# Nutrient Enhancement of Freshwater Streams to Increase Production of Pacific Salmon

## Introduction

This white paper is intended for resource managers and will discuss the use of stream nutrient enhancement as a tool for increasing survival of juvenile salmonids. It is becoming widely recognized that nutrient enhancement can have a positive benefit to natural salmonid stocks. In streams where the number of returning salmon are dwindling, the lack of nutrients may be one of the factors limiting recovery. The HSRG advocates nutrient enhancement to replenish nutrient levels in the absence of enough naturally seeded carcasses. The HSRG also recognizes the possibility of, and consequences of disease transmission from carcasses.

The objectives of this white paper are:

- review and summarize existing literature describing the development, use, and evaluation of stream nutrient enchancement;
- describe areas of uncertainty;
- provide recommendations.

### Definition of the Topic

The declining abundance of wild salmonid populations in the Pacific Northwest can be attributed to a combination of factors. Restoring populations to levels capable of sustaining consumptive fisheries will require addressing all these issues. 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. Increasing the nutrient levels in freshwater streams has been studied and implemented to mitigate for the reduced nutrient load and lowered stream productivity. There are two methods for doing this:

1 Allocating larger escapements so that returning adults can transport nutrients naturally.

  Reevaluating escapement goals to provide for nutrient transport has been proposed and would generally require escapements that are 2 to 15 times higher than those currently allocated (Bilby et al. 2001; Knudsen et al. 2003; Michael 1998; Michael 2003; Peery et al. 2003). The use of live fish has the added benefit of reducing siltation in the rivers through their red-digging activities. Achieving these escapements in many areas would be possible only with hatchery fish, which could in turn negatively affect the reproductive success of wild fish in those rivers, and it must therefore be considered in the context of other HSRG recommendations. This issue deserves attention but will not be expanded here.

2 Artificial nutrient enhancement:
   a. Application of fertilizers: The application of fertilizer to increase wild fish production has been conducted in the Pacific Northwest for years. Currently, there are two methodologies 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, and the like. Water quality monitoring associated with the application of these fertilizers has shown that they 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 but will not be further discussed here.
   b. Application of carcass analogs
   c. Distribution of salmonid carcasses from fish hatcheries

# Findings

## Why Nutrient Enhancement?

There is general agreement that returning anadromous salmon represent an important source of transporting marine derived nutrients (MDN) into freshwater ecosystems in the Pacific Northwest (Cederholm et al. 1999; Naiman et al. 2002). These MDN are detected in a wide 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 et al. 2005), birds and mammals (Jauquet et al. 2003). It follows that MDN are an integral part of a properly functioning ecosystem with anadromous salmon. Because the size of the salmon runs have declined in comparison to historic levels, the quantity of MDN has also declined. Streams are therefore generally thought to be in nutrient deficit (Gresh et al. 2000). In many salmon streams, this lack of nutrients could be one of the factors limiting recovery either directly and indirectly. Nutrient enhancement may therefore be an important component of a wholistic recovery program.

## Benefits of Nutrient Enhancement

In oligotrophic (nutrient-poor) systems primary production often increases in response to the addition of nitrogen and phosoporus (two of the main nutrients transported by salmonids) However, carcasses have little effect on primary production in nutrient-rich streams. When primary production does increase, it can have a cascading effect through the food chain (Kline et al. 1990; Kohler et al. 2008). Invertebrate production increases in response to the increased food, and these in turn provide more food for fish and other aquatic animals.

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, but the relationship between larger size and survival is complicated by other effects (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 et al. 1982; Henderson and Cass 1991; Holtby et al. 1990; Koenings et al. 1993; Tipping 1986; Tipping 1997; Ward et al. 1989), but again, this is a complicated relationship, affected by many other factors. While these findings imply that the addition of MDN to streams would improve the survival and thus the run-size of anadromous salmon (i.e. that there is a positive feedback loop), this hypothesis has not yet been tested, and it is certain that the effects would be complicated by many other factors. It is also clear that the reduction is MDN is usually only one of many issues limiting the recovery of anadromous salmon, all of which would need to be addressed for successful recovery.

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 et al. 2005).

## Carcasses vs. Carcass Analogues

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. Volunteer groups have been found to be a cost-efficient and effective method for distributing hatchery carcasses thoughout a watershed.

Because sufficient carcasses may not be available, can be relatively inconvenient to distribute, and represent a source of disease transmission, researchers have develop carcass analogues as a substitute. Carcass analogues are essentially dried fish pellets (Pearsons et al. 2007) that are also treated to kill disease organisms. The analogues lack the variety of tissues available from carcasses, and may be consumed more quickly than carcasses. However, they 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. A few studies have compared the performance of carcasses and carcass analogues ((Mesa et al. 2007; Wipfli et al. 2004; Zendt and Bill 2006) and found the analogues to be effective and convenient.

## Risks Associated with Nutrient Enhancement

Disease transmission: The distribution of 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 of these 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 that may have died of infectious disease. This includes pre-spawning adult mortalities and juvenile mortalities from hatchery ponds.

Contaminant deposition: There is growing evidence that adult salmon transport contaminants from the marine environment back into freshwater, and that large numbers of spawning salmon can increase the levels of PCBs well above background levels (Compton et al. 2006; Krummel et al. 2005; Krummel et al. 2003; Missildine 2005). The risk of depositing contaminants in carcasses needs to be weighed against the benefits.

Over-nutrification: While many streams have less MDN, human activity around streams has increased the levels of some nutrients, particularly phosphorus. 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 addition of nutrients may exceed guidelines established in the Clean Water Act. While those guidelines are not necessarily established with a full understanding of the ecosystem, a lack of compliance with the guidelines will need to be addressed by resource managers.

## Recommendations:

The HSRG strongly endorses nutrification through the use of adult hatchery carcasses or carcass analogs. Regardless of whether the nutrients are supplied through the use of carcasses or carcass analogues, certain guidelines and protocols should be applied to all nutrient enhancement projects. These 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 analogues does not optimize this management tool and may in some cases be counter-productive. Widespread distribution without evaluation further misses opportunities to understand the effects of the program.

Comprehensive protocols and guidelines for nutrient enhancement have been developed by (Ashley and Stockner 2003) and by Washington Department of Fish and Wildlife and Fisheries and Oceans Canada. These can be adapted to local needs. Programs should be followed up with a thorough evaluation to ensure the intended goals are being met.

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