhancement.

1. *Larger Escapement Allocation*. The concept behind larger allocations is that more adult salmonids returning to the streams will result in a higher natural nutrient load. Re-evaluation of escapement goals would generally require escapements that are 2 to 15 times higher than those currently allocated (Bilby et al. 2001; Knudsen, Symmes, and Margraf 2003; Michael 1998; Michael 2003; Peery, Kavanagh, and Scott 2003). Nonetheless, this method should be considered during the decision-making process. A possible added benefit of larger escapements would be reduction in stream siltation because more fish would dig more spawning redds.[2] However, increasing escapements with only hatchery-origin fish will negatively affect the reproductive success of wild fish, and therefore must be considered in the context of other HSRG broodstock management recommendations.

[1] White papers were prepared by the HSRG to address topics relevant to hatchery reform. They are intended to stimulate discussion and provide background, documentation and explanations not included in the body of the HSRG's report.

[2] Digging redds disturbs silted substrates, allowing fines to be washed away. Redds which are not affected by siltation are generally more successful.

2. *Artificial nutrient enhancement*. There are three methods of artificially enhancing nutrient loads: direct application of fertilizers, the application of "carcass analogs", and the distribution of salmonid carcasses from fish hatcheries.

The first method involves application of fertilizer to increase wild fish production. This method has been used in the Pacific Northwest for years. Currently, there are two methods in use. One involves the introduction of liquid fertilizer into the water, either through large "slug" doses or through low level drip. The second involves the placement of solid fertilizer pellets that dissolve at a predetermined rate, releasing nutrients over a period of months. Both methods have been shown to cause substantial increases in fish growth, survival, condition factors, etc. Water quality monitoring has shown that the fertilizers are rapidly taken up into the food chain and are generally not detectable in the water column outside of the treatment area/reach. This method of fertilization is widely used and described in the literature.

The remainder of the discussion in this paper is focused on nutrient enhancement using carcass analogs and salmonid carcasses.

3 Findings

3.1 Why Nutrient Enhancement

Returning anadromous salmon are an important source of marine-derived nutrients (MDN) and serve as the primary method of nutrient transport for freshwater ecosystems in the Pacific Northwest (Cederholm et al. 1999; Naiman et al. 2002). MDN have been detected in a variety of aquatic and terrestrial plants and wildlife (Gende et al. 2002; Hicks et al. 2005) including aquatic insects (Lessard and Merritt 2006), mosses and liverworts (Wilkinson, Hocking, and Reimchen 2005), and birds and mammals (Jauquet et al. 2003). It is clear that MDN are an integral part of properly functioning anadromous ecosystems. The level of MDN in an anadromous system depends upon the returning salmon runs: the reduced run sizes have decreased the nutrient input to the streams. Today, most ecosystems with anadromous salmon are considered to be in a "nutrient deficit" (Gresh, Lichatowich, and Schoonmaker 2000). This lack of nutrients could be one of the factors limiting recovery either directly and indirectly in many salmon streams. Nutrient enhancement may, therefore, be an important component of a holistic recovery program.

3.2 Benefits of Nutrient Enhancement

Studies have shown that addition of salmon carcasses has little effect on primary production in nutrient-rich streams. In oligotrophic (nutrient-poor) systems, however, primary production often increases in response to the addition of nitrogen and phosphorus, two of the main nutrients transported by salmonids. Increased primary production has a cascading effect through the food chain (Kline et al. 1990; Kohler, Rugenski, and Taki 2008). Invertebrate production increases in response to the increased food, and these in turn provide more food for fish and other aquatic animals. Marine derived nutrients from salmon carcasses have been detected in many species of birds and mammals, and some seem to rely heavily on salmon carcasses (Ben-David 1997; Ben-David et al. 1997; Cederholm et al. 1999; Jauquet et al. 2003). Carcass dispersal and scavenging can facilitate the transfer of MDN to riparian environments (Meehan, Seminet-Reneau, and Quinn 2005).

The increase in food through invertebrate production and direct consumption of the salmon carcasses and eggs results in significant increases in growth of juvenile salmonids (Bilby et al. 1998; Lang et al. 2006) and other fishes (Wipfli et al. 2003). Larger size seems to confer some over-winter survival advantage, although the relationship between larger size and survival is complicated by size-independent factors that affect survival, such as water flow, winter temperature, and food availability (Connolly and Petersen 2003; Ebersole et al. 2006; Lang et al. 2006; Quinn and Peterson 1996). Larger juvenile salmonids also tend to survive to maturity at higher rates than smaller juveniles (Bilton, Alderdice, and Schnute 1982; Henderson and Cass 1991; Holtby, Andersen, and Kadowaki 1990; Koenings, Geiger, and Hasbrouck 1993; Tipping 1986; Tipping 1997; Ward et al. 1989), although this is also a relationship complicated by other factors that affect survival, most notably ocean conditions.

While these findings imply that the addition of MDN to streams would improve the survival (and subsequent run size) of anadromous salmon, this hypothesis has not yet been tested. In addition, it is likely that the effects would be complicated by other factors. It is also clear that the reduced MDN is usually only one of many issues limiting the recovery of anadromous salmon, all of which would likely need to be addressed for successful recovery.

3.3 Carcasses vs. Carcass Analogs

The generally positive ecosystem responses to the addition of salmon carcasses has prompted resource managers to begin distributing carcasses of adults returning to hatcheries into rivers and streams of the Pacific Northwest. In its regional hatchery reviews, the HSRG observed inconsistent use of carcass distribution among and within agencies. Some hatcheries distributed all of their available carcasses while others buried them all in landfills. For hatcheries that do distribute salmon carcasses, volunteer groups have been found to be a cost-efficient and effective distribution method.

Because sufficient carcasses may not be available, and because they can be relatively inconvenient to distribute, and represent a source of disease transmission (see below), researchers have developed carcass analogs as a substitute. Carcass analogs are essentially pellets made from dried spawned-out salmon (Pearsons, Roley, and Johnson 2007) which are treated to kill disease organisms. The fish pellets lack the variety of tissues available from carcasses, and may be consumed more quickly than carcasses. Therefore, analogs may not benefit as many organisms as carcasses. However, analogs are much easier to transport and distribute, they can be stored as needed, and, because they are disease-free, they can be transferred between watersheds. The few studies focusing on carcass analog use compared to fish carcasses have found the analogs to be effective and convenient (Mesa et al. 2007; Wipfli, Hudson, and Caouette 2004; Zendt and Bill 2006).

3.4 Risks Associated with Nutrient Enhancement

Enhancement appears to be a useful tool for raising the nutrient level in freshwater systems. It is, however, not without its risks. The primary risks are disease transmission (with carcasses), introduction of contaminants, and over-nutrification.

3.4.1 *Disease transmission*

The distribution of salmon carcasses represents a potential vector for disease transmission. To reduce this risk, the HSRG recommends the following:

- Certify that adult broodstock is free of viral pathogens before planting. The adult sampling level should be a minimum of 60 fish for carcass plantings within the same watershed and 150 fish for plantings in different watersheds within the same fish health management zone.
- Freeze carcasses before planting to reduce the infectious titers of pathogenic organisms in the salmon carcasses. This measure will decrease the risk of transmission of certain disease organisms (Evelyn 2001; Margolis 1977).
- Plant carcasses only within the historic range of the species being used for nutrient enhancement.
- Do not plant adults or juveniles which may have died of infectious disease. This includes pre-spawning adult mortalities and juvenile mortalities from hatchery ponds.

3.4.2 Contaminant deposition

There is growing evidence that adult salmon transport contaminants from the marine environment back into freshwater. For example, it has been shown that large numbers of spawning salmon can increase the levels of PCBs in a stream well above background levels (Compton et al. 2006; Krummel et al. 2005; Krummel et al. 2003; Missildine 2005). The risk of introducing contaminants along with nutrients needs to be considered for each stream system.

3.4.3 Over-nutrification

Though the level of marine-derived nutrients has dropped in many streams, some nutrients are entering streams as a result of human activity. Phosphorus in particular can be increased by human activity adjacent to streams. Therefore, nutrient enhancement, particularly in the spring and summer when temperatures are warmer and there are more hours of sunlight, could exacerbate algal blooms and negatively affect fish production (Compton et al. 2006). Furthermore, the nutrient additions may cause the receiving waters to exceed guidelines established in the Clean Water Act.

4 Recommendations

The literature indicates that artificial enhancement can be of great benefit in raising the level of nutrients in freshwater systems. The methods endorsed by the HSRG are distribution of adult hatchery carcasses or carcass analogs. Certain guidelines and protocols should be applied to all nutrient enhancement projects. Nutrification projects require careful planning and evaluation to ensure that the resources are used wisely and that the risks to the resource are understood. There is widespread agreement in the published literature that haphazard distribution of carcasses or analogs does not optimize this management tool and may, in some cases, be counter-productive. Opportunities to understand the effects of distribution programs will be missed without including evaluation as part of the projects.

Comprehensive protocols and guidelines for nutrient enhancement have been developed by Ashley and Stockner (2003), Washington Department of Fish and Wildlife3 and Fisheries and Oceans Canada4. These protocols and guidelines can be adapted to local

[3] http://wdfw.wa.gov/hab/ahg/shrg_t11.pdf
[4] http://www-heb.pac.dfo-mpo.gc.ca/publications/pdf/carcass_guide_e.pdf

needs. Programs should be followed up with a thorough evaluation to ensure the intended goals are being met.

5 References

Ashley, K. I., and J. G. Stockner. 2003. Protocol for applying limiting nutrients to inland waters. Pages 245-258 *in* Nutrients in salmonid ecosystems: Sustaining production and biodiversity.

Ben-David, M. 1997. Timing of reproduction in wild mink: The influence of spawning Pacific salmon. *Canadian Journal of Zoology* **75**(3):376-382.

Ben-David, M., T. A. Hanley, D. R. Klein, and D. M. Schell. 1997. Seasonal changes in diets of coastal and riverine mink: The role of spawning Pacific salmon. *Canadian Journal of Zoology* **75**(5):803-811.

Bilby, R. E., B. R. Fransen, P. A. Bisson, and J. K. Walter. 1998. Response of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) to the addition of salmon carcasses to two streams in southwestern Washington, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **55**(8):1909-1918.

Bilby, R. E., B. R. Fransen, J. K. Walter, C. J. Cederholm, and W. J. Scarlett. 2001. Preliminary evaluation of the use of nitrogen stable isotope ratios to establish escapement levels for Pacific salmon. *Fisheries* **26**(1):6-14.

Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon *Oncorhynchus kisutch* on returns at maturity. *Canadian Journal of Fisheries and Aquatic Sciences* **39**(3):426-447.

Cederholm, C. J., M. D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries* **24**(10):6-15.

Compton, J. E., C. P. Andersen, D. L. Phillips, J. R. Brooks, M. G. Johnson, M. R. Church, W. E. Hogsett, M. A. Cairns, P. T. Rygiewicz, B. C. McComb, and C. D. Shaff. 2006. Ecological and water quality consequences of nutrient addition for salmon restoration in the Pacific Northwest. *Frontiers in Ecology and the Environment* **4**(1):18-26.

Connolly, P. J., and J. H. Petersen. 2003. Bigger is not always better for overwintering young-of-year steelhead. *Transactions of the American Fisheries Society* **132**(2):262-274.

Ebersole, J. L., P. J. Wigington, Jr., J. P. Baker, M. A. Cairns, M. R. Church, B. P. Hansen, B. A. Miller, H. R. LaVigne, J. E. Compton, and S. G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. *Transactions of the American Fisheries Society* **135**(6):1681-1697.

Evelyn, T. T. P. 2001. The effects of chilling, freezing and cold-smoking on the infectious titre of certain microbial fish pathogens that may occasionally be present in marketed salmon flesh. Pages 225-229 *in* C. J. Rodgers, editor. Risk Analysis in Aquatic Animal Health. Proceedings of an International Conference, Paris, France, 8-10 February 2000.

Gende, S. M., R. T. Edwards, M. F. Willson, and M. S. Wipfli. 2002. Pacific salmon in aquatic and terrestrial ecosystems. *BioScience* **52**(10):917-928.

Gresh, T., J. Lichatowich, and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. *Fisheries* **25**(1):15-21.

Henderson, M. A., and A. J. Cass. 1991. Effect of smolt size on smolt-to-adult survival for Chilko Lake British Columbia Canada sockeye salmon *Oncorhynchus nerka*. *Canadian Journal of Fisheries and Aquatic Sciences* **48**(6):988-994.

Hicks, B. J., M. S. Wipfli, D. W. Lang, and M. E. Lang. 2005. Marine-derived nitrogen and carbon in freshwater-riparian food webs of the Copper River Delta, southcentral Alaska. *Oecologia* **144**(4):558-569.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon *Oncorhynchus kisutch*. *Canadian Journal of Fisheries and Aquatic Sciences* **47**(11):2181-2194.

Jauquet, J., N. Pittman, J. A. Heinis, S. Thompson, N. Tatyama, and J. Cederholm. 2003. Observations of chum salmon consumption by wildlife and changes in water chemistry at Kennedy Creek during 1997-2000. Pages 71-88 *in* Stockner, J., editor. Nutrients in salmonid ecosystems: Sustaining production and biodiversity. Symposium 34. American Fisheries Society, Bethesda, Maryland.

Kline, T. C., J. J. Goering, O. A. Mathisen, P. H. Poe, and P. L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon .1. Delta-N-15 and Delta-C-13 evidence in Sashin Creek, Southeastern Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* **47**(1):136-144.

Knudsen, E. E., E. W. Symmes, and F. J. Margraf. 2003. Searching for a life history approach to salmon escapement management. Pages 261-276 *in* Stockner, J., editor. Nutrients in salmonid ecosystems: Sustaining production and biodiversity. Symposium 34. American Fisheries Society, Bethesda, Maryland.

Koenings, J. P., H. J. Geiger, and J. J. Hasbrouck. 1993. Smolt-to-adult survival patterns of sockeye salmon (*Oncorhynchus nerka*): Effects of smolt length and geographic latitude when entering the sea. *Canadian Journal of Fisheries and Aquatic Sciences* **50**(3):600-611.

Kohler, A. E., A. Rugenski, and D. Taki. 2008. Stream food web response to a salmon carcass analogue addition in two central Idaho streams. *Freshwater Biology* **53**(3):446-460.

Krummel, E. M., I. Gregory-Eaves, R. W. Macdonald, L. E. Kimpe, M. J. Demers, J. P. Smol, B. Finney, and J. M. Blais. 2005. Concentrations and fluxes of salmon-derived polychlorinated biphenyls (PCBs) in lake sediments. *Environmental Science & Technology* **39**(18):7020-7026.

Krummel, E. M., R. W. Macdonald, L. E. Kimpe, I. Gregory-Eaves, I. M. J. Demers, J. P. Smol, B. Finney, and J. M. Blais. 2003. Delivery of pollutants by spawning salmon - Fish dump toxic industrial compounds in Alaskan lakes on their return from the ocean. *Nature* **425**(6955):255-256.

Lang, D. W., G. H. Reeves, J. D. Hall, and M. S. Wipfli. 2006. The influence of fall-spawning coho salmon (*Oncorhynchus kisutch*) on growth and production of juvenile coho salmon rearing in beaver ponds on the Copper River Delta, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* **63**(4):917-930.

Lessard, J. L., and R. W. Merritt. 2006. Influence of marine-derived nutrients from spawning salmon on aquatic insect communities in southeast Alaskan streams. *Oikos* **113**(2):334-343.

Margolis, L. 1977. Public health aspects of codworm infection: a review. *Journal of the Fisheries Research Board of Canada* **34**(7):887-898.

Meehan, E. P., E. E. Seminet-Reneau, and T. P. Quinn. 2005. Bear predation on Pacific salmon facilitates colonization of carcasses by fly maggots. *American Midland Naturalist* **153**(1):142-151.

Mesa, M. G., C. D. Magie, T. C. Robinson, E. S. Copeland, and P. J. Connolly. 2007. Nutrient assessment in the Wind River watershed: Report of phase III activities in 2006. Prepared for Lower Columbia Fish Enhancement Group and Lower Columbia Fish Recovery Board.

Michael, J. H. Jr. 1998. Pacific salmon spawner escapement goals for the Skagit river watershed as determined by nutrient cycling considerations. *Northwest Science* **72(**4):239-248.

Michael, J. H., Jr. 2003. Toward new escapement goals: Integrating ecosystem and fisheries management goals. Pages 277-282 *in* J. Stockner, editor. Nutrients in salmonid ecosystems: Sustaining production and biodiversity. Symposium 34. American Fisheries Society, Bethesda, Maryland.

Missildine, B. 2005. Salmon carcass deployment: A potential pathway for PCB contamination. *Fisheries* **30**(1):18-19.

Naiman, R. J., R. E. Bilby, D. E. Schindler, and J. M. Helfield. 2002. Pacific Salmon, Nutrients, and the Dynamics of Freshwater and Riparian Ecosystems. *Ecosystems* (2002)5: 399-417.

Pearsons, T., D. Roley, and C. Johnson. 2007. Development of a carcass analog for nutrient restoration in streams. *Fisheries* **32**(3):114-124.

Peery, C. A., K. L. Kavanagh, and J. M. Scott. 2003. Pacific salmon: setting ecologically defensible recovery goals. *BioScience* **53**(7):622-623.

Quinn, T. P., and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. *Canadian Journal of Fisheries and Aquatic Sciences* **53**(7):1555-1564.

Tipping, J. 1986. Effect of release size on return rates of hatchery sea-run cutthroat trout. Progressive Fish-Culturist 48(3):195-197.

_____, J. M. 1997. Effect of smolt length at release on adult returns of hatchery-reared winter steelhead. *Progressive Fish-Culturist* **59**(4):310-311.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout *Oncorhynchus mykiss* back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River British Columbia Canada. *Canadian Journal of Fisheries and Aquatic Sciences* **46**(11):1853-1858.

Wilkinson, C. E., M. D. Hocking, and T. E. Reimchen. 2005. Uptake of salmon-derived nitrogen by mosses and liverworts in coastal British Columbia. *Oikos* **108**(1):85-98.

Wipfli, M. S., J. P. Hudson, and J. P. Caouette. 2004. Restoring productivity of salmon-based food webs: Contrasting effects of salmon carcass and salmon carcass analog additions on stream-resident salmonids. *Transactions of the American Fisheries Society* **133**(6):1440-1454.

Wipfli, M. S., J. P. Hudson, J. P. Caouette, and D. T. Chaloner. 2003. Marine subsidies in freshwater ecosystems: Salmon carcasses increase the growth rates of stream-resident salmonids. *Transactions of the American Fisheries Society* **132**(2):371-381.

Zendt, J., and B. Sharp. 2006. Influences of stocking salmon carcass analogs on salmonids in Klickitat River tributaries. 2001-2005 Completion Report, Project No. 200105500, 25 electronic pages (BPA Report DOE/BP-00007534-1).