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Benthic Macroinvertebrate Monitoring at Seahurst Park 2006, Post-Construction of Seawall Removal

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KCD
King Conservation District

Key Words

Shoreline restoration, Puget Sound, benthic invertebrates, Talitridae, intertidal zone, shoreline modifications, juvenile salmon, Seahurst Park

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Executive Summary

This report describes the first post-construction restoration monitoring of benthic invertebrates at Seahurst Park, located on Puget Sound in the City of Burien. Shoreline modifications have altered many of the natural habitats in nearshore areas of Puget Sound. Restoration efforts completed in February 2005 at Seahurst Park removed a section of seawall along the shoreline and restored intertidal habitat. By incorporating pre-construction monitoring conducted in 2004 with this initial post-construction monitoring in 2006, we will be able to begin to assess the restoration effort. The main goal of this study was to compare the benthic macroinvertebrates at the project restoration site and a nearby reference beach to provide initial post-construction monitoring.

Ideally, the project site will one day closely match the reference site in terms of invertebrate densities, assemblages, and taxa richness. Increased densities means that the numbers of invertebrates will have increased since restoration, and improved assemblages and taxa richness means that the types and diversity of taxa will be similar to the reference beach. These improved conditions will presumably benefit juvenile salmon by providing increased prey resources for feeding.

Benthic cores were taken during three months (June, July, September) and at three different tidal heights (+12, +8 and +5’ MLLW), identical to the pre-construction monitoring. Results indicated that the benthic invertebrate assemblages have changed since the restoration activities, and in certain instances have become closer to those at the reference beach. This has all occurred after the first year of restoration, as the seawall removal concluded in February 2005, and post-construction monitoring was initiated in June 2006. At all elevations there were less differences between the project and reference site in September as compared to June and July, perhaps signifying development of the restored community throughout the sampling.

Overall, measurements showed that densities are still low and there are some differences in the assemblages between the project and the reference beaches. However, there was high taxa richness at the project beach throughout all elevations. This signifies that although the densities and assemblages are still progressing to that of the reference beach, there has been a good initial colonization in a variety of taxa. Furthermore, the previously modified seawall elevations of +12 and +8 have shown improvements since removal of the seawall, as illustrated by higher densities

in 2006 as compared to 2004. The +5 elevation seems to be most affected by the regrading of the beach, with distinct differences in invertebrate assemblages as compared to those from pre-construction and reference beach samples. It is unknown whether this is indicative of an early restoration stage, or due to physical alterations caused by the beach regrade and changes in sediment size. Future sediment samples at the +5 elevation would help to enlighten any such causal mechanisms.

The restoration at Seahurst Park has produced a promising initial response in the development of the benthic invertebrate community, although differences do still exist between the restored and reference beach. It will be important to continue to monitor the benthic invertebrate community in future years, in order to evaluate site development. By continuing to monitor, we can assess invertebrate community response after the initial disturbance of construction, and the extent to which the invertebrate community develops to be similar to the adjacent reference beach habitat. Future efforts should seek to more thoroughly link samplings and results with other physical and ecological monitoring, in order to more adequately assess the overall progression of the site. Such monitoring will be useful to help guide other restoration and enhancement activities along shorelines of Puget Sound, and benefit the recovery of endangered salmonids.

Introduction

Endangered ocean-type juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Pacific Northwest use estuarine and nearshore habitats early in their outmigration and rearing period (Simenstad et al. 1982). Since Chinook and other nearshore fishes utilize shoreline areas, the different habitat types that are represented can affect fish abundance, distribution, and behavior patterns (Toft et al. 2007). This is also true for invertebrates, which are an important prey component of many fish (Sobocinski 2003, Toft 2005). Nearshore habitat restoration often emphasizes these important invertebrates, with the goal of increasing their production to more natural levels and increasing ecological function of the site.

This study describes initial post-construction monitoring of the benthic invertebrates along the shoreline at Seahurst Park in the City of Burien, where restoration activities completed in February 2005 removed a section of seawall and restored supratidal and intertidal habitat, (Figs. 1-3; USCOE 2003). By incorporating pre-construction monitoring from 2004 (summarized in Toft 2005) with this initial post-construction monitoring in 2006, we will be able to begin to assess the restoration effort. The main goal of this study was to compare the benthic macroinvertebrates at the project restoration site and a nearby reference beach, in order to provide initial post-construction monitoring.

Material and Methods

Two sites were sampled: (1) the seawall removal project site at Seahurst Park (Proj), and (2) the reference beach (Ref) immediately south of Seahurst Park (Fig. 1). Invertebrates were collected at three different tidal heights that spanned the elevations affected by restoration (Fig. 2), in order to assess biota associated with different tidal elevations:

(1) MHHW at both sites, approximately +12’ MLLW (Fig. 4). This area is where beach-wrack is typically formed (the accumulation of debris deposited by an ebbing tide, consisting of marine algae and organic matter from terrestrial riparian sources such as wood and leaves), and is at an elevation where seawall material was removed at the project site.

(2) The foot of the previous shoreline modification at the project site (approximately +8’ MLLW; Fig. 5) and at the same tidal height in the reference site. This provides comparable data at the elevation where the shoreline modification previously interacted with the water.

(3) +5’ MLLW at both sites, the low elevation of the beach regrade.

Seven samples were randomly collected along a 100 ft transect with a benthic core at each site and tidal elevation (Figs. 4, 5). Benthic cores were 10 cm in diameter and taken to a depth of 15 cm (Fig. 6). Cores were taken once a month during June, July and September. June and July represent peak periods of juvenile Chinook and coho (*Oncorhynchus kisutch*) salmonid migration, and September represents high vegetation-wrack depositions. These months and methods are also comparable to previous datasets (Sobocinski 2003, Toft 2005).

Samples were fixed in 10% formalin and dyed with rose-bengal to aid in sorting and identification. In the laboratory they were transferred to isopropanol for preservation. Cobble, mud, wood, and other detritus were removed to the extent possible with sieving (to 500 microns), and macroinvertebrates were identified and counted using a dissecting microscope (Fig. 7).

Data was entered into Microsoft Excel, and univariate ANOVA tests (alpha = 0.05) were used to analyze total invertebrate densities in the statistical program S-Plus (Zar 1996). Taxa richness was measured as the total number of taxa recorded at each site.

Invertebrate assemblages were analyzed using multivariate statistics: nonmetric multidimensional scaling (NMDS) ordination, analysis of similarity (ANOSIM), and similarity percentage (SIMPER) analysis (Primer version 6 software, Clarke and Warwick 2001). These analyses uncover patterns in multivariate groupings of the data, which is helpful when analyzing datasets with multiple species compositions.

Densities were log-transformed for ordination, and species that did not account for more than 3% of the total abundance of any one sample were not included. NMDS was used to graphically plot differences in species assemblages onto two-dimensional charts in multidimensional space based on a Bray-Curtis similarity matrix, thus the axes have no scale. ANOSIM has been widely used for testing hypotheses about spatial differences and temporal changes in species assemblages as well as for detecting environmental impacts (Chapman and Underwood 1999, Valesini et al. 2004). ANOSIM gives a p-value similar to an ANOVA, with values of $p < 0.05$ indicating significance. ANOSIM also generates a value of R to determine biological importance. The R value is scaled between -1 and +1, with a value of zero representing no difference among a set of samples, and the closer the value to 1 the greater the biological importance of the differences. In ANOSIM, comparison of pair-wise R values, measuring how separate groups are on a scale of 0 (indistinguishable) to 1 (completely separated) gives an interpretable number for the difference between groups. When differences were found using ANOSIM, then SIMPER analysis was used for identifying which species primarily accounted for observed differences in invertebrate assemblages between sites. SIMPER generates a ranking of the percent contribution of the species that are most important to the significant differences between factors.

Results

2006 Post-Construction Benthic Invertebrates

Results of ANOVA tests on total invertebrate densities indicated that densities were significantly greater at the reference site as compared to the project site (Table 1). The only exception to this was in September when there were no differences at Ref +12 and greater densities at Proj +8.

In 2006, the Project site exceeded the Reference site in taxa richness for every elevation (Table 2). At Proj +8, taxa richness was considerably higher in 2006 as compared to 2004.

For taxa grouped into general categories, the most abundant groups were oligochaetes, aquatic crustaceans, terrestrial amphipod/isopods, polychaetes, nematodes, and nemertea/turbellaria (Fig. 8). Oligochaetes were the most abundant taxa, and were greater at Reference sites except at Proj +8 in September. There were especially low numbers of oligochaetes at Proj +5 in June and July. Nematodes were relatively abundant at most sites, except for low numbers at Ref +5. Nemertea and turbellaria tended to be most abundant at the Ref +8 and Ref +12 sites.

Densities of terrestrial amphipods and isopods (mostly beachhopper amphipods in the family Talitridae) were most abundant at the +12 elevation, with lower densities at +8, and only one occurrence at +5 (Fig. 9; Table 3). While juvenile talitrids usually dominated beachhopper numbers, adults of three species occurred: *Traskorchestia georgiana, Traskorchestia traskiana,* and *Megalorchestia pugettensis* (listed in order of ascending maximum size). Densities of talitrids varied by month, with greater numbers at Ref +12 in June, about equal numbers in July, and greater numbers at Proj +12 in September. At Ref +12 the larger species *M. pugettensis* had greater proportions especially in July, while at Proj +12 the smaller *Traskorchestia* spp. had greater proportions in July and September.

As a group, insects (adults and larvae), arachnids (mites-acarina and spiders-araneae), and collembolans (springtails in families Hypogastruridae, Isotomidae, and Sminthuridae) had overall fairly low numbers, and were most abundant at the +12 and +8 elevations (Fig. 10; Table 3). The most common taxa were acarina, Hypogastruridae, Ephydridae diptera larvae in June, adult Sphaeroceridae diptera in September, coleoptera (beetle) larvae, and adults of the coleopteran family Staphylinidae. Densities at the Project site were typically equal to or higher than those at the Reference site.

As would be expected, aquatic crustaceans were more abundant at lower tidal elevations, with the majority occurring at the +5 tidal level (Fig. 11; Table 3). Ref +5 greatly exceeded Proj +5 in numbers of aquatic crustaceans, especially the amphipods *Eogammarus confervicolus*, *Allorchestes* spp. (mostly the species *A. angusta*), and *Paramoera* spp. (mostly the species *P. bousfieldi* and *P. mohri*), and the isopod *Gnorimosphaeroma oregonense*. The isopod *Exosphaeroma inornata* was the only species of any abundance at Proj +5.

Similar to crustaceans, only a few taxa of polychaete worms were relatively abundant in the samples. Polychaetes had highest densities at the +5 elevation, except for the small archiannelid *Protodriloides chaetifer*, which had a large peak in abundance at Ref +8 in July (Fig. 12; Table 3). The glycerid *Hemipodia simplex* was common at Proj +5, while the family Nereidae was most common at Ref +5, both reaching highest abundances in July.

There were no major trends in densities of aquatic mollusks, and numbers were very low compared to other taxa (Fig. 13; Table 3). Densities were greatest at lower elevations, and most were juvenile mussels, most likely of the abundant intertidal species *Mytilus edulis.*

Multivariate analysis of the 2006 benthic invertebrate assemblages based on densities proved to be a “useful” model according to statistical guidelines (stress less than 0.2 considered useful; (Clarke and Warwick 2001), showing a NMDS ordination 2-d stress of 0.1 for June, and 0.14 for July and September (Fig. 14). These low stress levels mean that the ordination plots are useful representations of the groupings of data points based on the overall invertebrate assemblages in each sample. For all months, the three different elevations grouped separately, and the +5 elevation had the greatest separation between Ref and Proj. Ref and Proj also grouped separately at the +8 and +12 elevations, although the clusters were closer together than at +5.

These differences in the ordination plots of the overall invertebrate assemblages were further analyzed with ANOSIM and SIMPER statistical tests. 1-way ANOSIMS on sites for each month show that all of the Ref and Proj sites for each elevation have significantly different invertebrate assemblages ($p < 0.05$) with high biological separation ($R > 0.04$) especially at the +5 elevation (Table 4). SIMPER analysis for all months combined shows the species which most contribute to these significant differences (Table 4), summarized as: (1) at +12 elevation, differences in species of Talitridae amphipods and nemertea at Ref, (2) at +8 elevation, turbellaria at Ref, and minor difference in densities of nematodes and oligochaetes, and (3) at the +5 elevation, amphipods, isopods, and oligochaetes at Ref, and the polychaete *Hemipodia simplex* at Proj.

As a further example of these invertebrate assemblage differences, the ordination plot from June is shown along with bubble plots of the densities of four key taxa for each sample (juvenile Talitridae, turbellaria, *Eogammarus confervicolus*, and *Hemipodia simplex;* Fig. 15). There is a clear separation of both elevation and Ref/Proj, with the greatest difference at the +5 elevation.

Comparison of Pre- and Post-Construction Benthic Invertebrates

For general taxa categories, the +12 elevation Project site had lower densities in 2006 as compared to both 2004 and 2006 levels at the Reference site, but had somewhat similar overall taxa composition (Fig. 16). Proj +8 had much higher densities in 2006 than it did in 2004, while Proj +5 had lower densities, fewer amphipods, and more glycerids in 2006 than in 2004.

ANOVA tests were conducted on total invertebrate densities between Project sites in each year for each elevation and month, summarized in Table 5 (at the +12' elevation in 2004 the Reference site was used, as there was no comparable Project elevation before removal of the seawall). At both the +12 and +5 elevations, June and July densities were higher in 2004, with no difference in September. At the +8 elevation, densities were significantly higher in 2006 during September, with no differences in June and July.

Overall taxa richness in 2006 was greater by five taxa, as compared to 2004 (Table 2). Most between-year differences in taxa richness were minor, except at the Proj +8 site, where number of taxa in 2006 was almost twice that of 2004.

Multivariate analysis of the 2004 and 2006 benthic invertebrate assemblages at the Project site based on densities proved to be a "useful" model according to statistical guidelines (stress less than 0.2 considered useful; (Clarke and Warwick 2001), showing a NMDS ordination 2-d stress of 0.18 for all months combined (Fig. 17). Project sites in 2004 and 2006 grouped distinctly, but there was some overlap especially at the +12 and +8 elevations, with most separation at the +5 elevation.

1-way ANOSIMS on the same 2004 and 2006 data showed that the groups detected by NMDS had significantly different invertebrate assemblages ($p < 0.05$) at Project sites for each elevation, but with low biological separation at the +12 and +8 sites ($R < 0.2$), and moderate biological separation at +5 ($R < 0.4$; Table 6). SIMPER analysis on general taxonomic groupings showed that the taxa most contributing to these significant differences (Table 6) were: (1) at +12 elevation, low biological separation was caused by less terrestrial amphipods and more nematodes in 2006, (2) at +8 elevation, low biological separation was caused by more nematodes, oligochaetes, and collembola in 2006, and (3) at the +5 elevation, moderate biological separation was caused by more oligochaetes, amphipods, and turbellaria in 2004, and more glycerids in 2006.

Discussion

Pre-construction monitoring of benthic macroinvertebrates in 2004 illustrated that the seawall and reference sites were different, based on samples from the three different tidal elevations (Toft 2005). The Proj +8 site at the base of the seawall had low overall densities and was depleted in invertebrates that were typical at the Ref +12 site. The presence of the seawall also caused other physical alterations such as coarsening of gravel and increased wave energy (Sobocinksi 2003).

The results of initial post-construction monitoring in 2006 shows that the benthic invertebrate assemblages have changed after the restoration activities, and in certain instances have become closer to those at the reference beach. This has all occurred in a period of one year after the restoration: seawall removal concluded in February 2005, and post-construction monitoring was initiated in June 2006. Thus, it appears that even a relatively short post-construction recovery period can allow time for the invertebrate community to at least partially recruit and establish on the restored beach. Furthermore, at all elevations there were fewer differences between the project and reference site in September as compared to June and July, perhaps signifying continuing development of the community at the restored site throughout the sampling.

Results of the invertebrate sampling can best be discussed in relation to the different tidal elevations, as detailed by the restoration activities at each elevation. At the +12 elevation, there was previously a seawall that truncated the intertidal zone, preventing a benthic assemblage from developing at this elevation prior to restoration. It is clear that invertebrates have occupied this site since restoration, as taxa richness was higher at Proj +12 than Ref +12. However, overall densities are still progressing to that of the reference beach, as only in September were the densities statistically the same, with higher densities at Ref +12 in June and July. Terrestrial amphipods (beachhoppers in the family Talitridae) are typical of this elevation, and although they were present at the restoration site, the major species at the two sites were different. However, it is promising that the invertebrate assemblages are generally similar, and that there are only minimal differences with the pre-construction assemblage, suggesting that with time the restoration site will more closely approach that of the reference beach.

The +8 elevation was previously the location of the base of the seawall, and therefore subject to physical alterations in sediments and wave activity that altered the invertebrate community (i.e., pre-restoration results). Invertebrates have also rapidly occupied this site since restoration, resulting in a taxa richness that was higher at Proj +8 than Ref +8, and almost double that of pre-restoration levels. The benthic invertebrate community may still be stabilizing at the restored beach, as in June and July densities were higher at Ref +8, but by September they were greater at Proj +8. Evidence for a stabilization process also occurs in comparison to pre-construction levels, as by September the 2006 densities were greater than that in 2004. Also, taxa compositions are generally similar between the two sites, but with different densities or variations between months. Hopefully these positive post-restoration trends will continue in future years.

The +5 elevation was at the low level of the regrade of the restored beach, and is the elevation with the most differences both pre- and post-restoration and between the reference and restored beaches. Overall taxa richness was similar to that of pre-construction levels, and was actually highest at Proj +5. However, densities were greater at Ref +5 for every month of sampling in 2006, and Proj +5 densities were lower in 2006 than in 2004 for June and July.

There were notable differences in the assemblage structure between both the reference and restored beach and the sampling years; the Proj +5 site had less amphipods and oligochaetes, and more Glyceridae polychaete worms. The reasons for this are unknown, and could be indicative of an early restoration stage. However, the differences could also be the result of different habitat qualities specific to the restored and reference sites, such as physical alterations caused by the beach regrade and changes in sediment size. Although sediment sizes were not sampled at this elevation, we observed that sediments were smaller at the restoration site than at the reference beach. Future sampling may help to explain these types of differences, if invertebrate communities converge with time, or if more physical data is collected at this elevation.

It is important to compare these results to other studies that have been conducted during the Seahurst restoration. Completed or planned post-construction monitoring includes: beach profile and sediments, eelgrass, forage fish spawning, and Seattle Aquarium citizen science monitoring. Initial eelgrass monitoring has shown no observations of construction-related impacts to eelgrass distributions (Anchor 2005). Sediments analyzed from +8.5 and +11’ MLLW elevations have shown that the material used to restore the beach was similar to the reference area and was suitable for the site (Johannessen and Chase 2005). These results illustrate that the impacts of construction were minimal, and that the physical restoration of the beach is similar to the reference beach. However, future sampling should seek to have more cohesion and interaction between the monitoring components, which so far have been operating somewhat independently of each another. Additional post-construction funding and monitoring will hopefully encourage these interactions; for example, planning to analyze sediment samples during the same time period as benthic invertebrates, and adding a sediment transect at the +5’ MLLW elevation in order to gain insight into observed differences in invertebrate assemblages.

Other types of ecological monitoring that have proved informative elsewhere could be considered for future monitoring efforts at Seahurst Park. Previous datasets sampling with insect fallout traps have shown that the Seahurst reference site has a productive riparian zone, as it had the greatest taxa richness and difference in density and diversity between the beach and seawall site (Sobocinksi 2003). Insects have not been sampled since restoration, and would be a good addition to monitoring the progression of the site. Since the removal of the seawall, presumably both benthic invertebrates and terrestrial insects have been made more available to juvenile salmonids as potential prey items, although fish and their diets have not been sampled. Snorkel surveys were tested in 2006 to assess their feasibility at the site, specifically around the fallen trees that project into the water at the reference site (conducted on a high tide at 7:30 A.M. on July 13, 2006). Snorkeling was successful at observing underneath the fallen trees, and two pairs of large trout were observed in shallow water under two different logs (ranging 15-27.5 cm in length, 1.0-1.5 m water depth). Other species observed were smelt, flatfish, and crabs; many snorkel transects would be needed in order to properly survey the site, due to the gradual slope and broad expanse of the beach. Beach seines could also be used as a general characterization of the fish community, and enclosure nets would allow for the holding of fish for several hours at different habitat types to test feeding patterns (Cordell et al. 2006, Toft et al. 2007).

In conclusion, although there are still some differences between the restored and reference sites, the restoration at Seahurst Park has resulted in a positive initial response in the development of the benthic invertebrate community. It will be important to continue to monitor the benthic invertebrate community and other biotic habitat attributes in future years, in order to assess site development. By continuing to monitor, we can continue to document invertebrate community response after the initial disturbance of construction, and the extent to which the invertebrate community converges with the adjacent reference beach habitat. Future efforts should seek to more thoroughly link samplings and results with other physical and ecological monitoring, in order to more adequately assess the overall progression of the site. Such monitoring will be useful to help guide other restoration and enhancement activities along shorelines of Puget Sound, and benefit the recovery of endangered salmonids.

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Figures

Figure 1. Location of Project and Reference transects at Seahurst Park, pre-restoration.

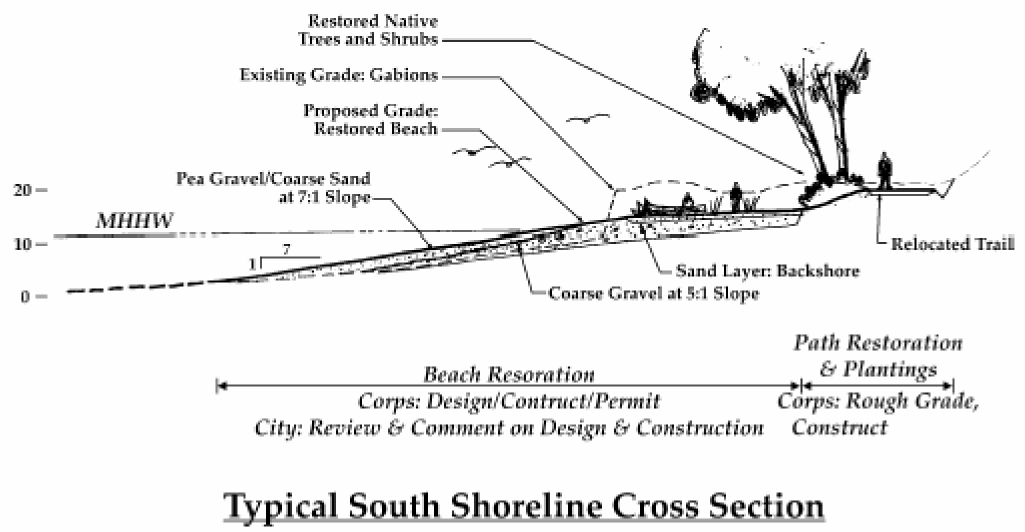


Figure 2. Plan for shoreline restoration at Seahurst Park (USCOE 2003).

Figure 3. Restoration site after removal of the seawall.

Figure 4. Transect for benthic invertebrate sampling at the reference beach site, +12’ MLLW.

Figure 5. Transect for benthic invertebrate sampling at the seawall restoration site +8' MLLW, pre-construction.

Figure 6. 10 cm diameter core used for sampling benthic invertebrates to a 15 cm depth.

Figure 7. A benthic sample after sieving and removal of cobble and other detritus, with application of the red dye rose-bengal to aid in processing. The large organisms are terrestrial amphipods (Talitridae).

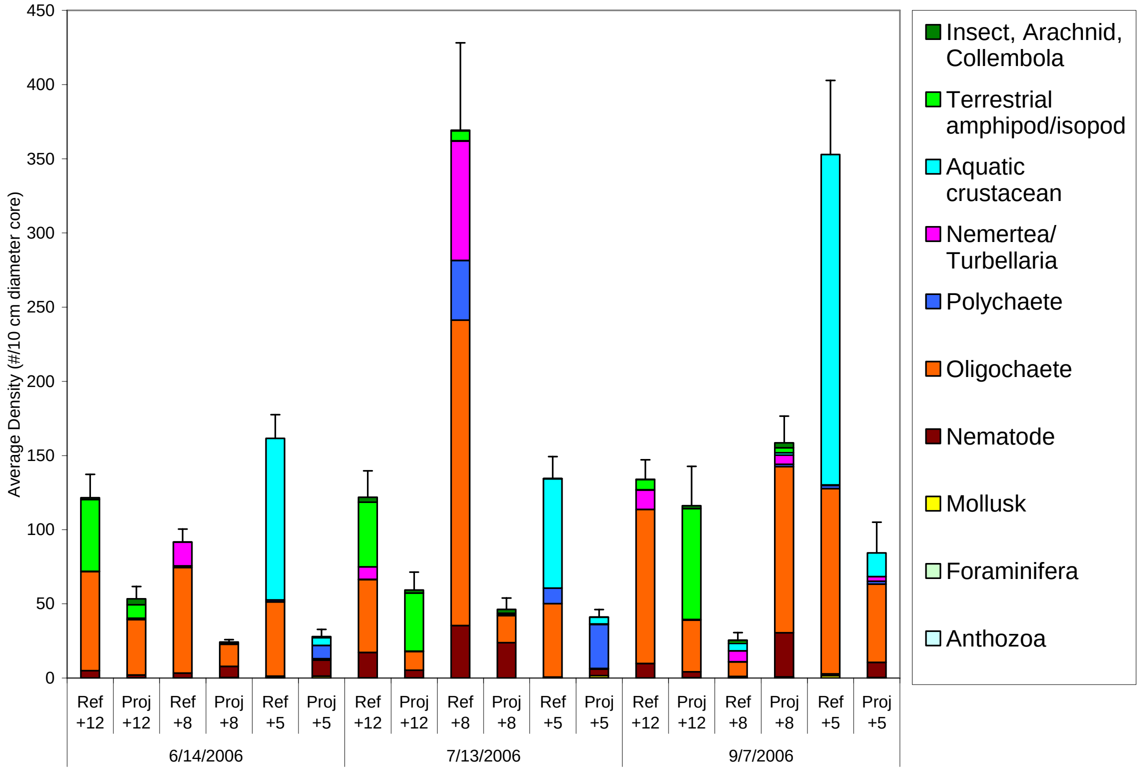


Figure 8. Average densities and general taxa composition of all sampled invertebrates. Order in legend reflects that in columns, rare taxa may not be visible in graph. Error bars represent standard error. Ref=Reference, Proj=Project.

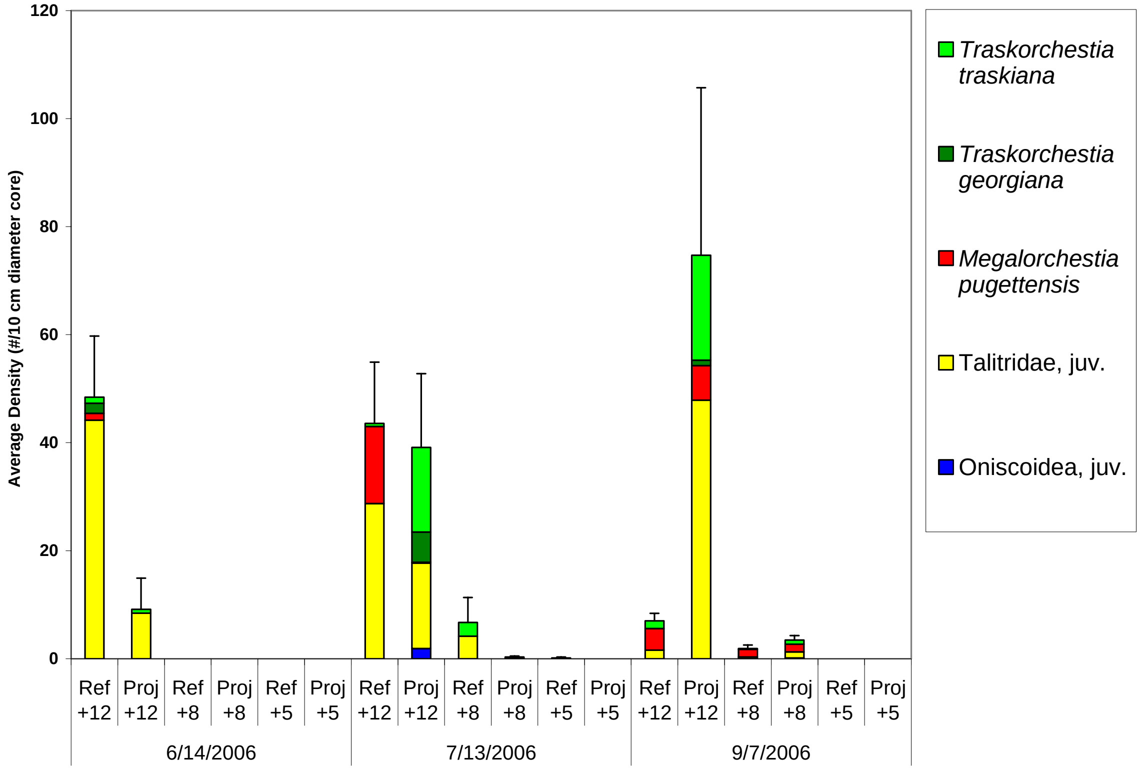


Figure 9. Average densities and taxa composition of terrestrial amphipods (three species of Talitridae) and isopods (Oniscoidea).

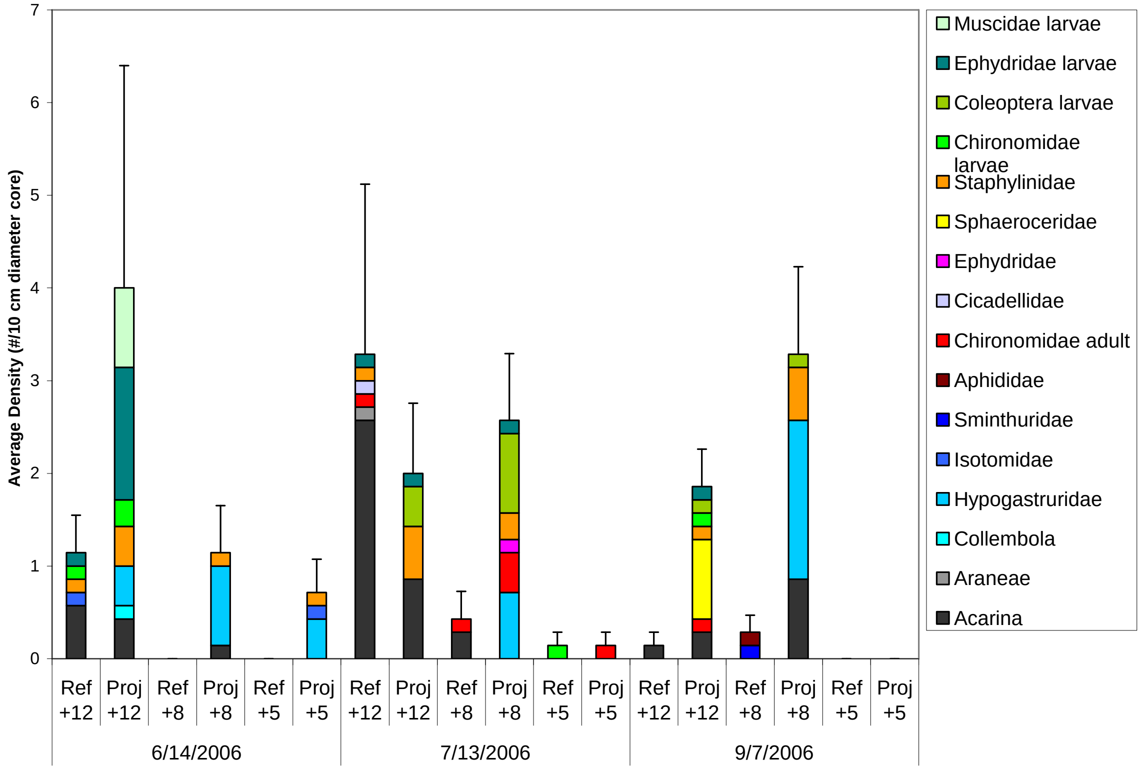


Figure 10. Average densities and taxa composition of insects, arachnids, and collembola.

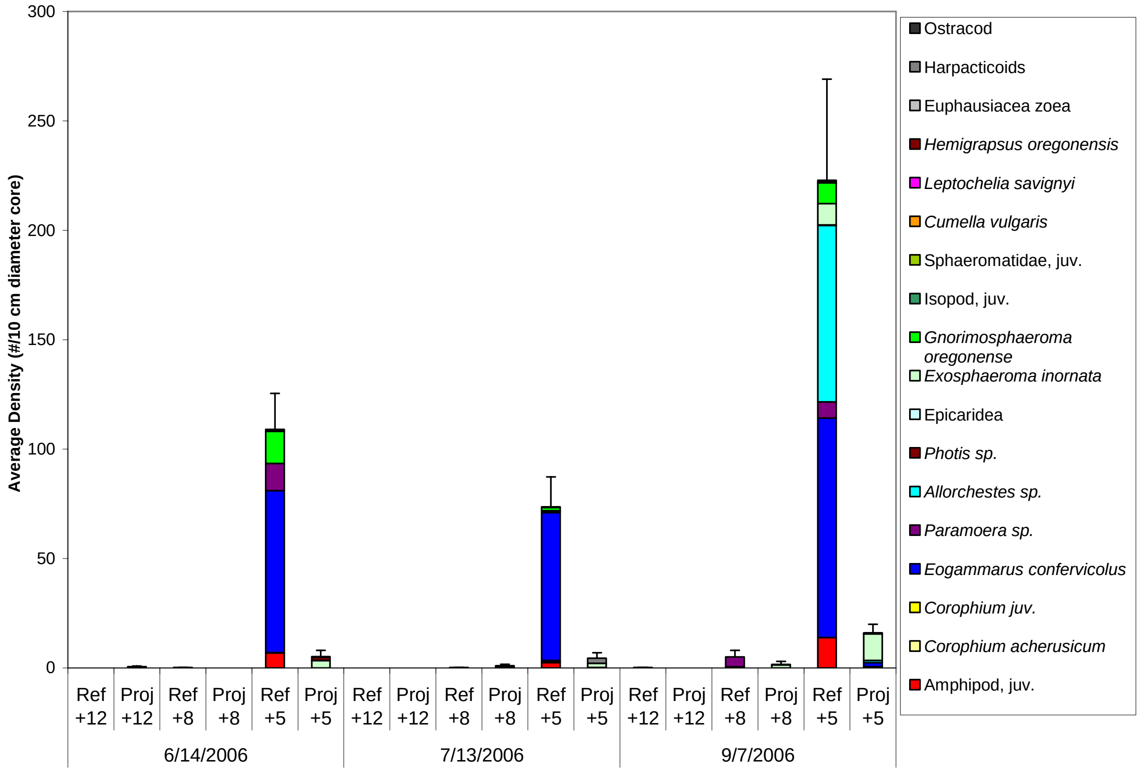


Figure 11. Average densities and taxa composition of aquatic crustaceans.

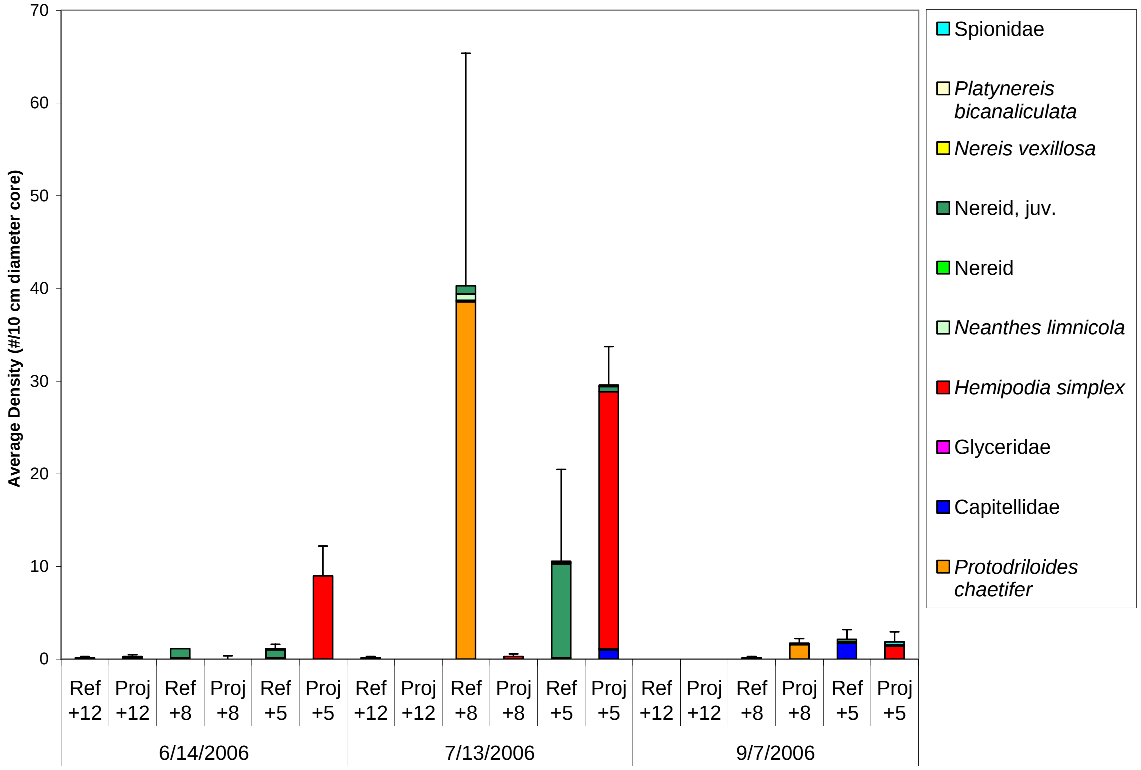


Figure 12. Average densities and taxa composition of polychaete worms.

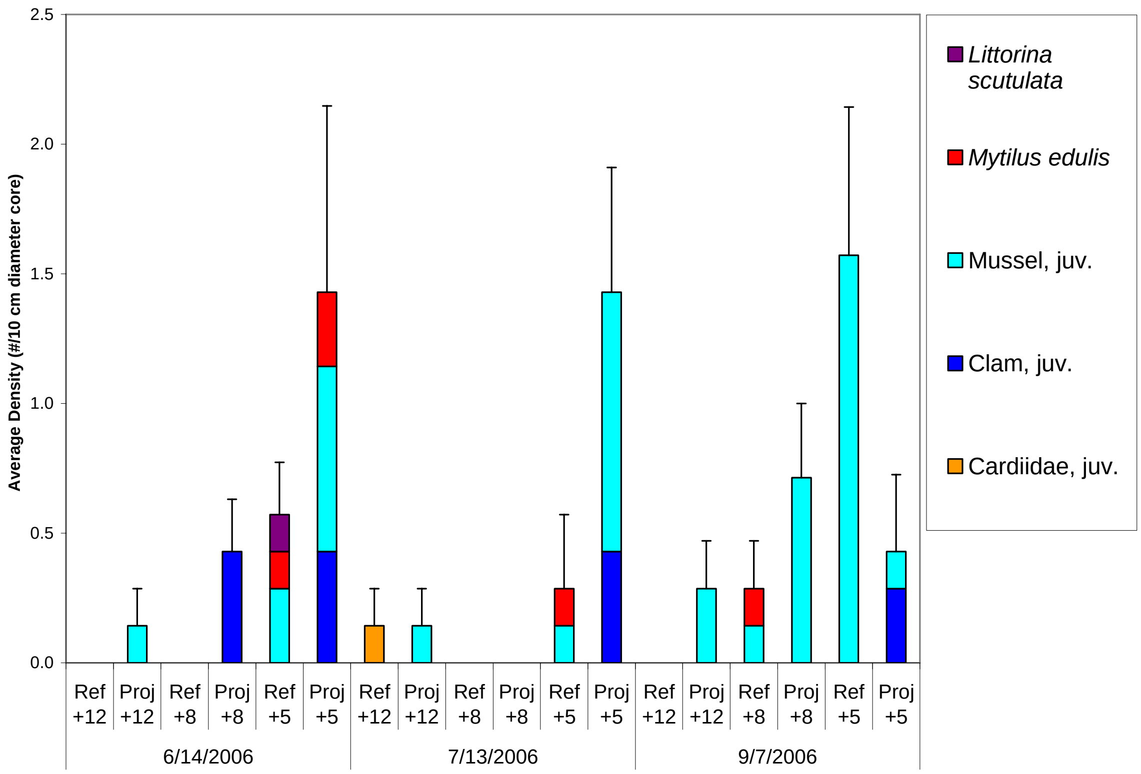


Figure 13. Average densities and taxa composition of aquatic molluscs.

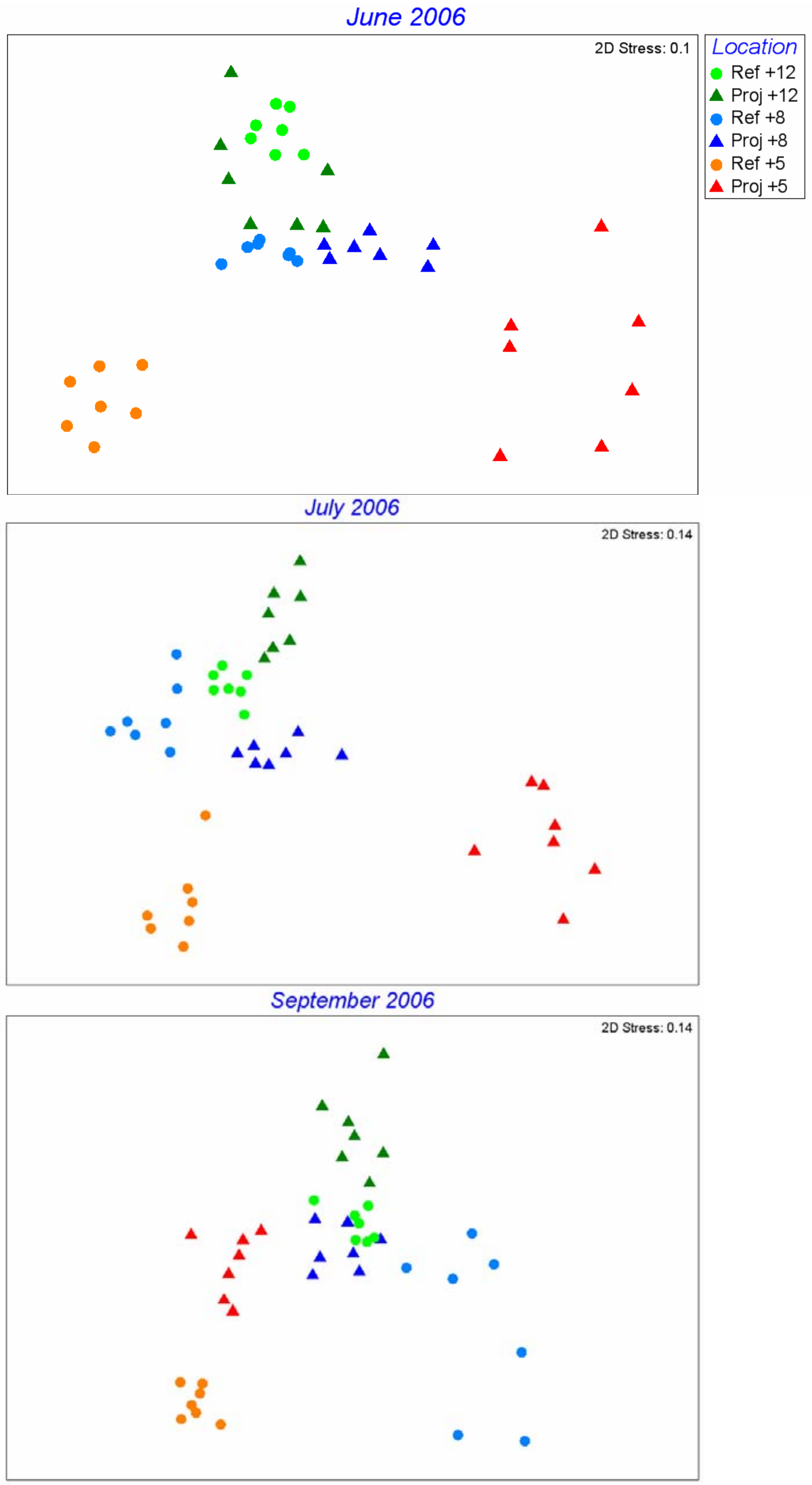


Figure 14. Multivariate analysis of the benthic invertebrate data for each month in 2006, using NMDS ordination. Each symbol represents an individual sample.

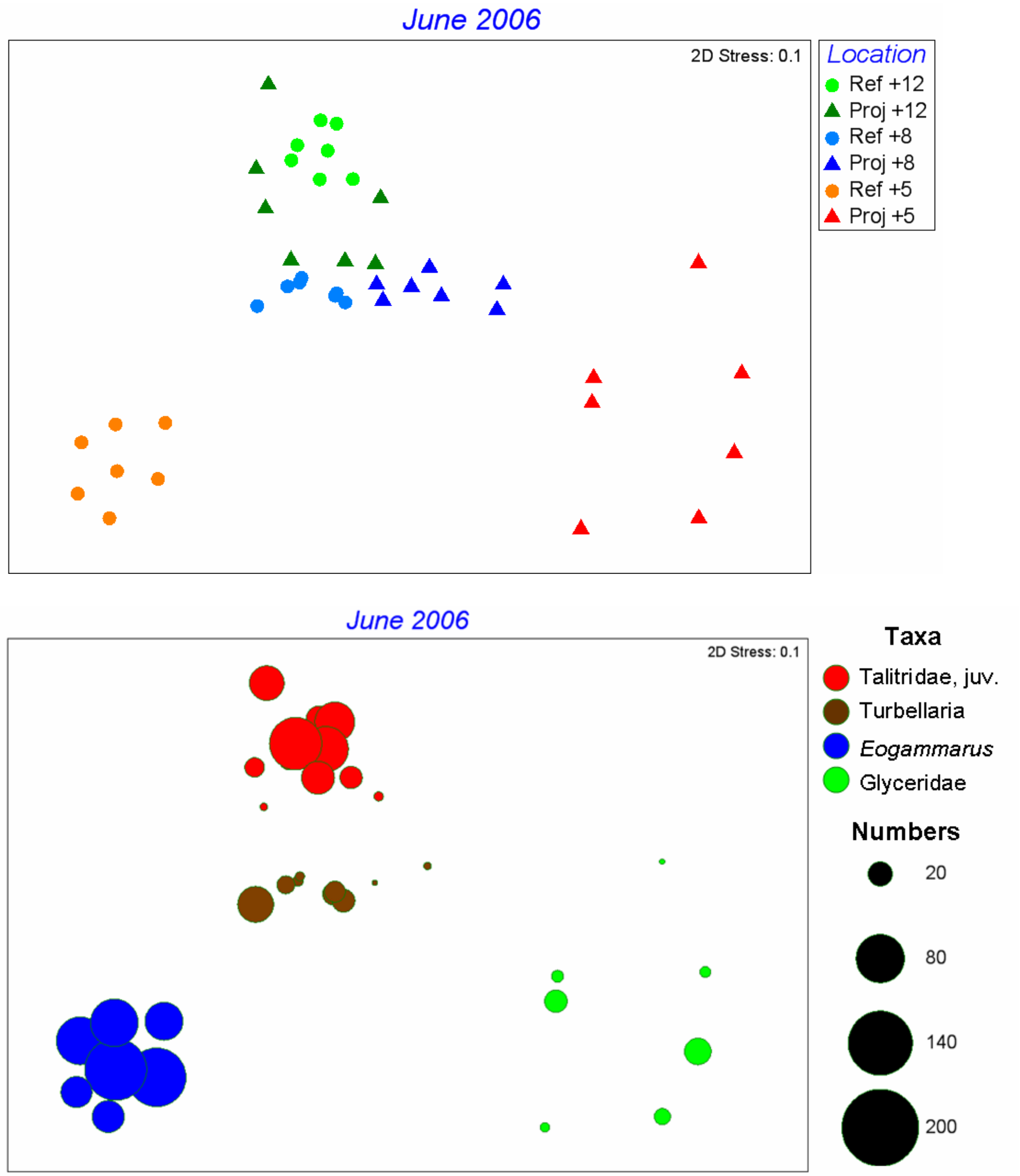


Figure 15. Multivariate analysis of the benthic invertebrate data for June 2006, using NMDS ordination and bubble plot of numbers of representative taxa: juvenile terrestrial amphipods (Talitridae), flatworms (Turbellaria), aquatic amphipods (*Eogammarus confervicolus*), and the polychaete *Hemipodia simplex* (Glyceridae). Symbols are in the same location in each plot.

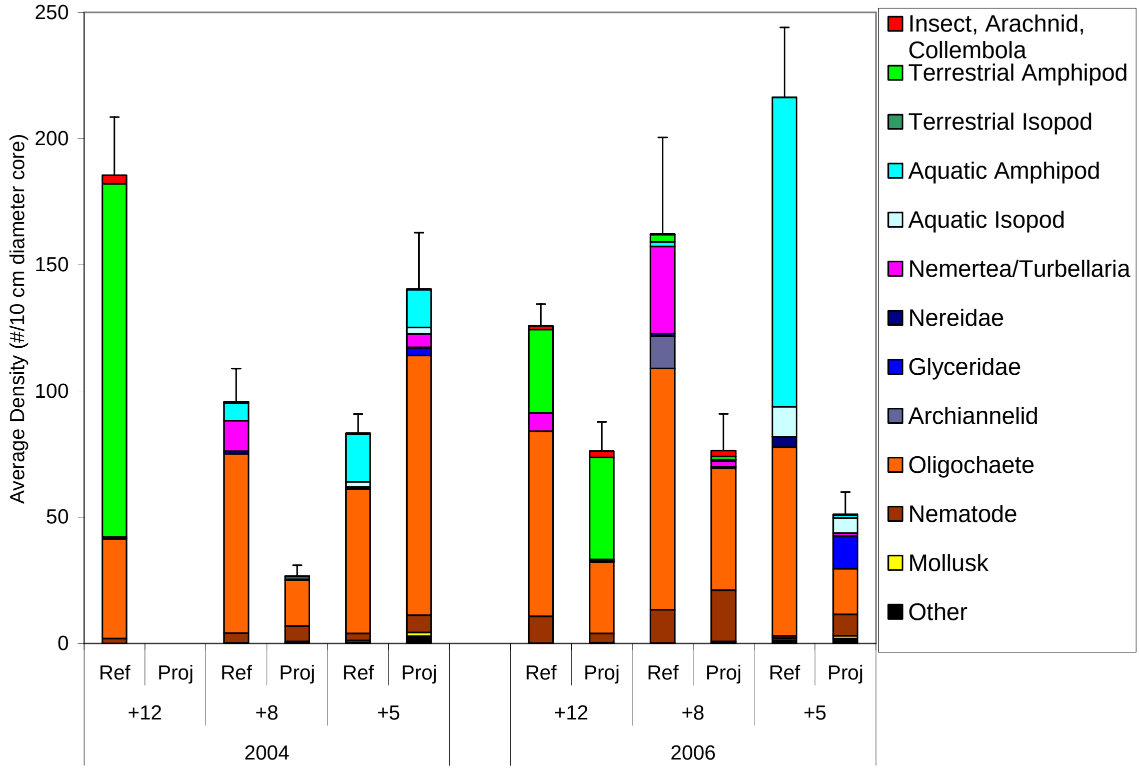


Figure 16. Average densities and general taxa composition of all sampled invertebrates compared between 2004 (pre-restoration) and 2006 (post-restoration), averaged across June, July, and September for each year.

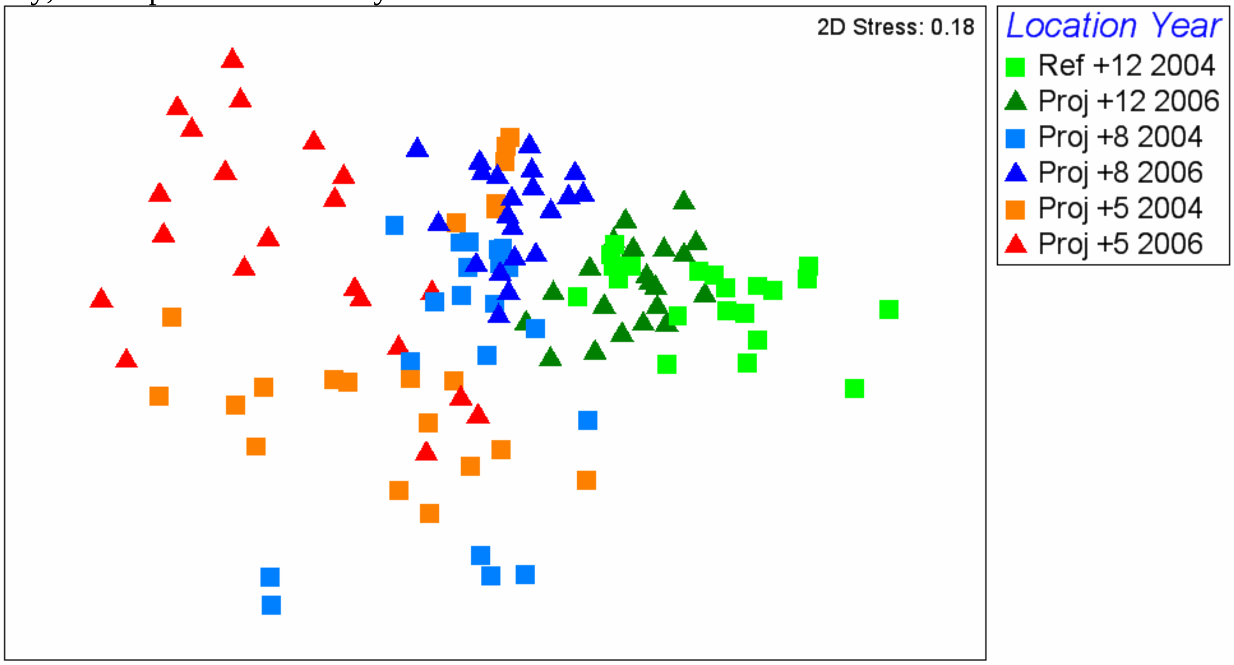


Figure 17. Multivariate analysis of the benthic invertebrate data compared between 2004 (pre-restoration) and 2006 (post-restoration) at the Project site, using NMDS ordination. At the +12' elevation in 2004 the Reference site was used, as there was no comparable Project elevation before restoration. Each symbol represents an individual sample.

Tables

Table 1. Summary ANOVA p-values of Total Invertebrate significant differences between Reference and Project sites for each elevation and month in 2006, values in column indicate significantly greater densities for either Reference or Project.

Elevation	Date	Reference	Project
12'	June	0.0024	
	July	0.013	
	Sept	-	-
8'	June	0.0000068	
	July	0.00015	
	Sept		0.000012
5'	June	0.0000037	
	July	0.000064	
	Sept	0.00032	

Table 2. Taxa Richness of benthic invertebrates in both 2004 and 2006.

Site	2004	2006
Ref +12	22	20
Proj +12	X	24
Ref +8	18	21
Proj +8	14	26
Ref +5	26	26
Proj +5	34	32
Total	61	66

Table 3. Average densities of benthic invertebrates, and taxa listings. R=Reference, P=Project.

		6/14/06						7/13/06						9/7/06					
Taxa Groupings	Taxa	R+12	P+12	R+8	P+8	R+5	P+5	R+12	P+12	R+8	P+8	R+5	P+5	R+12	P+12	R+8	P+8	R+5	P+5
Terrestrial Amphipods	*Traskorchestia traskiana*	1.1	0.7	0.0	0.0	0.0	0.0	0.6	15.7	2.6	0.1	0.0	0.0	1.4	19.4	0.1	0.7	0.0	0.0
	Traskorchestia georgiana	1.9	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
	Megalorchestia pugettensis	1.3	0.0	0.0	0.0	0.0	0.0	14.3	0.1	0.0	0.0	0.0	0.0	4.0	6.4	1.4	1.4	0.0	0.0
	Talitridae, juv.	44.1	8.4	0.0	0.0	0.0	0.0	28.7	15.9	4.1	0.1	0.1	0.0	1.6	47.9	0.3	1.1	0.0	0.0
Terrestrial Isopod	Oniscoidea, juv.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Arachnids	Acarina	0.6	0.4	0.0	0.1	0.0	0.0	2.6	0.9	0.3	0.0	0.0	0.0	0.1	0.3	0.0	0.9	0.0	0.0
	Araneae	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Collembola	Collembola	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hypogastruridae	0.0	0.4	0.0	0.9	0.0	0.4	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0
	Isotomidae	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sminthuridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Insects	Aphididae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	Chironomidae adult	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.4	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
	Chironomidae larvae	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Cicadellidae	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Coleoptera larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.9	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
	Ephydridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ephydridae larvae	0.1	1.4	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Muscidae larvae	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Sphaeroceridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
	Staphylinidae	0.1	0.4	0.0	0.1	0.0	0.1	0.1	0.6	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.6	0.0	0.0
Aquatic Crustaceans	*Hemigrapsus oregonensis*	0.0	0.0	0.0	0.0	0.7	1.4	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.9	0.0
	Cumella vulgaris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	Leptochelia savignyi	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Exosphaeroma inornata	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.3	2.0	0.0	0.0	0.0	1.4	9.7	12.1
	Gnorimosphaeroma oregonense	0.0	0.0	0.0	0.0	14.7	0.1	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.1	9.6	0.1
	Sphaeromatidae, juv.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	Epicaridea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isopod, juv.	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Allorchestes sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.7	1.0
	Eogammarus confervicolus	0.0	0.0	0.0	0.0	74.0	0.0	0.0	0.0	0.0	0.0	67.6	0.0	0.0	0.0	0.4	0.0	100.3	1.9
	Paramoera sp.	0.0	0.0	0.1	0.0	12.4	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	4.6	0.0	7.4	0.0
	Photis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
(continued next page)	*Corophium acherusicum*	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3 cont. Average densities of benthic invertebrates, and taxa listings. R=Reference, P=Project.

		6/14/06						7/13/06						9/7/06					
Taxa Groupings	Taxa	R+12	P+12	R+8	P+8	R+5	P+5	R+12	P+12	R+8	P+8	R+5	P+5	R+12	P+12	R+8	P+8	R+5	P+5
Aquatic Crustaceans	*Corophium* juv.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Amphipod, juv.	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.1	0.0	2.4	0.1	0.0	0.0	0.0	0.0	13.9	0.6
	Euphausiacea zoea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ostracod	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1
	Diosacchus spinatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
	Harpacticus sp.	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Paralaophonte sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	Parathalestris californica	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Amonardia perturbata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
	Amphiascus cinctus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	Zaus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Aquatic Mollusks	Cardiidae, juv.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Clam, juv.	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.3
	Littorina scutulata	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mussel, juv.	0.0	0.1	0.0	0.0	0.3	0.7	0.0	0.1	0.0	0.0	0.1	1.0	0.0	0.3	0.1	0.7	1.6	0.1
	Mytilus edulis	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Polychaetes	Capitellidae	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.1	1.7	0.0
	Glyceridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Hemipodia simplex	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.3	0.0	27.7	0.0	0.0	0.0	0.0	0.0	1.4
	Neanthes limnicola	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nereidae	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Nereidae, juv.	0.0	0.0	1.0	0.0	0.9	0.0	0.1	0.0	0.9	0.0	10.1	0.6	0.0	0.0	0.1	0.0	0.3	0.1
	Nereis vexillosa	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Platynereis bicanaliculata	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Protodriloides chaetifer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.6	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0
	Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3
Foraminifera	Foraminifera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Nematode	Nematode	5.0	1.9	3.4	7.4	0.9	10.7	17.1	5.1	35.4	23.9	0.4	4.6	9.9	4.0	0.9	29.7	1.3	10.1
Oligochaete	Oligochaete	66.9	37.4	71.1	14.9	50.0	1.0	49.1	12.7	205.9	18.3	49.4	0.4	103.9	34.9	9.7	111.9	124.9	52.9
Nemertea/Turbellaria	Nemertea	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.1	10.4	0.0	0.0	0.3	6.7	0.4	0.3	1.7	0.3	3.1
	Turbellaria	0.0	0.0	15.9	0.4	0.0	0.0	0.0	0.0	70.0	0.0	0.0	0.1	6.3	0.0	7.1	4.4	0.0	0.0
Anthozoa	Anthozoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Table 4. Summary statistics using multivariate analysis on 2006 invertebrate densities. ANOSIM is equivalent to a univariate ANOVA, with significant differences ($p < 0.05$) and high biological importance ($R > 0.4$). SIMPER analyzes the species that have the largest contributions to statistical differences (top 5 in each category included).

1-way ANOSIM on Habitats

	June		**July**		**September**	
Tidal Elevation	p-value	R-value	p-value	R-value	p-value	R-value
Ref/Proj +12	0.002	0.598	0.001	0.830	0.002	0.741
Ref/Proj +8	0.002	0.872	0.003	0.999	0.003	0.642
Ref/Proj +5	0.003	1.000	0.001	1.000	0.002	0.967

SIMPER Analysis

	Average densities of log-transformed data		
Ref/Proj +12	**Project**	**Reference**	**% Contribution**
Talitridae, juv.	2.40	2.54	15.80
Traskorchestia traskiana	1.45	0.50	11.97
Nemertea	0.12	1.24	11.67
Megalorchestia pugettensis	0.56	1.19	11.16
Nematode	1.34	2.18	10.09
Ref/Proj +8	**Project**	**Reference**	**% Contribution**
Turbellaria	0.57	2.76	20.60
Nematode	2.79	1.77	15.64
Oligochaete	3.40	3.87	13.93
Protodriloides chaetifer	0.28	0.82	6.36
Nemertea	0.24	0.71	5.94
Ref/Proj +5	**Project**	**Reference**	**% Contribution**
Eogammarus confervicolus	0.28	4.06	18.63
Oligochaete	1.52	4.18	14.15
Hemipodia simplex	1.93	0.00	9.82
Gnorimosphaeroma oregonense	0.07	1.72	7.71
Amphipod, juv.	0.14	1.72	7.44

Table 5. Summary ANOVA p-values of Total Invertebrate significant differences between 2004 pre-construction and 2006 post-construction at the Project site for each elevation and month, values in column indicate significantly greater densities for either 2004 or 2006. At the +12' elevation in 2004 the Reference site was used, as there was no comparable Project elevation before restoration.

Elevation	Month	2004	2006
12'	June	0.0032	
	July	0.015	
	Sept	-	-
8'	June	-	-
	July	-	-
	Sept		0.000017
5'	June	0.0294202	
	July	0.000319	
	Sept	-	-

Table 6. Summary statistics using multivariate analysis on 2004 and 2006 invertebrate densities. ANOSIM is equivalent to a univariate ANOVA, with significant differences ($p < 0.05$) and high biological importance ($R > 0.4$). SIMPER analyzes the species that have the largest contributions to statistical differences (top 5 in each category included).

1-way ANOSIM on Habitats

	2004/2006	
Tidal Elevation	p-value	R-value
Proj/Ref +12	0.002	0.155
Proj +8	0.001	0.133
Proj +5	0.001	0.389

SIMPER Analysis

	Average densities of log-transformed data		
Proj/Ref +12	**2004**	**2006**	**% Contribution**
Terrestrial Amphipod	4.44	2.88	29.88
Oligochaete	3.08	3.19	16.95
Nematode	0.72	1.34	14.25
Insect larvae	0.50	0.39	8.57
Arachnid	0.54	0.32	8.13
Proj +8	**2004**	**2006**	**% Contribution**
Nematode	1.51	2.79	23.00
Oligochaete	2.52	3.40	19.75
Collembola	0.03	0.58	8.23
Turbellaria	0.18	0.57	7.98
Aquatic Isopod	0.37	0.18	6.80
Proj +5	**2004**	**2006**	**% Contribution**
Oligochaete	3.66	1.52	21.24
Glyceridae	0.73	1.93	12.89
Aquatic Amphipod	1.72	0.42	11.88
Turbellaria	1.40	0.03	10.48
Nematode	1.42	1.90	9.13

Appendix: Photographs of Representative Invertebrates

(photographs taken by Jeff Cordell)

The terrestrial amphipod *Traskorchestia traskiana*.

The aquatic amphipod *Eogammarus confervicolus*.

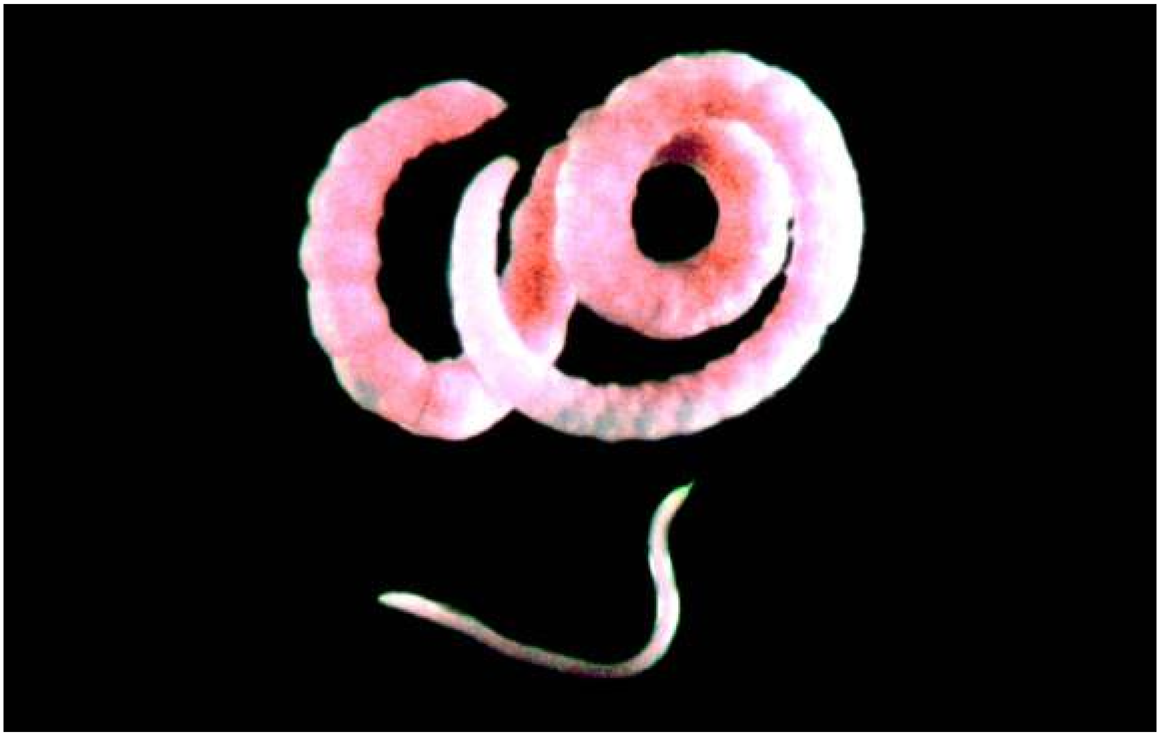
The aquatic amphipod *Paramoera bousfieldi*.

The aquatic amphipod *Allorchestes angusta*.

The aquatic isopod *Gnorimosphaeroma* spp.

The springtail Collembola.

The Glyceridae polychaete worm *Hemipodia simplex*.



Oligochaete and Nematode worms.