# Effect of Salmon Carcass Seeding for Nutrient Enrichment on the Macroinvertebrate Community of Pine Creek, Mount St. Helens National Volcanic Monument, Washington

### Progress Report February 2009

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## Summary

Dams constructed on the Lewis River in the southern Washington Cascades have provided a barrier to anadromous salmon and steelhead trout migration for 80 years. Pine Creek in the upper Lewis River watershed above dams was historically an important spawning habitat for salmonids. As a result of dam relicensing agreements, anadromous salmonids populations are to be returned to the Pine Creek basin starting in 2012. Pine Creek is a cold, oligotrophic stream system with only moderate benthic invertebrate standing crops, and an important food source for juvenile anadromous and resident salmonids.

In anticipation of the 2012 reintroduction of runs, a project has been initiated to distribute salmon carcasses along the stream channel to boost nutrients and hopefully benthic invertebrate production. Carcass seeding has occurred in December 2006, 2008 and 2009, with several more years of seeding planned. Due to poor returns in 2007, carcasses were not available from the participating hatchery. Benthic invertebrate standing crops were assessed in October 2006 (baseline before carcass enrichment), October 2007 (1 year of enrichment) and October 2009 (2 years of enrichment), at four Pine Creek mainstem and one tributary station receiving enrichment, and one control tributary station that was not seeded with carcasses.

During the course of this project the Pine Creek basin experienced a major flood in November 2006 that caused extreme bedload movement throughout the basin and destruction of riparian vegetation along sections of the mainstem, but not at the tributary stations. Consequently, nutrient enrichment following the flood at mainstem stations may be coming from two sources, carcass seeding, and also from increased algal production due to the more open nature of the stream channel. Preliminary observations on standing crops of benthic invertebrates and how densities may be affected by salmon carcass nutrient enrichment are presented here. Several more years of monitoring are planned to track trends.

- The November 2006 flood caused a catastrophic decline of 65-92% in benthic macroinvertebrate densities at the six Pine Creek stations, as measured 11 months later in October 2007.

- By October 2009, nearly three years after the flood and after two years of carcass seeding, total macroinvertebrate densities had increased by about an order of magnitude over those seen in October 2007.

- Comparing October 2009 (after two years of enrichment) total macroinvertebrate densities with the October 2006 (baseline, pre-enrichment), densities were: 1.8 to 2.5 higher at the 4 stations receiving direct carcass seeding, lower (96 %) at the mainstem station furthest downstream that did not receive direct seeding, and lower (86 %) at the tributary control station that was not seeded.

- Major changes in invertebrate groups between the 2006 baseline year and 2009, include: substantial increases in segmented worm (Oligochaeta) densities at all stations; substantial increases in *Oligophlebodes*, an algal scraper caddisfly at most stations directly seeded; overall increase in algal scrapers at stations directly seeded; and a substantial increase in collector-gatherer (consumers of fine particulate organic matter) at the two mainstem stations furthest downstream.

- Results to date suggest that seeding is directly boosting algal production and in turn scraper densities at stations receiving direct seeding. Enrichment also appears to be secondarily boosting collector-gatherer densities at all enriched stations, with impacts magnified in the lower Pine Creek mainstem.

## Introduction

Salmon carcasses have successfully been used to boost nutrient enrichment in streams in the Pacific Northwest (Bilby et al. 1998, Chaloner and Wipfli 2002, Stockner 2003). When Merwin Dam was completed in 1931, it cut off salmon runs to the upper Lewis River Watershed, removing an important source of nutrients for the system. Beginning in 2006, carcasses were introduced into the Pine Creek sub-watershed of the Lewis River Watershed to build up the nutrient level, boosting food production for juvenile bull trout. Bull trout are listed as a threatened species under the Endangered Species Act.

Merwin Dam was constructed on the North Fork of the Lewis River approximately 14 miles upstream from Woodland, Washington in 1931 to produce hydroelectric power. It is a complete barrier to anadromous fish, effectively cutting off over 170 miles of stream to salmon and steelhead. Species affected include spring and fall chinook, coho, chum salmon, and steelhead trout. Pine Creek, which is upstream from Merwin Dam, is one of two prime bull trout streams on the Gifford Pinchot National Forest.  Stream temperatures are cold year round with 7 day summer peak temperatures of about 14 degrees Celsius.

Even though the Dam blocked passage of anadromous fish, some fish were trucked upstream and released into the river for several years after completion. All fish species were greatly reduced by Merwin Dam, and eventually only coho and a few chinook salmon were transported around the Dam. This practice was stopped altogether around 1957.

More recently however, as part of a habitat preparation project for reintroduction of salmon into the upper North Fork Lewis River system, approximately 2,000 coho per year have been released into Swift Reservoir since 2005. A few of these fish must have spawned in Tributary P8, because a small amount of juvenile coho have been observed in this tributary by Washington Department of Fish and Wildlife crews during bull trout surveys. Further, as part of the relicensing effort, PacifiCorp, Inc. (owners of Merwin, Yale and Swift Dams) has agreed to reintroduce salmon and steelhead above the reservoirs in 2012. A new 50 year operating license was issued for all three reservoirs in 2008.

The Pine Creek system was heavily affected by the eruption of Mount St. Helens in 1980 when a lahar flow scoured the length of the stream channel, ripping out riparian vegetation and dramatically changing the substrate of the system. A 37-ton boulder was deposited on Forest Road 25, approximately 30 feet above the normal stream level during the eruption. Additionally, the subsequent floods of 1996 and 2006 removed much of the system's newly established riparian vegetation.

Tributary P8 was also affected by the lahar flow. It is the most important spawning stream in the Pine Creek Tributary.

**Project and monitoring objectives:**

Pine Creek is a cold, oligotrophic stream system historically supporting salmon runs that returned nutrients to the stream system. Absence of returning salmon for 80 years and the nutrients their carcasses provide, may have depressed benthic macroinvertebrate production in the basin. Will the artificial addition of salmon carcasses significantly boost macroinvertebrate production and in turn boost production of both resident salmonids and anadromous salmonid juveniles when they are returned to the basin?

## Study Site

Pine Creek originates on Mount Saint Helens in the southern Washington Cascades and flows to the SE for 20 kilometers before joining the Lewis River just upstream of the Swift Creek Reservoir (Figure 1). Snow runoff probably feeds the headwater, but much of the year Pine Creek is dry for miles until a spring about ½ mile below Forest Road 83, brings Pine Creek to its full flow within a short distance. This pattern continues at least into December when carcasses are flown in to the creek.

In 2005 Pine Creek had a level II stream survey performed on the first 7.5 miles of it. It was broken into 3 reaches. The lowest mile of the first reach is being subdivided into vacation cabin lots. Red Alder (*Alnus rubra*) is the dominant vegetation type in this section. The next mile is Forest Service managed lands and has larger conifers in its riparian overstory. Upstream from this point red alder is the dominant riparian vegetation. Reach 1 was from the confluence to tributary P8, Reach 2 from tributaries P8 to P10 and Reach 3 from tributary P8 to the end of survey. The substrate is composed of cobble intermixed with small and large boulders. Gradients averaged three to five percent and stream riffle widths varied from 36 feet in the lower reaches to 17 feet in the upper reach. The pool riffle ratio averaged 5/95 with very little large woody material in the system. Discharge was un-measureable due to high velocity and steep gradients. Pine Creek had a seven day maximum average of 14.4 degrees Celsius in 2005. There are some terraces in the flood plain of Pine Creek but it mainly has long (500 or more feet) steep stream banks beyond the terraces composed of ash from previous Mount St. Helens eruptions.

Tributary P8 had a level II stream survey performed on the lower 2.67 miles in 2005, as well. Red alder dominates the understory riparian vegetation and small conifers dominate the overstory. Substrate was composed mainly of cobble and small boulders and the gradient averaged 3.5 percent. Pool Riffle ratio is 20/80 and discharge was measured at 23.5 CFS. P8 had a seven day maximum average of 15.4 degrees Celsius in 2005. There are some terraces in the confluence area of P8 but it mainly has long (500 or more feet) steep stream banks beyond the terraces composed of ash from previous Mount St. Helens eruptions. Finally, it is much less open to sunlight than Pine Creek with a mean riffle width of 15.4 feet.

Tributary P7 was our control reach and had no carcasses distributed in it. Approximately 2.9 miles were surveyed in 2005. Three reaches were identified; with the uppermost reach a small segment that was considerably different than the lower two reaches. The riparian area was composed of red alder and Douglas fir. Substrate was cobble and small boulders and the average gradient was 3.6 percent in reach one and 8.6 percent in reach two. The pool riffle rate averaged about 45/55 over the first two reaches. Mean riffle width was about 15 feet. The seven day maximum average for P7 was 13.0 degrees Celsius in 2005. Discharge was measured at 2.4 CFS.

This pilot study was conducted between 2006 and 2009. A major flood in November 2006 caused extensive flushing, bed-load movement and scouring of substrates. A flood recurrence interval this event represents is not known, however 15.2 inches of precipitation fell in the headwaters of Pine Creek in 24 hours, which set a Washington State record.

During the course of the study, the water years (as measured from October 1-September 30) were:

October 2005-September 2006: typical flows with no major flood events
October 2006-September 2007: catastrophic flood event in November 2006
October 2007-September 2008: typical flows with no major flood events
October 2008-September 2009: typical flows with no major flood events

## Methods

Salmon carcasses were distributed throughout Pine Creek beginning December 2006. A helicopter with a specially modified fire fighting bucket distributed most of the carcasses, however approximately 800 pounds were distributed by hand at the Monument boundary in 2006 and 2008. The helicopter carried 450 pounds per bucketful and had a release mechanism that controlled how fast the carcasses were released. The bucket was attached to the helicopter with 100 feet of long-line to enable maneuverability around riparian trees. Approximately 8,500 pounds were distributed over 2.3 mile of Tributary P8, another 10,000 pounds were distributed on Pine Creek for 2.5 miles above the confluence of P8 and another 6,500 pounds were distributed between the Monument Boundary and the confluence of P8 (Figure1.) for a total of 25,000 pounds. In 2007, carcasses were not distributed due to poor fish runs that did not allow the hatchery to provide carcasses. Carcasses were again distributed in 2008 with approximately 8,000 pounds distributed over 2.3 miles of Tributary P8, another 8,000 pounds were distributed on Pine Creek for 2.5 miles above the confluence of P8 and another 5,000 pounds were distributed between the Monument Boundary and the confluence of P8 for a total of 21,000 pounds. Carcasses were again distributed in 2009 with approximately 6,000 pounds in P8, 5,000 pounds in Pine Creek upstream of P8 and another 3,500 pounds distributed in Pine Creek upstream of the Monument Boundary for a total of 14,500 pounds. Carcasses distributed in 2009 were not part of this analysis because macroinvertebrate samples will be collected in October 2010.

Macroinvertebrate were sampled at 6 stations on Pine Creek in mid-October of 2006, 2007 and 2009 (Figure 1). The October 2006 sampling represents baseline conditions prior to carcass dispersal following a typical water year but just prior to the November 2006 flood that heavily impacted macroinvertebrate communities throughout the basin. The October 2007 sampling was 11 months after this major flood and 10 months after the initial December 2006 salmon carcass distribution.

Four stations were located along the mainstem of Pine Creek beginning near the mouth (Figure 1). The station located at Pine Creek **Mainstem near mouth** did not receive any direct placement of carcasses, though it may receive nutrients washed down from carcass placement that began 3.2 kilometers upstream at the **Mainstem @ Monument boundary** station. The **Tributary P8 near mouth** station is at the base of a major tributary that received carcass additions all three years, while the **Tributary P7 near mouth** station is a control station at the base of a major tributary that did not receive any carcass additions.

Because of budget constraints, macroinvertebrate sampling was limited to a single sample at each station. Samples were acquired from with a D-frame net, 500 micron mesh from three different points in riffle habitat to form a single composite sample representing 8 square feet of stream bottom. At each of the three riffle points sampled, the net was anchored to the stream bottom and an area 30 cm wide and extending 80 cm upstream was sampled. Armor layer rocks were brushed of invertebrates allowing dislodged invertebrates to be washed into the net, and then tossed aside. Sediment beneath the armor layer was stirred with feet to a depth of 5 cm, again allowing invertebrates to be washed into the net.

Samples were scope sorted at 6-12X magnifications. A random portion of the sample containing a minimum of 500 organisms was sorted and identified. Standard taxonomic effort in the identification of macroinvertebrates followed U.S. EPA Environmental Monitoring and Assessment Program protocols (www.epa.gov/emap/). Results presented here are converted to a full sample and square meter basis.

## Results and Discussion

The objective of this pilot study was to determine if salmon carcass enrichment would have a dramatic and perhaps a year after year cumulative impact on macroinvertebrate standing crops in the Pine Creek basin. Given the results to date, it is unfortunate that a more quantitative and replicated sampling protocol was not used, and that sampling in more baseline years prior to carcass enrichment was not conducted to determine pretreatment variability in macroinvertebrate standing crops.

### Total macroinvertebrate densities

Table/Figure 1 lists and illustrates total macroinvertebrate densities found at the six Pine Creek stations over the three years sampled. In 2006, prior to enrichment, total densities varied from 5961 $m^2$ at the more open station near the mouth to between about 1000-3000 $m^2$ at the upstream stations and tributaries. Densities in this range are typical for oligotrophic, forested, montane streams in the maritime Northwest (Wisseman, unpublished data). Stream water is cold, with limited nutrients derived from volcanic rocks.

The November 2006 flood in the basin appears to have caused a major resetting of the benthic macroinvertebrate community even 11 months later when the October 2007 samples were taken and 10 months after the first round of carcass placement. Macroinvertebrate densities at the six stations were 65-92% lower in 2007 than found in 2006. Pine Creek is a cold-water, montane stream that does not have a distinctive division between cold season and warm season communities. Essentially, there is only a cold adapted community that is present in the stream in the larval or egg stage most of the year. The November 2006 flood appears to have caused mass mortality in most benthic taxa and their recovery in the system was slow. Warm adapted taxa are not naturally present to boost densities during the summer and early fall.

Macroinvertebrate sampling did not occur again until October 2009, about three years after the flood and after two salmon carcass enrichments in December 2006 and 2008. Total densities at all stations in October 2009 increased about an order of magnitude over those found post-flood in 2007. At the three mainstem stations that received direct carcass addition, total densities increased 2.1 to 2.5 times over densities measured in 2006 baseline year. Densities in Tributary P8 (enriched) were 1.8 times those found in 2006, while in Tributary P7 (not enriched) densities were lower in 2009, 86% of the 2006 level.

Total invertebrate densities at the **Mainstem near mouth** station were slightly lower (96%) in 2009 than 2006 after two years of carcass enrichment. The nearest carcass placement to this station was 3.2 kilometers upstream. The apparent lack of a boost in density provided by two years of carcass enrichment could be due to a number of factors that only tracking trends for several more years can answer. Possible explanations are:

1. There is a rapid uptake of nutrients from decomposing carcasses in upstream reaches, leaving little available to pass downstream for uptake at the station near the mouth.

2. Around 6000 total invertebrates per square meter as seen at this station in 2006 and 2009, and at **Mainstem u/s Tributary P8** in 2009 is about the maximum potential for macroinvertebrate standing crops in the basin, regardless of nutrient enrichment levels.

3. Nutrient enrichment is boosting macroinvertebrate populations, but recovery from the November 2006 is still progressing.

## Total taxa richness

Forested montane streams in the Pacific Northwest with low human disturbance and moderate habitat complexity typically have 40-60 total taxa in benthic samples from riffle habitats when the standard taxonomic effort used in this study is applied (Wisseman, unpublished data). Total taxa richness at the six Pine Creek stations varied between 26 and 70 taxa between 2006 and 2009 (Table/Figure 2). That is a considerable range for one stream basin.

Discounting the 2007 data following major flooding the previous year, the mainstem stations on Pine Creek have relatively low taxa richness. The station near the mouth falls in the typical range with 49 and 57 total taxa in 2006 and 2009, respectively, but the three stations further upstream had only 31-42 taxa during 2006 and 2009. This suggests that habitat complexity is not very high along most of the mainstem, and also near the mouth of Tributary P8 where total taxa richness was only 40 and 45 taxa in 2006 and 2009. Tributary P7 had a total taxa richness of 66 and 70 in 2006 and 2009, suggesting that habitat complexity is much higher in the stream reach near the mouth of this tributary.

The impact to benthic fauna from the November 2006 floods as assessed by the 2007 samples is very striking (Table/Figure 2). The mainstem stations lost between 1 and 9 taxa. The tributaries were impacted much greater, losing 17 taxa, or about one-third of the fauna at Tributary P8, and 38 taxa, over half the fauna at Tributary P7. The loss of a third to over half the fauna at these tributary stations can only be termed catastrophic. Taxa in all insect and non-insect groups were lost. Why the fauna at the mainstem stations fared better following the flood is not known. Perhaps there was less overall bed-load movement and more refugia for invertebrates to weather the flood, or recolonization during the 11 months between the flood and the October 2007 sampling may have been more rapid in mainstem than the tributaries.

By the October 2009 sampling, total taxa richness at all stations had recovered dramatically from the lows seen in 2007 (Table/Figure 2). Total taxa richness at all stations except Tributary P8 (-5 taxa) was slightly to moderately greater than seen in the 2006 baseline sampling, with increases in the total taxa richness of 2-8 taxa. All taxonomic groups increased in taxa richness at least at a few of the stations. The groups that added the greatest number of taxa and at the most stations were caddisflies (Trichoptera) and true flies (Diptera).

## Non-insects including segmented worm (Oligochaeta) densities

Non-insect benthic macroinvertebrate taxa found in the Pine Creek basin are flatworms, round worms, segmented worms, several snails, seed shrimp and aquatic mites. Overall diversity of the non-insect fauna is low, with 0-4 taxa total found at any one site. Both mollusks and crustaceans are present but in very low abundance. Cold water, high stream gradient and low levels of calcium ions in the water limit these groups.

Non-insects occurred in low abundance at all Pine Creek stations in the baseline year 2006 before enrichment, making up between 2.7 and 10.4% of the benthic fauna (Table/Figure 3). They virtually disappeared from the system following the November 2006 floods, as measured 11 months later by the October 2007 sampling. Densities of non-insects rebounded in 2009 at all Pine Creek stations, and were 1.9 to 8.2 times higher than seen in the 2006 baseline year.

**Oligochaeta (segmented worms**) were the dominant non-insect taxa present and contributed the most to the 2009 bounce in densities among the non-insects (Table/Figure 4). It is well known that segmented worm populations respond positively and rapidly to organic enrichment (Brinkhurst and Gelder 2001).

Segmented worm densities ranged from 36-253 $m^2$ in 2006, the baseline year; 0-38 $m^2$ in 2007 after the flood; and rose to 304-1081 $m^2$ in 2009 after 2 years of enrichment.

Worm densities in 2009 at the **Tributary 7 near mouth** control site increased 2.4 times over those found in 2006, indicating that the flood itself may have stimulated worm populations, perhaps through deposition of fine sediment or increased algal production. Worm densities at the 5 stations enriched with carcasses were 2.2 to 9.2 times higher in 2009 than in 2006, with an average increase of 6.1 times. Worm populations at the enriched stations are probably responding to both flood disturbance and enrichment.

Worm densities climbed most dramatically between 2006 and 2009, nearly an order of magnitude, at the **Mainstem near mouth** station. The dramatic rise in densities at this station may indicate that nutrients from the salmon carcasses are spiraling downstream several miles below where they were placed.

## Insect densities

**Mayfly (Ephemeroptera)** densities varied considerably between the Pine Creek stations and between years (Table/Figure 5). In the 2006 baseline year, densities were high at **Mainstem near mouth**, moderate at **Tributary 7 near mouth**, and low at the remaining stations. Densities in 2007 following the flood were low at all stations.

In 2009 mayfly densities were nearly the same as found in 2006 at all stations except **Mainstem @ Monument boundary**, where densities were 9.3 times higher in 2009 over 2006. This increase was due mainly to the baetid mayflies *Baetis bicaudatus* and *Baetis tricaudatus*, and to a lesser extent the heptageniid mayflies *Epeorus grandis* and *Rhithrogena*. *Baetis bi/tricaudatus* comprised 24% of the total community at the **Mainstem @ Monument boundary** station in 2009. High densities of this pair of sister species are usually found in stream reaches that have recently received considerable disturbance, whether the disturbance is physical in nature (substrate resorting and scour) or chemical (acute toxic episodes). High densities of *Baetis species* at this station in 2009 may indicate that the stream reach is still undergoing annual physical disturbance after the 2006 flood.

As of 2009, mayflies do not appear to be responding dramatically to the nutrient enrichment from salmon carcasses.

**Stonefly (Plecoptera**) density trends along the longitudinal axis of Pine Creek and between years was relatively similar to the mayflies (Table/Figure 6). This order of insects is composed mainly of species that are predators or shredders of detritus. In 2006, density in the mainstem of Pine Creek was lower than the tributary stations, except at the **Mainstem near mouth** station. Stoneflies are most abundant and diverse in smaller, forested streams, and higher densities in the smaller tributary streams is consistent with this. Stonefly densities at the **Mainstem near mouth** station were three or more times higher than for any other station, with *Zapada species* (Nemouridae), particularly *Zapada cinctipes* being very abundant. This same genus was also abundant at this site in 2009. *Zapada species* are shredders of detritus. Considering their low abundance in the mainstem above the mouth, this suggests that detritus is a more abundant food source near the mouth of Pine Creek. Perhaps much of the detritus that enters the mainstem is flushed down and deposited near the mouth.

As with all other groups, stonefly density and richness displayed dramatic declines at all stations following the November 2006 flood, and had not rebounded by October 2007, even with the December 2006 addition of carcasses. Stonefly densities and richness recovered substantially by 2009, particularly in the tributaries, but appear not to have been augmented by two years of carcass addition. The three-fold increase in stonefly density at the **Mainstem @ Monument boundary** station in 2009 versus 2006 is due to the early recruitment of early instar Taeniopterygidae nymphs at his station in 2009.

**Caddisflies (Trichoptera**) were common to abundant at most Pine Creek stations (Table/Figure 7). Larvae of the various caddisfly species derive their nutrition from a variety of food sources. Those found in Pine Creek include predators, shredders of detritus, and filterers, with scrapers of algae being dominant.

Both richness and density of caddisflies plummeted at all stations in 2007. Recovery in density by 2009 was lower than 2006 at the two mainstem stations furthest downstream. Densities at the two mainstem stations further upstream and in both the enriched and control tributaries were higher in 2009 than in 2006, with densities at **Mainstem u/s Tributary P8** and **Tributary P8 near mouth** 2-3 times higher in 2009. **Mainstem u/s Tributary P8** total caddisfly density exceeded 5000 per square meter. That is a very high density for caddisflies in a mid-order, cold, montane, Pacific Northwest stream.

Much of the dynamic in caddisfly densities seen at Pine Creek from 2006-2009 was due to one species, *Oligophlebodes* probably *minutus*, whose larvae scrape algae (Table/Figure 8). *Oligophlebodes* is common and widespread throughout western North America, but is patchily distributed. It is not understood why it may be common in a stream like Pine Creek, but then be absent or rare in the next ten adjacent drainages. The increase in density of this species at the two upper mainstem stations and in Tributary P8 in 2009 is probably in partial response to two years of carcass enrichment, indicating that algal production may have been significantly enhanced in these stream reaches. The November 2006 flood may have also contributed to an increase in algal production by widening and opening the channel to more sunlight.

**Midge (Diptera: Chironomidae)** densities in 2006 were high at the **Mainstem near mouth** and **Tributary P7 (control)** stations (Table/Figure 9), perhaps because these are lower gradient stations where fine particulate organic matter, the food of most midges, is more abundant. Densities at all stations plummeted in 2007, then recovered substantially only at the two lowest mainstem stations.

## Feeding Groups

**Algal scrapers** were common at all stations in 2006 and displayed a relatively narrow range in densities between stations (Table/Figure 10). Again, densities plummeted in 2007 following the flood. Scraper density was only slightly higher in 2009 than 2006 at the Tributary P7 control station (not enriched), while at the enriched stations densities were moderately to substantially higher in 2009 except at the **Mainstem near mouth** station. The spike in scraper density in 2009 at **Mainstem u/s Tributary P8** is due mainly to the caddisfly scraper *Oligophlebodes* (above).

Algal scraper densities appear to have been enhanced by carcass enrichment and also perhaps from channel widening and opening effects of the November 2006 flood.

**Collector-gatherers** consume fine organic particles (living and dead) in or on surface sediments. All Pine Creek stations had higher densities of collector-gatherers in 2009 than were found in both 2006 and 2007 (Table/Figure 11). Densities at the Tributary P7 control station increased by only 129% from 2006 to 2009, while the remaining enriched stations saw increases ranging from 155 to 794%. Collector-gatherer taxa exhibiting the most increase were segmented worms (Oligochaeta), midges (Chironomidae), and *Baetis* mayflies.
Increased algal production eventually leads to an increase in fine particulate organic matter, as algae dies and decays or is consumed and excreted by invertebrates. Greatest densities of collector-gatherers were seen in 2009 at the two lowest stations on the mainstem of Pine Creek. This pattern would be consistent with greater algal production occurring in upstream reaches (by some combination of enrichment and channel opening), followed by deposition of more fine particulate matter in the lower mainstem reaches, as the byproduct of this increased production was flushed downstream.

**Shredders** of detritus consume decaying leaves, needles and woody material that enter the stream. Most of the shredders in Pine Creek are stoneflies. In 2006 shredders were most abundant at the **Mainstem near mouth** station and at the mouth of Tributaries P7 and P8 (Table/Figure 12). Shredder densities were low at the remaining mainstem stations in all years, perhaps because these reaches are higher gradient and narrower channels have more hydraulic power to flush detritus downstream. The higher densities of shredders near the mouth of Pine Creek and the mouths of the tributaries, is probably a result of more detritus being deposited and retained in these reaches, acting as detritus sinks.

Shredder densities were at zero or nearly so at all stations in October 2007, following the November 2006 flood. The impact of this flood on the shredder community was catastrophic. Only the **Mainstem @ Monument** boundary station displayed a small increase in shredder densities by October 2009 over 2006. Shedder populations in Pine Creek appear to be still recovering from the 2006 flood nearly three years after this event occurred. No response to nutrient enrichment from salmon carcasses is evident. Enhancement of shredders through nutrient addition would follow an indirect pathway if any. Microbial communities on decaying organic matter that are responsible for much of the nutritive value to invertebrates, may be enhanced by an increased availability of soluble nutrients.

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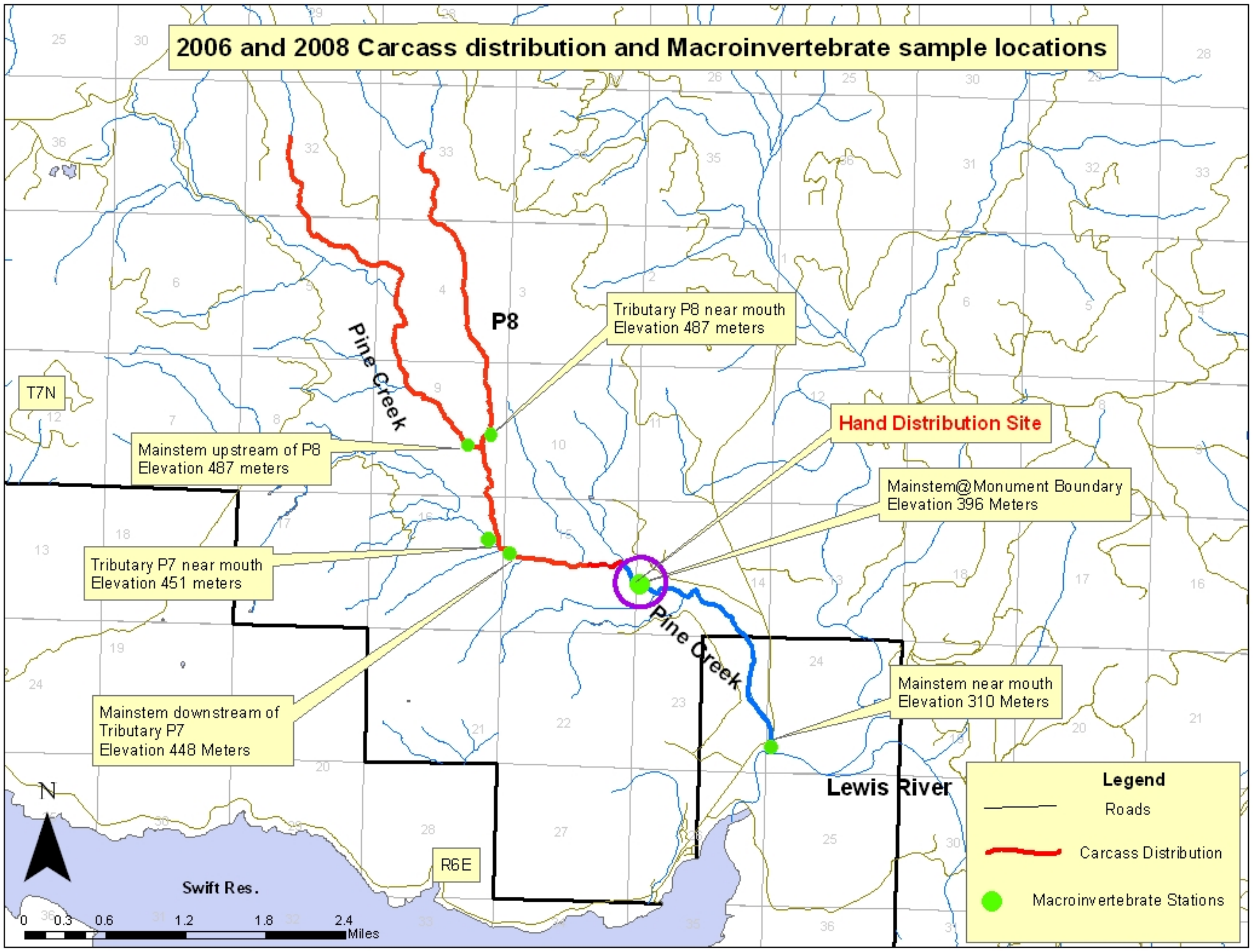
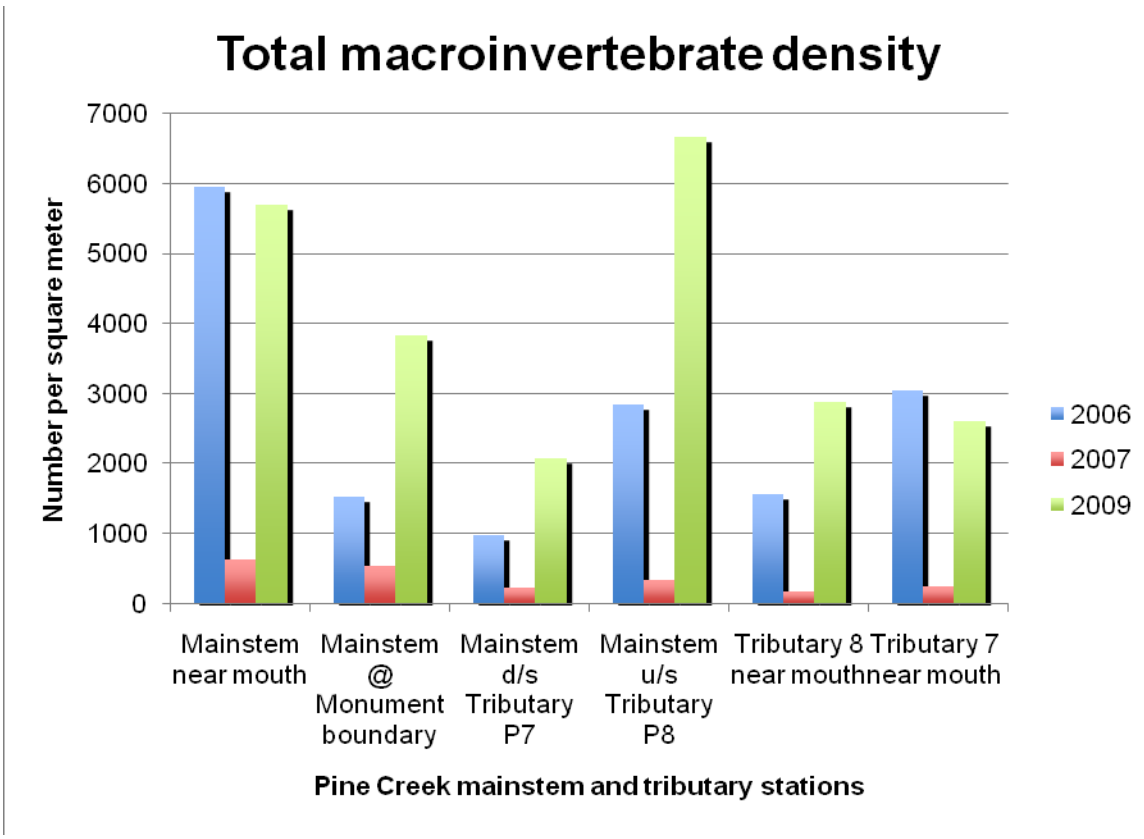



Figure 1. 2006 and 2008 Carcass Distribution and Macroinvertebrate Sample Locations

**Pine Creek Salmon Carcass Enrichment Study**
WA: Mount St. Helens National Volcanic Monument
Mid-October invertebrate sampling, multipoint composite sample, riffle habitat, 500 micron mesh.
Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

**Table/Figure 1**
**Total invertebrate density per square meter**

| **Stations** | | **Years** | | **Treatment** |
|---|---|---|---|---|
| | **2006** | **2007** | **2009** | |
| Mainstem near mouth | 5961 | 620 | 5705 | Carcass enriched |
| Mainstem @ Monument boundary | 1528 | 533 | 3833 | Carcass enriched |
| Mainstem d/s Tributary P7 | 970 | 225 | 2076 | Carcass enriched |
| Mainstem u/s Tributary P8 | 2841 | 328 | 6660 | Carcass enriched |
| Tributary 8 near mouth | 1566 | 162 | 2878 | Carcass enriched |
| Tributary 7 near mouth | 3034 | 236 | 2604 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**

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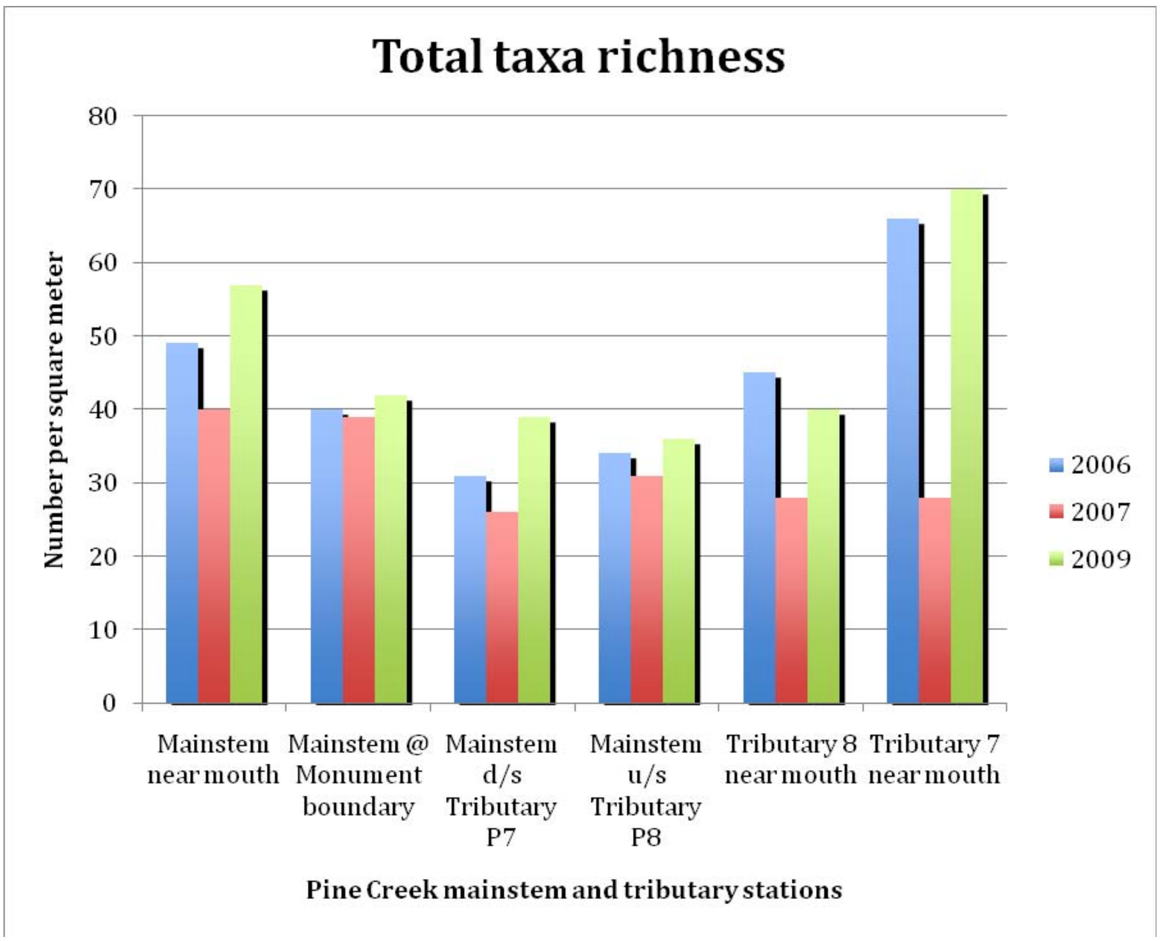
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.

Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

## Table/Figure 2

### Total taxa richness

| Stations | Years | | | Treatment |
|---|---|---|---|---|
| | 2006 | 2007 | 2009 | |
| Mainstem near mouth | 49 | 40 | 57 | Carcass enriched |
| Mainstem @ Monument boundary | 40 | 39 | 42 | Carcass enriched |
| Mainstem d/s Tributary P7 | 31 | 26 | 39 | Carcass enriched |
| Mainstem u/s Tributary P8 | 34 | 31 | 36 | Carcass enriched |
| Tributary 8 near mouth | 45 | 28 | 40 | Carcass enriched |
| Tributary 7 near mouth | 66 | 28 | 70 | Control, not enriched |



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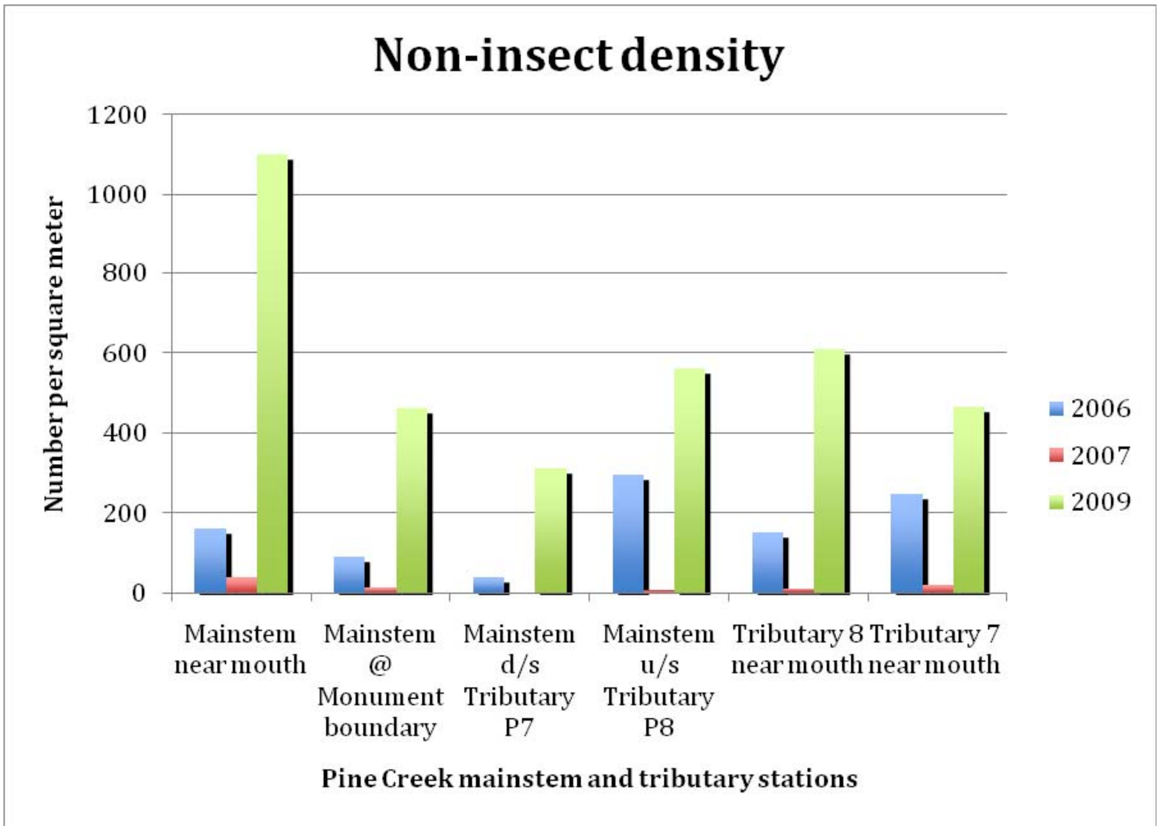
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.
Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

## Table/Figure 3
## Non-insect density per square meter

| Stations | Years | | | Treatment |
|---|---|---|---|---|
| | 2006 | 2007 | 2009 | |
| Mainstem near mouth | 161 | 39 | 110 | Carcass enriched |
| Mainstem @ Monument boundary | 89 | 13 | 460 | Carcass enriched |
| Mainstem d/s Tributary P7 | 38 | 0 | 311 | Carcass enriched |
| Mainstem u/s Tributary P8 | 295 | 8 | 562 | Carcass enriched |
| Tributary 8 near mouth | 151 | 10 | 608 | Carcass enriched |
| Tributary 7 near mouth | 248 | 20 | 465 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**

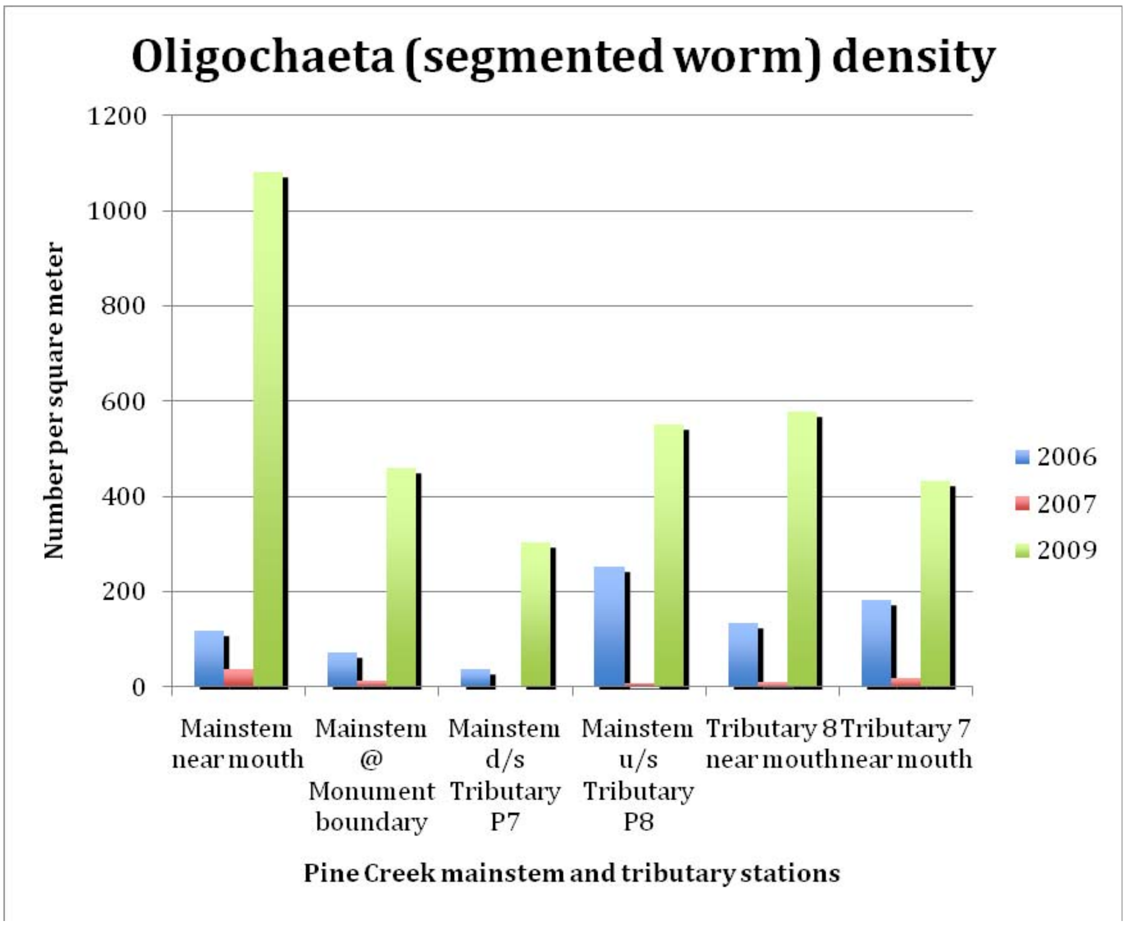
WA: Mount St. Helens National Volcanic Monument

Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.

Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

## Table/Figure 4
## Oligochaeta (worm) density per square meter

| Stations | 2006 | 2007 | 2009 | Treatment |
|---|---|---|---|---|
| | | Years | | |
| Mainstem near mouth | 118 | 38 | 1081 | Carcass enriched |
| Mainstem @ Monument boundary | 73 | 12 | 460 | Carcass enriched |
| Mainstem d/s Tributary P7 | 36 | 0 | 304 | Carcass enriched |
| Mainstem u/s Tributary P8 | 253 | 8 | 551 | Carcass enriched |
| Tributary 8 near mouth | 135 | 9 | 578 | Carcass enriched |
| Tributary 7 near mouth | 183 | 19 | 433 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**

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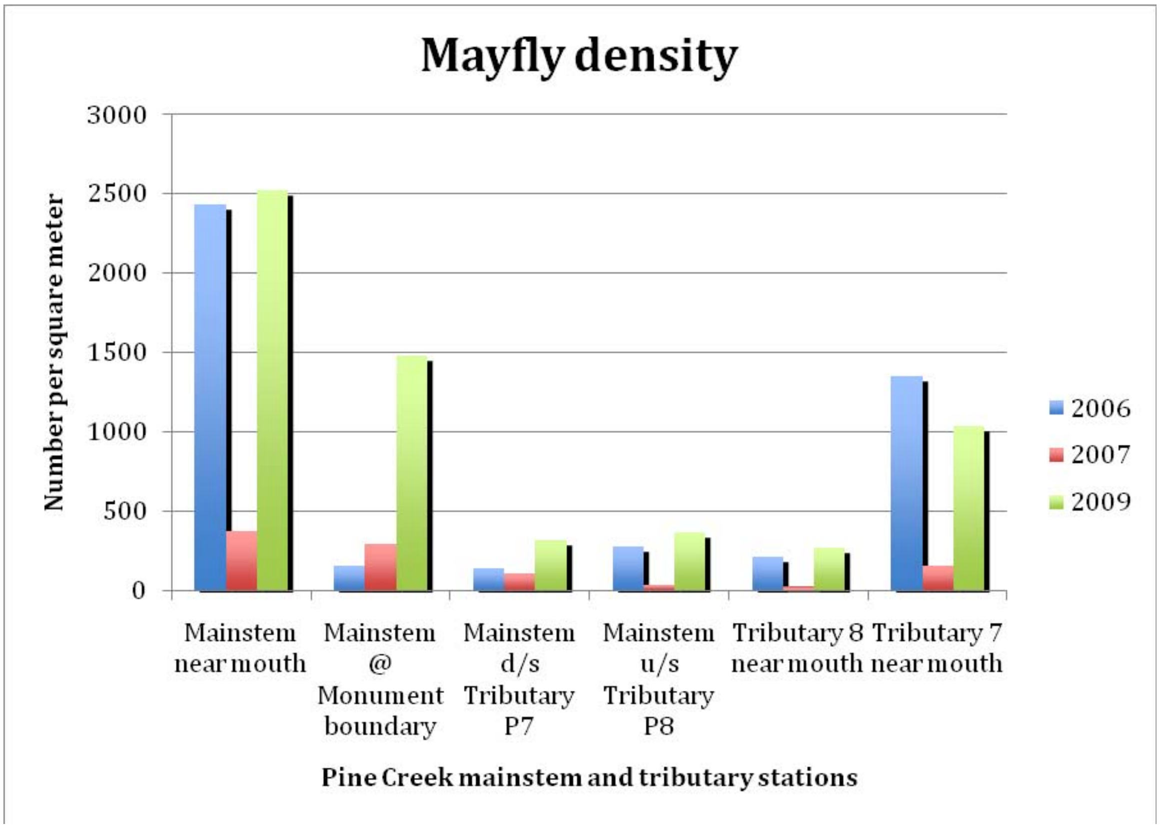
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.

Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

**Table/Figure 5**

**Mayfly density per square meter**

| **Stations** | Years | | | **Treatment** |
|---|---|---|---|---|
| | **2006** | **2007** | **2009** | |
| Mainstem near mouth | 2433 | 378 | 2518 | Carcass enriched |
| Mainstem @ Monument boundary | 159 | 292 | 1477 | Carcass enriched |
| Mainstem d/s Tributary P7 | 138 | 105 | 320 | Carcass enriched |
| Mainstem u/s Tributary P8 | 281 | 32 | 369 | Carcass enriched |
| Tributary 8 near mouth | 215 | 27 | 266 | Carcass enriched |
| Tributary 7 near mouth | 1351 | 153 | 1036 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**

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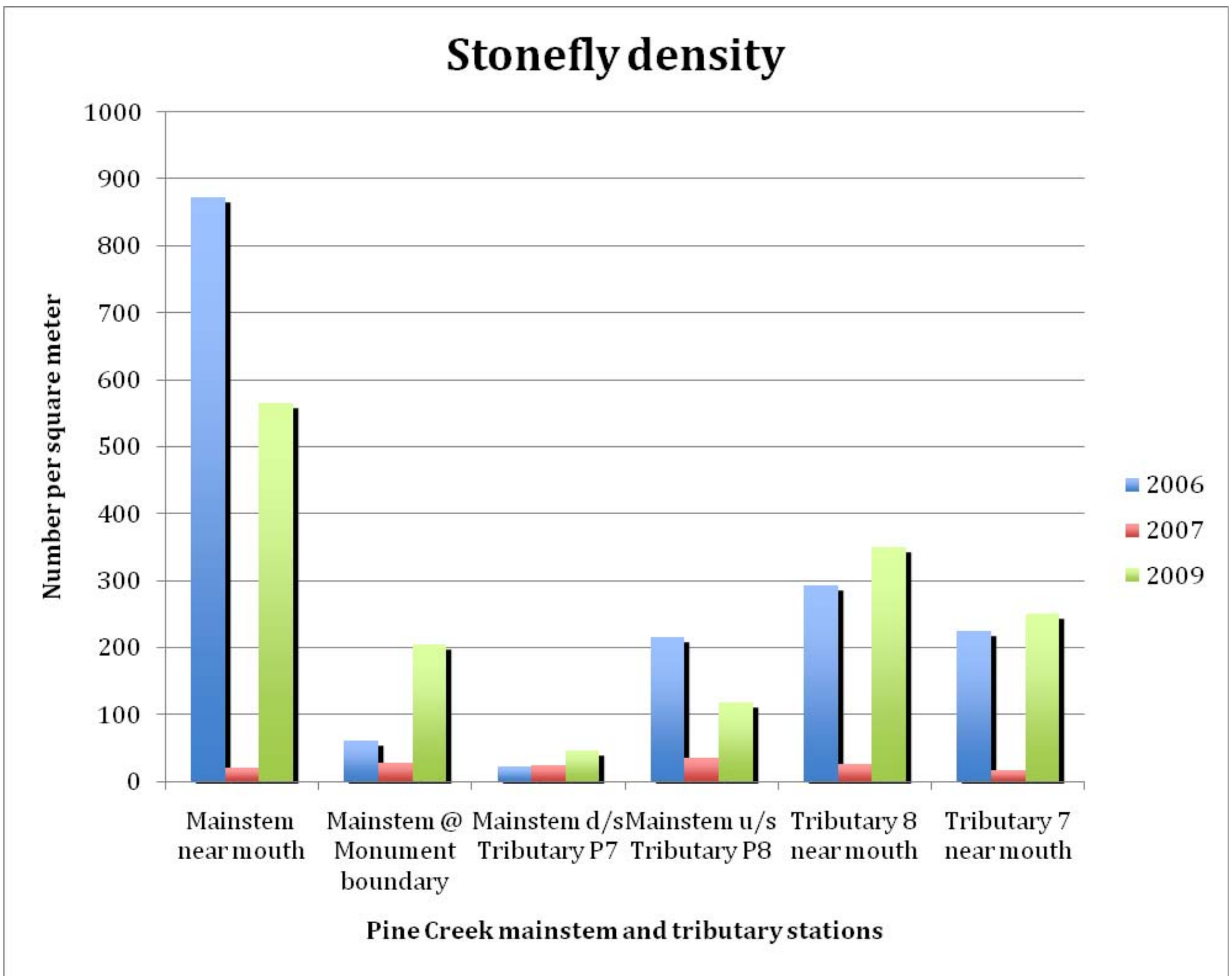
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.

Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

## Table/Figure 6
## Stonefly density per square meter

| Stations | Years | | | Treatment |
|---|---|---|---|---|
| | 2006 | 2007 | 2009 | |
| Mainstem near mouth | 873 | 21 | 565 | Carcass enriched |
| Mainstem @ Monument boundary | 61 | 28 | 204 | Carcass enriched |
| Mainstem d/s Tributary P7 | 23 | 24 | 46 | Carcass enriched |
| Mainstem u/s Tributary P8 | 216 | 36 | 118 | Carcass enriched |
| Tributary 8 near mouth | 293 | 26 | 349 | Carcass enriched |
| Tributary 7 near mouth | 225 | 16 | 250 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**
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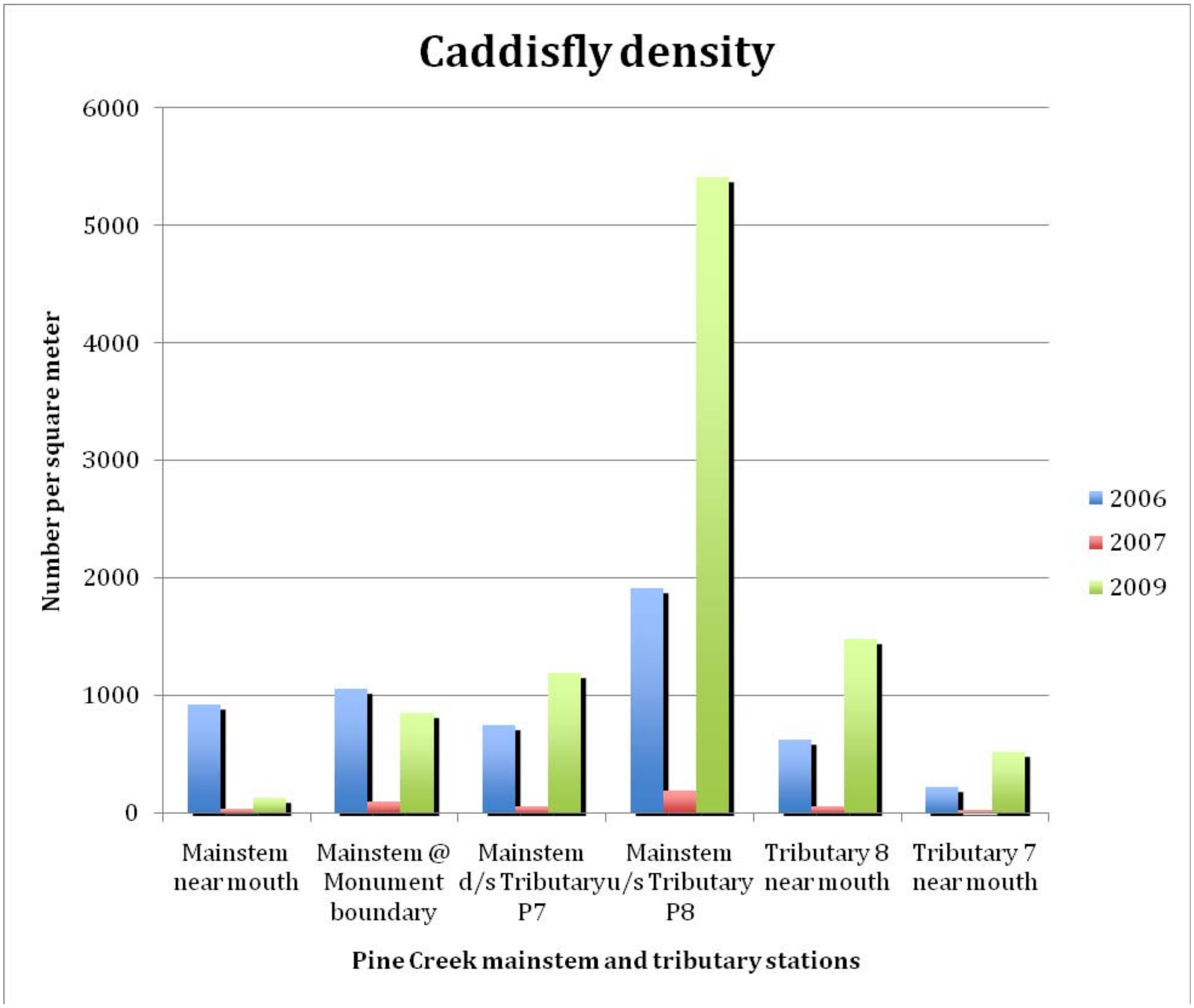
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.
Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

## Table/Figure 7
### Caddisfly density per square meter

| Stations | | Years | | Treatment |
|---|---|---|---|---|
| | 2006 | 2007 | 2009 | |
| Mainstem near mouth | 926 | 37 | 132 | Carcass enriched |
| Mainstem @ Monument boundary | 1061 | 98 | 847 | Carcass enriched |
| Mainstem d/s Tributary P7 | 749 | 55 | 1189 | Carcass enriched |
| Mainstem u/s Tributary P8 | 1909 | 194 | 5404 | Carcass enriched |
| Tributary 8 near mouth | 628 | 54 | 1479 | Carcass enriched |
| Tributary 7 near mouth | 225 | 25 | 519 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**

WA: Mount St. Helens National Volcanic Monument

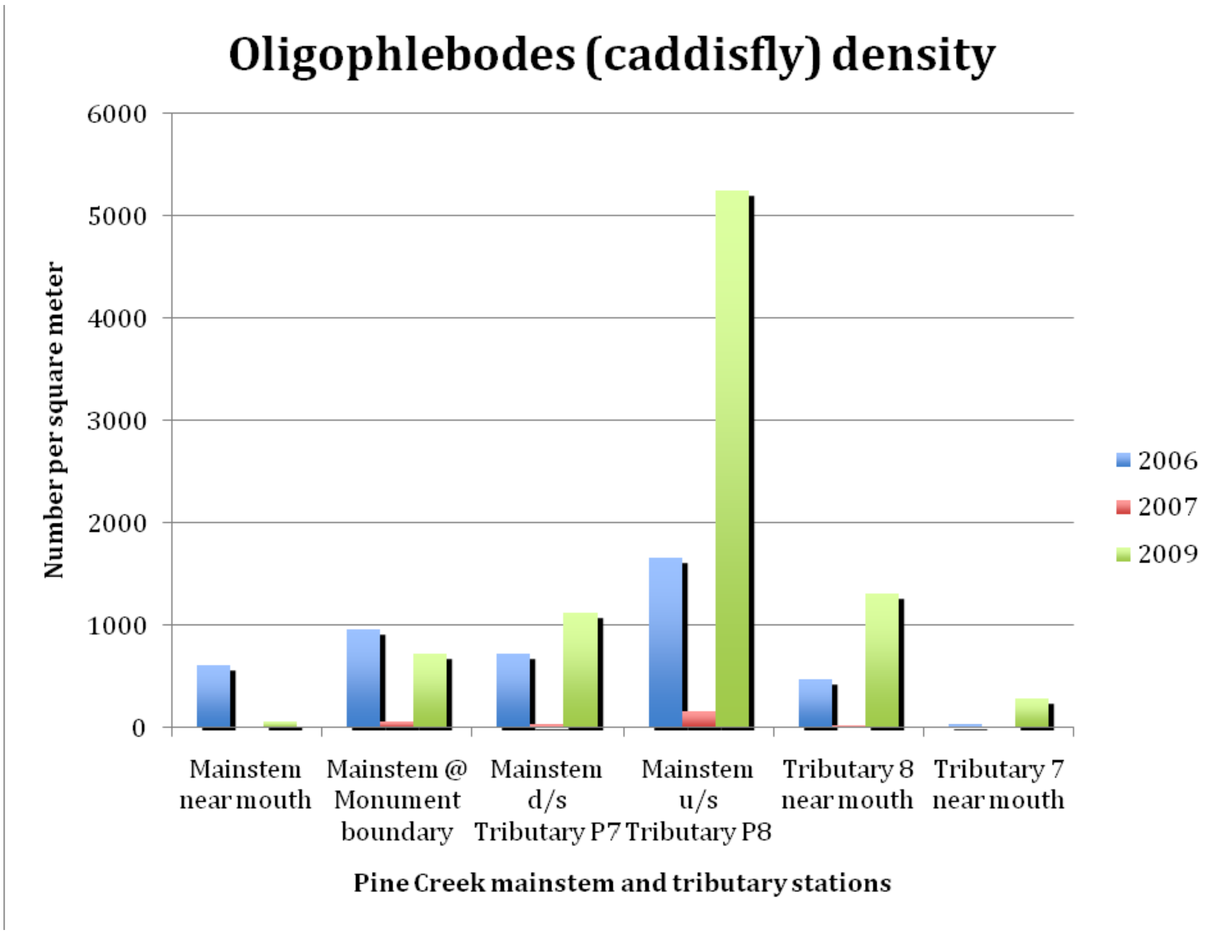
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.

Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

**Table/Figure 8**

**Oligophlebodes (caddisfly) density per square meter**

| **Stations** | **Years** | | | **Treatment** |
|---|---|---|---|---|
| | **2006** | **2007** | **2009** | |
| Mainstem near mouth | 603 | 9 | 56 | Carcass enriched |
| Mainstem @ Monument boundary | 960 | 54 | 724 | Carcass enriched |
| Mainstem d/s Tributary P7 | 720 | 35 | 1125 | Carcass enriched |
| Mainstem u/s Tributary P8 | 1662 | 155 | 5251 | Carcass enriched |
| Tributary 8 near mouth | 468 | 20 | 1307 | Carcass enriched |
| Tributary 7 near mouth | 27 | 1 | 285 | Control, not enriched |



## Pine Creek Salmon Carcass Enrichment Study

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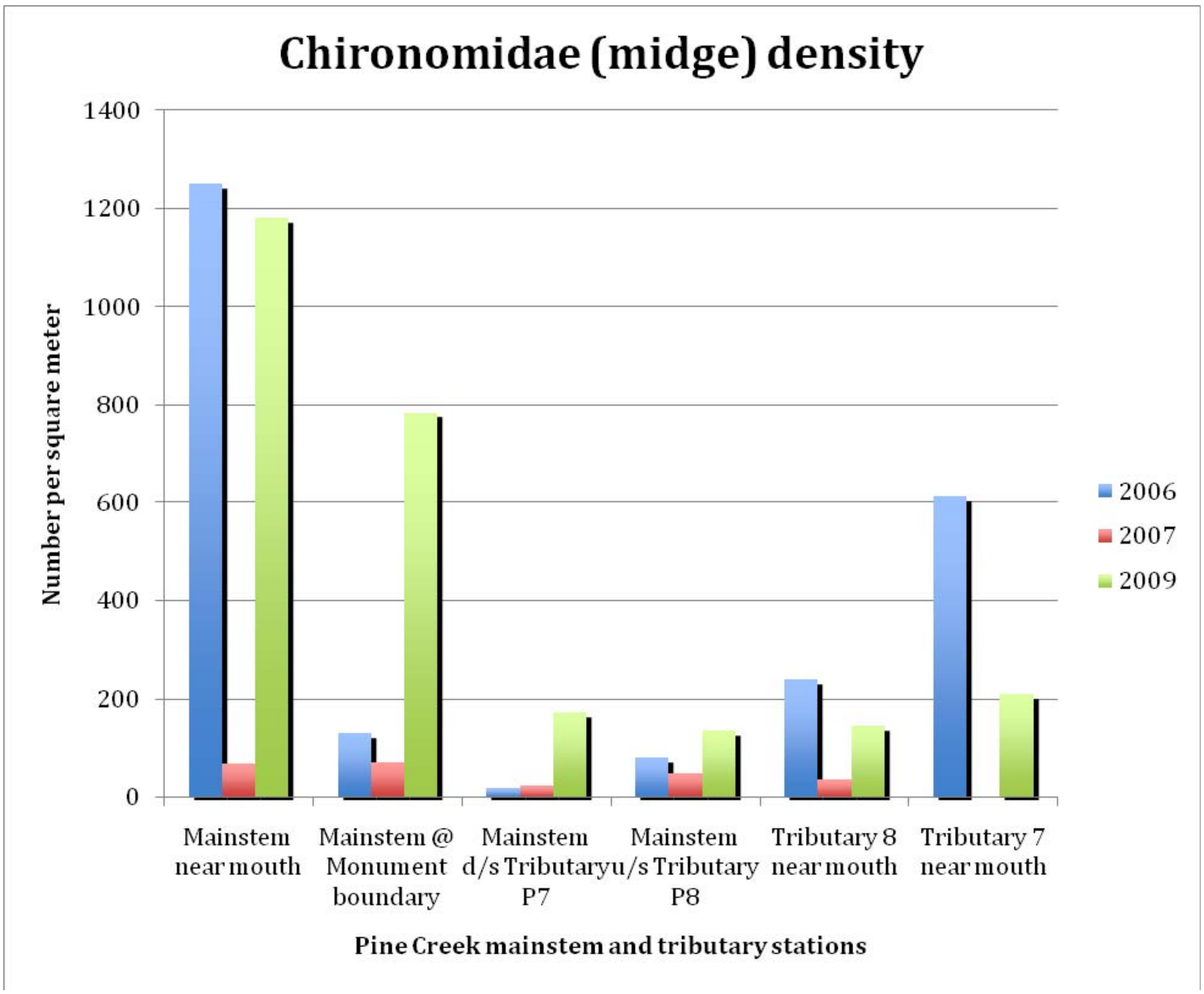
Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

### Table/Figure 9

**Chironomidae midge density per square meter**

| Stations | Years | | | Treatment |
|---|---|---|---|---|
| | 2006 | 2007 | 2009 | |
| Mainstem near mouth | 1250 | 69 | 1181 | Carcass enriched |
| Mainstem @ Monument boundary | 130 | 71 | 783 | Carcass enriched |
| Mainstem d/s Tributary P7 | 18 | 24 | 173 | Carcass enriched |
| Mainstem u/s Tributary P8 | 81 | 49 | 135 | Carcass enriched |
| Tributary 8 near mouth | 239 | 35 | 145 | Carcass enriched |
| Tributary 7 near mouth | 613 | 2 | 210 | Control, not enriched |



## Pine Creek Salmon Carcass Enrichment Study

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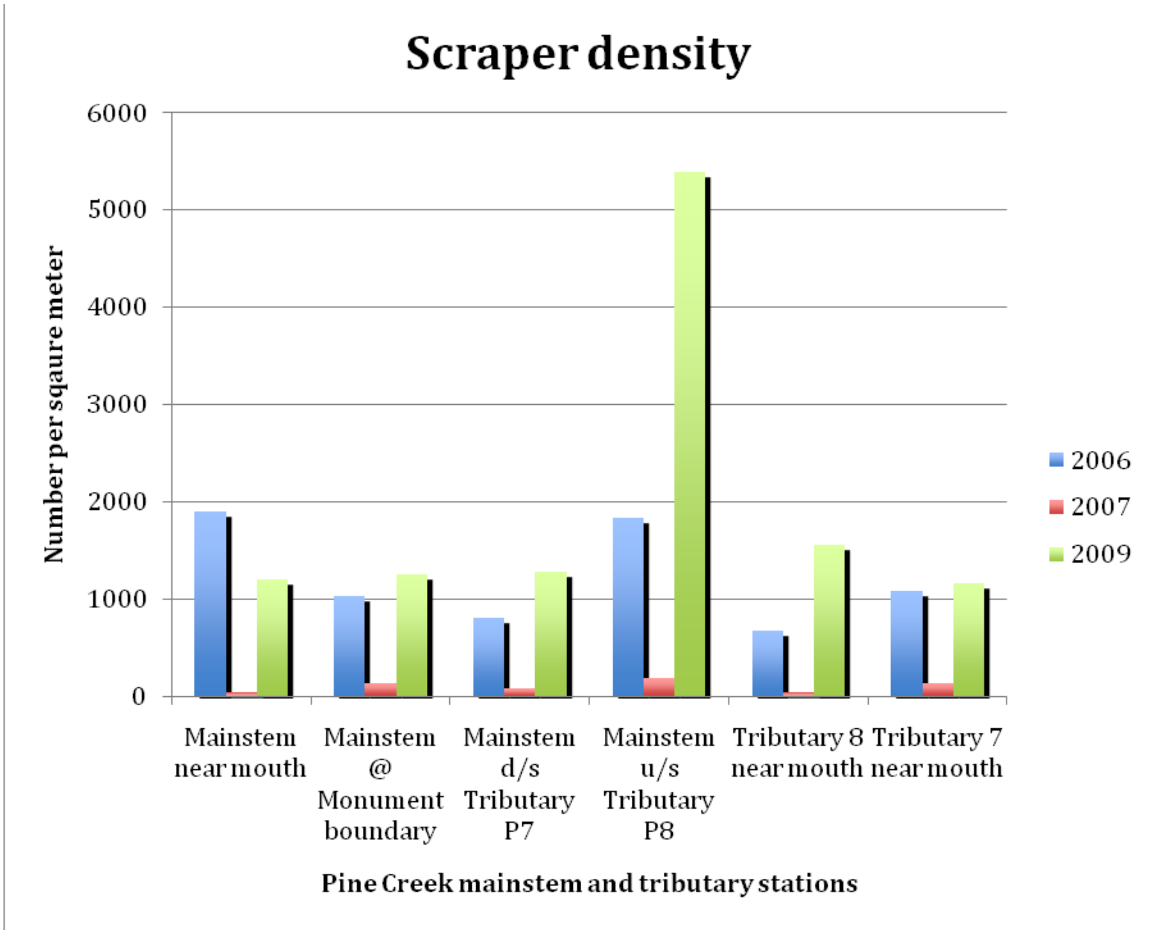
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.
Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

### Table/Figure 10
### Scraper density per square meter

| Stations | Years | | | Treatment |
|---|---|---|---|---|
| | **2006** | **2007** | **2009** | |
| Mainstem near mouth | 189 | 37 | 1203 | Carcass enriched |
| Mainstem @ Monument boundary | 102 | 136 | 1248 | Carcass enriched |
| Mainstem d/s Tributary P7 | 811 | 78 | 1276 | Carcass enriched |
| Mainstem u/s Tributary P8 | 1835 | 193 | 5388 | Carcass enriched |
| Tributary 8 near mouth | 681 | 48 | 1560 | Carcass enriched |
| Tributary 7 near mouth | 1086 | 137 | 1157 | Control, not enriched |



**Pine Creek Salmon Carcass Enrichment Study**

WA: Mount St. Helens National Volcanic Monument

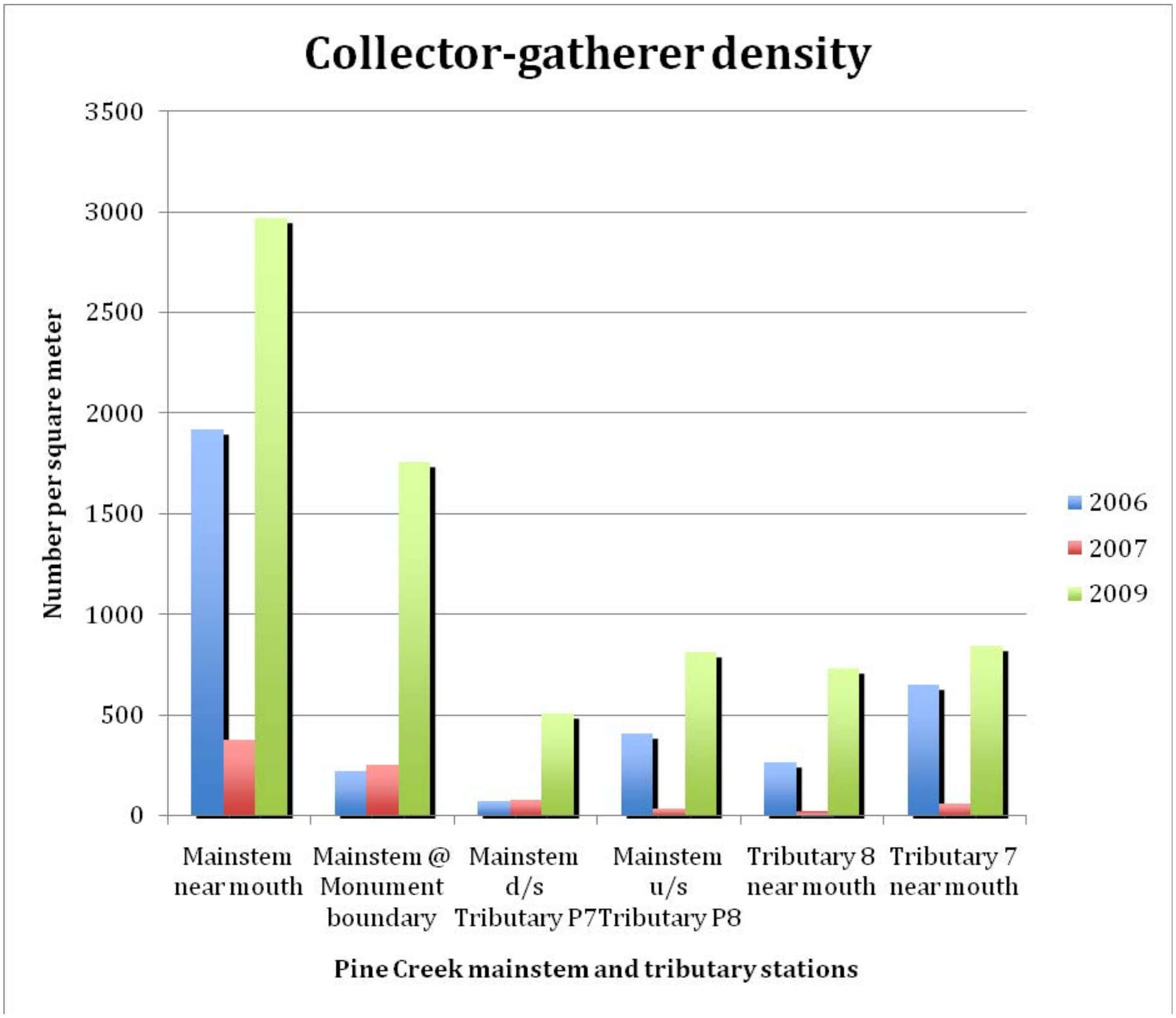
Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.

Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

**Table/Figure 11**

**Collector-gatherer density per square meter**

| **Stations** | | **Years** | | **Treatment** |
|---|---|---|---|---|
| | **2006** | **2007** | **2009** | |
| Mainstem near mouth | 1917 | 378 | 2972 | Carcass enriched |
| Mainstem @ Monument boundary | 221 | 250 | 1754 | Carcass enriched |
| Mainstem d/s Tributary P7 | 69 | 76 | 506 | Carcass enriched |
| Mainstem u/s Tributary P8 | 410 | 33 | 812 | Carcass enriched |
| Tributary 8 near mouth | 264 | 25 | 729 | Carcass enriched |
| Tributary 7 near mouth | 651 | 57 | 842 | Control, not enriched |



## Pine Creek Salmon Carcass Enrichment Study

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Mid-October sampling, multipoint composite sample, riffle habitat, 500 micron mesh.
Analysis by Aquatic Biology Associates, Inc., Corvallis, OR

### Table/Figure 12
### Shredder density per square meter

| Stations | Years | | | Treatment |
|---|---|---|---|---|
| | 2006 | 2007 | 2009 | |
| Mainstem near mouth | 1066 | 0 | 500 | Carcass enriched |
| Mainstem @ Monument boundary | 53 | 23 | 102 | Carcass enriched |
| Mainstem d/s Tributary P7 | 48 | 15 | 11 | Carcass enriched |
| Mainstem u/s Tributary P8 | 200 | 29 | 57 | Carcass enriched |
| Tributary 8 near mouth | 374 | 27 | 291 | Carcass enriched |
| Tributary 7 near mouth | 667 | 4 | 92 | Control, not enriched |