Effect of Dam Removal on Aquatic Communities in the Salmon River, New York
Final Report 2013

Project #2005-0129-013

Submitted to the National Fish and Wildlife Foundation

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30 April 2013

Revised 31 May 2022

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By

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Executive Summary

Dam removal has become a major part of restoring fragmented aquatic communities to approximate pre-disturbance conditions by reconnecting various reaches of rivers and tributaries. Removal of the Fort Covington Dam on the Salmon River in 2009, nearly 100 years after construction, reconnected about 22 km of river and its tributaries and established continuity in the aquatic community in this part of the river. Phase 1 of this study (2002–2004) was designed to collect data on the aquatic community (defined here as sediment, macroinvertebrates, fish, and aquatic plants) in the Salmon and Little Salmon rivers to evaluate the effects of removing the Fort Covington Dam. The Little Salmon River was used as a control where no alterations were made. Post-dam removal data collections were made in 2010 and 2012. Additional fish data was obtained in 2008. Mussel data was not collected in a structured way until 2005 and continued through 2012.

The Salmon and Little Salmon rivers were dominated by sand in the glides and cobble substrate in the riffles. These characteristics were not altered by the removal of the dam, although the dimensions of some riffles increased. The sediment that was mobilized by the increased water velocity within the former impoundment was primarily sand that was redistributed in the lower river. Scouring of bank sediments started soon after the dam was breached and continued in specific areas during the post-dam removal study. Bottom contours in selected areas of the former impoundment clearly show the deposition and later erosion of sand. The deposition of sand in the lower river will affect the macroinvertebrate assemblage as well as mussels for many years.

The number of macroinvertebrates collected increased by 45% in 2012 compared to 2010 but habitat characteristics were not altered to an extent that would cause major changes in the six indices used to characterize the community: Chironomidae midges were dominant in the glides and Baetidae mayflies were dominant in five of the six riffles. No significant differences were found in the number of EPT families, Total Families, Percent Chironomidae, Percent Dominants, or the Family Biotic Index when comparing pre-dam to post-dam years.

The mussel density in the former impoundment was significantly lower in post-dam years (2010 to 2012) due to the lowering of the water level in the impoundment, which stranded, and subsequently killed, approximately 77% of the impoundment population in 2009. Deposition of sand in downriver areas buried an unknown number of

mussels. The abundance of mussels was estimated from shell middens and perhaps represented a dense mussel bed. The middens included *Lampsilis ovata* and *Lampsilis cariosa*, considered to be in greatest conservation need by the New York Heritage Program; subsequent observations near the middens revealed a small group of living mussels, including *L. ovata*. Mussels in most glides were more abundant than mussels in riffles and were found in greater abundance on the east bank of transects: few mussels in glides were collected more than 2 m from either river bank. Mussels in riffles were only in slightly greater abundance on the west bank than in the center or east bank. The removal of the dam will allow upriver movement of fish species that serve as hosts for mussel glochidia, which could increase the mussel population; however, there was no evidence of mussel population differences between upriver and downriver areas prior to removal of the dam.

Brown Bullhead was the most abundant fish species. The major fish predators were Longnose Gar, Northern Pike, and Walleye. No American Eel was collected since 2003. Total scores for the fish IBI declined in the Salmon River from 48 in 2002 to 2004 to 38 in 2010 but increased to 46 in 2012. The total score for the Little Salmon River has varied between 40 and 44 for the four sampling periods of 2002–2004, 2008, 2010, and 2012. The IBI score was 'very good' for the Salmon River and 'good' for the Little Salmon River in 2012. Dam removal has not affected the fish population as yet.

Eastern Sand Darter (a threatened species in New York) was fifth in relative abundance in seine collections and was collected in three locations in the Salmon River but not in the Little Salmon River in 2012: Eastern Sand Darter was previously abundant at Lewis Marine but silt and algae covered the former sand habitat. The exotic Round Goby was collected in two locations in the Salmon River for the first time in 2010 and expanded in 2012 to include two locations in the Little Salmon River and one in the Salmon River.

The abundance and distribution of aquatic plants did not change substantially since the 1930s in the Little Salmon River but nearly all submersed plants were either removed or buried in the former impoundment downriver to the confluence after dam removal. A few *Vallisneria* and water cress have colonized the former impoundment. The more abundant plant genera in the Little Salmon River were *Potamogeton*, *Elodea*, and *Vallisneria* and provided the major nursery habitat for fish larvae and juveniles. The distribution of the exotic flowering rush *Butomus umbellatus* was similar to that in pre-dam years but the European frogbit *Hydrocharis morsus-ranae*, found in 2004, was not found after dam removal. Three invasive plant species were found in 2012 that were not seen previously: wild parsnip *Pastinaca sativa*, yellow iris *Iris pseudocorus*, and common reed *Phragmites australis*.

The removal of the dam altered the physical environment by increasing the water velocity, which led to scouring of the sand deposits, expansion of the riffles and a subsequent increase in macroinvertebrates. The sand was deposited in the lower river, which covered some areas of formerly rocky substrate, decreasing the relative water depth, and covering several apparently dense mussel beds. The mussel population decreased in the former impoundment due to stranding. There was no apparent change to the macrophytes or the fish population, although sampling for fish was affected by the physical changes to the river bed.

Introduction

Dams have altered the natural cycle of water flow, sediment transport, and water temperature regimes in many streams in the United States (Ligon et al. 1995). Dam removal has been emphasized as a tool for river restoration to approximate a more natural assemblage of aquatic communities and as a practical approach to dam management (Orr et al. 2006). Changes in land use and instream morphometry due to dams were frequently deleterious to the stream as well as costly in lost property (Schroeder and Savonen 1997), however, dams have also slowed the range expansion of introduced species, such as Carp and Round Goby, and the introduction of disease vectors (Cooper 2006; Hurst et al. 2012). Reproductive success of Sea Lamprey in Lake Ontario tributaries was reduced by the presence of dams (Christie 1974).

About 1100 dams have been removed in the US since 1912 (American Rivers 2013) but few of these removals have included published ecological studies (Hart et al. 2002; Burroughs et al. 2010). The published dam removal studies have revealed a complex response by the aquatic community to dam removal where macroinvertebrate density increased (Maloney et al. 2008), remained unchanged (Stanley et al. 2002), or declined downriver (Thomson et al. 2005), and fish abundance increased (Kanehl et al. 1997; Catalano and Bozek 2007) or decreased (Bednarek 2001). Water chemistry was not altered to a great extent by a run-of-river dam but Velinsky et al. (2006) noted that any observed changes were likely to be site-specific. In general, the assemblages of aquatic species in formerly impounded areas have come to approximate those found in more free-flowing conditions (Maloney et al. 2008).

The Salmon River drainage basin extends from the northwestern part of the Adirondack Park to the international border with Quebec, Canada (Figure 1), and covers 1456 km^2 with 1,000 km of stream (NYSDEC 1998). There are five dams remaining on the Salmon River and two dams on the Little Salmon River; these are a mixture of recreational, hydropower, and abandoned mill dams.

The Salmon River headwaters emerge near Elbow Ponds (north of Loon Lake) at an elevation of 548 m. The Little Salmon River headwaters arise near Twin Ponds at an elevation of 427 m. Both rivers have a steep gradient (approximately 11 m/rkm) until they reach the study area where the gradient ranges between 0.6 to 1.0 m/rkm. The rivers are 4th-order in the study area.

The objectives of this study were to determine the effect of removing the Fort Covington Dam by comparing the pre-dam removal characteristics of the aquatic community (2002–2004) to those in the post-dam removal period in 2010 and 2012. The Little Salmon River was used as a control since no physical alterations were expected there.

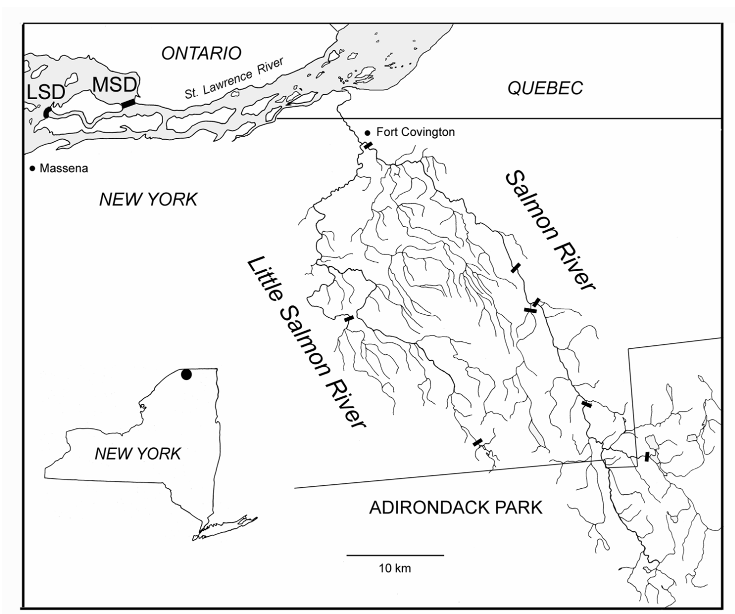


Figure 1. Location map of the Salmon and Little Salmon rivers, Franklin County, New York. The black boxes in the St. Lawrence River are the Long Sault Dam (LSD, left) and Robert Moses-Saunders Power Dam (MSD, right). The Fort Covington Dam was the most downriver dam in the Salmon River; the other boxes represent dams upriver from the study area.

Study area

The Fort Covington dam was located on the first riffle of the Salmon River, approximately 8 rkm from the St. Lawrence River. The original dam was built in the late 1800s as a wood crib structure, damaged in a freshet in 1912, and rebuilt in 1913 as a concrete run-of-river gravity dam that was used for hydroelectricity and as a grist mill. The impounded water formed two small ponds, one on each side of the river, which were drained when the dam was removed in 2009. Characteristics of the dam are described in the baseline data report (Cooper et al. 2004), as well as a discussion of the geology, land use, and elevation characteristics of the study area.

Flow characteristics. The greatest recorded mean daily discharge in the Salmon River was 3,280 cubic feet per second (cfs; 92.9 m^3/s; 1 April 1998) and 2,620 cfs (74.2 m^3/s; 20 March 1986) in the Little Salmon River, however, peak river flow can be much higher: 3,700 cfs (104.8 m^3/s; 29 December 1984) in the Salmon River and 3,420 cfs (96.8 m^3/s; 31 March 1998) in the Little Salmon River. River water level can respond rapidly to precipitation inputs, which can result in flooding (Figure 2) particularly if the winter ice is broken up with subsequent ice jams in narrow parts of the river.

Figure 2. Flooding in the lower Salmon River after a winter rain (0.9 cm), combined with air temperature of 12 °C, caused the breakup and jamming of the January 2010 ice cover (left) at the railroad bridge (near transect 2); and flooding after 7.6 cm of rain on 14–16 October 2010 (right).

Methods

Sampling design. Fifteen transects were established in 2002, nine in the Salmon River and six in the Little Salmon River, divided between riffles (transects 3, 7, 9, 13, 15) and glides (transects 1, 2, 4–6, 8, 10–12, 14). Three additional transects were sampled: a riffle exposed after dam removal (designated as 67), and transects at Lewis Marine and Deer Creek (Figure 3).Various combinations of these transects were used: sediment (1, 2, 4–6, 8, 10–12, 14, in 2002, 2010, and 2012), water chemistry (2, 7, 9, Deer Creek, 10, 13, 15 in 2002 to 2004, 2008, 2010, and 2012), macroinvertebrates (1–15, in 2002 to 2004, 2008, 2010 and 2012; and additionally, 67 in 2010 and 2012), fish (1, 2, 3, 6, 8, 9, 11, 12, 14, and Lewis Marine in 2002 to 2004, 2008, 2010, and 2012), unionid mussels (3, 5, 7, 8, 9, 12, 13, 15, Lewis Marine, and Deer Creek in 2005 through 2012), and all transects for aquatic plants in 2002 to 2012.

Transects were paired across rivers (riffle to riffle, glide to glide) with the exception of transects 1 through 3 — these three transects did not have analogous reaches in the Little Salmon River — and the riffle transect 67. Each transect was subdivided into east, center, and west areas (when facing north). The impoundment extended from just upriver of transect 3 to transect 7. The maximum sampling period was from April (or ice-out) to November but most samples were made between May and October.

Sediment. Three grabs taken with a 15 cm X 15 cm ponar dredge (0.02 m^2) were composited to make one sample from each subdivision (east, center, and west) in each glide transect (N = 30) to determine grain size. Samples were stored at 3.8 ºC until analyzed. Grain size was characterized into only three size categories in 2002 (sand, silt, and clay; Cooper et al. 2004) so archived samples were re-screened in 2010: dry material was screened through five mesh sizes (6 mm, 1 mm, 0.5 mm, 0.125 mm, and 0.062 mm). Silt (0.0039 to 0.031 mm) and clay (0.002 mm) proportions were determined by the dispersal method (Folk 1980) and all fractions reported as the percent dry weight of the original sample. The same procedure for grain size was followed for samples taken in 2010 and 2012. Sorting was determined by the inclusive graphic standard deviation method of Folk (1980), which relates the cumulative percent by weight of sediment fractions to phi values at four percentages (84%, 16%, 95%, and 5%):

$$\frac{\Phi 84 - \Phi 16}{4} + \frac{\Phi 95 - \Phi 5}{6.6}$$

The solution of this equation results in an estimate of the average particle size encompassing 95% of the size distribution. Porosity was determined by dividing bulk density (sediment dry weight divided by volume) by 2.65, the density of quartz, which was the predominant mineral. Pebble counts were made in the riffles in 2012 (Table 1) at a minimum of 100 locations using the zig-zag method (Bevenger and King 1995).

Estimates of embeddedness (Barbour et al. 1999) were made at five locations in the center of each riffle transect.

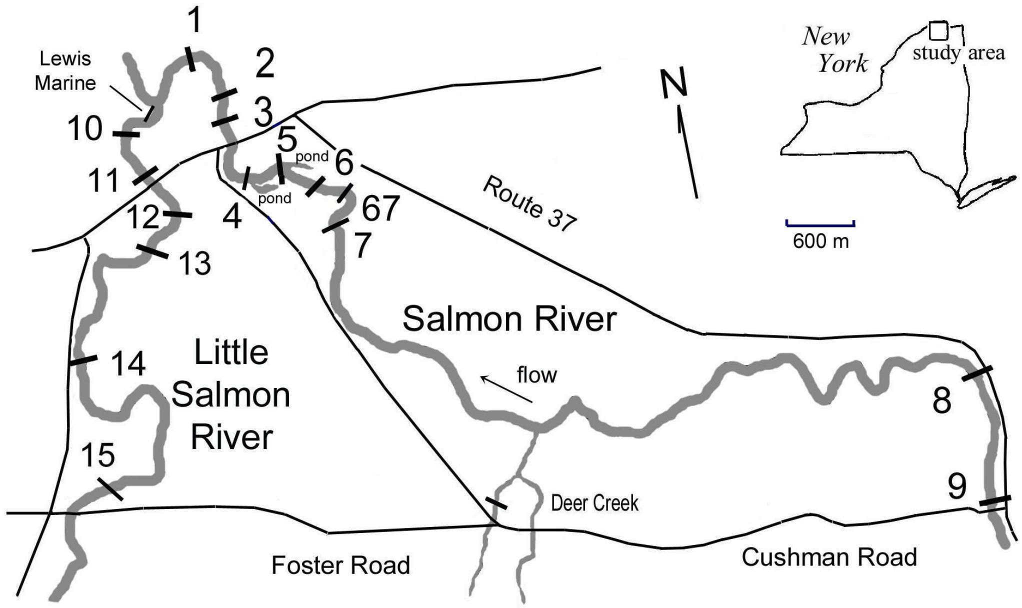


Figure 3. Location of transects sampled for sediments, macroinvertebrates, fish, and aquatic plants. Water level loggers were located near transects 6 and 10. Water temperature recorders were located near transects 6, 7, 9, 10, 13, and 15. A barometric pressure logger was located near transect 10. Transect 67 was a riffle that was exposed after the drawdown of the impoundment. Two ponds were formed by impounded water (transects 4 and 5), which were drained with removal of the dam upriver of transect 3.

Physical characteristics of transects. The maximum depth and width of each transect was determined by direct measurement in 2003, 2009 (five months after dam removal), and 2012; stream width was checked against aerial images taken by New York State Department of Environmental Conservation in 2008. Bank height was determined by placing a marked PVC pipe at the water edge and locating the top of the bank with a laser level from the opposite bank. Angle of the bank on each side of each transect was measured with a clinometer. Stream bottom contours were determined by direct measurement at 1 m intervals across each transect at similar discharge levels (3.1–5.5 m^3/s).

Water chemistry. Water temperature was recorded at 1 hr intervals using Onset thermographs at transects 7, 9, 13, and 15 and by level loggers at transects 3, 6 and 10. Recorders were deployed in late April to early May and removed in late October or early November. Monthly grab samples were used to estimate water temperature and dissolved oxygen (Hach sension6), pH (ecotestr ph2), total dissolved solids (TDSTestr3), alkalinity (Lamotte titrator), nitrogen ammonia, chloride, nitrate, sulfate, and turbidity (Hach colorimeter) at transects 2, 7, 9, 10, 13, 15, and Deer Creek. Onset level loggers recorded water level changes at 1 hr intervals at transects 3, 6, and 10 (Figure 3). A separate level logger was used to determine barometric pressure to correct the measured values of water level and to record air temperature at transect 10. Precipitation records for Massena, NY, were downloaded from the National Climatic Data Center (NOAA 2012).

Water velocity. Estimates of water velocity were made monthly from May through October (2008, 2010 and 2012) using a Price-type "mini" current meter at the center of transects 2, 3, 7, 9, 13, 15, and Deer Creek The bucket wheel was set at 40% of the water depth and recorded for 30 seconds. Velocity was generally too slow to be measured with the meter at transect 2 so estimates were made by timing a neutrally buoyant ball over a specific distance.

Macroinvertebrates. Macroinvertebrates (other than mussels) were collected with a rectangular kick net (0.26 m^2; 500µ mesh) in the riffles and a ponar dredge (0.023 m^2) in the glides (but not at Lewis Marine or Deer Creek). Samples were collected in October (2002), June and October (2003), June (2004), and July in 2008, 2010, and 2012. Four kick net samples were composited from the east, center, and west areas of each riffle transect and four ponar dredge samples were composited from the east, center, and west areas of each glide transect resulting in three samples from each transect. Each sample was washed through a 500µ mesh screen before compositing. All samples were preserved with 10% buffered formalin and returned to the laboratory for sorting and counting. Ethanol was not used as a field fixative due to large amounts of plant debris, which would decrease the effectiveness of the ethanol. No sub-sampling was used. Organisms were identified to the family level except for oligochaetes, nematodes, leeches, diptera pupae, diptera adults, and water mites. All organisms were then preserved in 70% ethanol.

Six indices were calculated for macroinvertebrates for each transect using 64 families (Appendix Table 2): *EPT* — the number of families in Ephemeroptera, Plecoptera, and Trichoptera; *richness* — the total number of families; *dominance* — sum of percentages of the five more abundant families out of the total number of individuals; *percent Chironomidae* — the percentage of chironomid midges out of the total number of individuals; *Family Biotic Index* — family tolerance value (Barbour et al. 1999) multiplied by abundance and divided by the total number collected; and *Percent Model Affinity* — a comparison of the percent similarity between seven taxonomic groups in the samples to the percent of the same taxonomic groups in a 'model' community (Novak and Bode 1992). The methods for Percent Model Affinity differed from that specified by Novak and Bode (1992) in that all organisms were used in the calculations rather than a 100-organism subsample. The Biological Assessment Profile (Bode et al. 1996) was not used in the present study as the macroinvertebrates were not identified to species.

Unionid mussels. Systematic sampling with three random starts (Strayer and Smith 2003) was used at transects 3, 5, 7, 8, 9, 12, 13, 15, Lewis Marine, and Deer Creek in July or August in 2005 through 2012. Double sampling (systematic plus excavation) was used at transects 5, 8, 12, and Lewis Marine. Each of three reaches across the river had 10 1-m^2 quadrats with each quadrat subdivided into four 0.25 m^2 areas. Reaches in Deer Creek were directed upriver due to its narrow width, and reaches at Lewis Marine were located only on the west side as the east side was too deep. Each sub-quadrat was searched with visual and tactile methods, and 20% of the sub-quadrats (randomly selected) were excavated. The excavated material was sifted through a 6-mm screen. An underwater viewing scope was used to facilitate finding mussels. Shorelines were searched for muskrat middens and empty shells were identified and measured. Population estimates were made for transects (Strayer and Smith 2003).

Fish. Collections of fish were made using hoop nets (1.2 m hoop, 6 m wings, 12 mm bar mesh) in October in 2002, May and September in 2003, June in 2004, and May and September in 2010 and 2012, and a 3 m X 1 m bag seine (3 mm mesh) in October in 2002, July and August in 2003, October in 2008, August and October in 2010, and June and September in 2012 in locations representing the various habitat types. Hoop nets were set overnight and fished in the same order as deployed. The total fishing time for each net was recorded. Seining was done in an upriver direction parallel to shore with each haul distance recorded. All fish were identified to species, and the majority was measured for total length (mm) and wet weight (g) in the field and returned alive to the collection area. Some minnows were preserved in 10% buffered formalin to verify their identification.

An index of biotic integrity (IBI) was constructed for fish for each river based on 12 metrics following Daniels et al. (2002). These metrics were 1) total number of fish species (excluding Carp, American Eel, and stocked trout); 2) number of benthic insectivores; 3) number of water column species (excluding Smallmouth and Largemouth Bass); 4) number of terete minnow species; 5) dominant species — 3 more abundant species as a percentage of the total number of species; 6) percentage of total individuals that were White Sucker; 7) percentage of total individuals that were omnivores; 8) percentage of total individuals that were insectivores; 9) percentage of total individuals that were top carnivores — Largemouth Bass, Smallmouth Bass, Northern Pike, Longnose Gar, and Walleye; 10) density as number/m^2 per river (these values were determined only from seining data since trap net data does not account for an area that is fished); 11) percentage of species that had two age classes (estimated from length frequency plots); and 12) the percentage of individuals that had tumors, lesions, or parasites. Each metric was then scored from 1 to 5 with 5 representing the least effect. The index was the sum of scores for the metrics.

Statistical methods. All statistical comparisons were made on untransformed variables using the General Linear Model in SAS (version 8.2, SAS 2001). Bonferroni t-tests were used to examine sorting and porosity for 2012 data as well as comparing pre- and post-dam removal data. Mussel distribution between riffles and glides was compared using the non-parametric Kolmogorov-Smirnov statistic. Macroinvertebrate density in three areas (east center, and west) in riffles and glides was compared using least-squares means as were comparisons of macroinvertebrate density between transects in the former impoundment and other transects, and mussel density by transect. Least-squares means used transect or sampling period as a covariate.

Aquatic plants. A qualitative survey was made of emergent and submersed aquatic plants within the study area in August of 2003, 2008, 2010, and 2012. Plants were identified to genus, ranked by abundance, and locations noted. The primary objective was to locate areas that could function as spawning areas for fish.

Results

Sediment. Sand comprised the greatest percentage of any fraction at all glide transects (Figure 4). The center of each river was composed primarily of very fine to medium sand (0.062 to 0.5 mm) with fine sand and silt along the river banks. Clay was the least abundant fraction in both rivers averaging less than 1% with the exception of the east side of transect 10 where it was 2 %. The west and east sides of both rivers were similar in grain size distribution although the west side contained a greater percentage of very fine sand. Pebble-sized grains were more abundant at transect 1 on the east side in

2012 than in 2010. The center area of both rivers has remained relatively unchanged since 2002 (Appendix Figure 1) with the notable exception of the large dissimilar sediments in the former impoundment exposed after the removal of the dam: these sediments have largely been scoured away since 2010.

Sorting and Porosity. Sediments were moderately to poorly-sorted in both rivers and had relatively high porosity in 2012. The east bank of the Salmon River was less sorted than the center or west bank but there was no significant difference by location (east, center, west: $F = 0.75$; $P = 0.49$). Sorting in the Little Salmon River was similar to that in the Salmon River with no significant differences by location ($F = 0.12$; $P = 0.88$). Porosity in the Salmon River was significantly greater in the center than in the east or west sides ($F = 14.7$; $P < 0.0003$) as was porosity in the center of the Little Salmon River ($F = 19.3$; $P = 0.0006$), but there were no significant differences in sorting or porosity in either river from 2002 to 2012 (Table 1).

Embeddedness was 20% at transects 7, 13, 15, and 67, 40% at transect 9, and 30% at transect 3 in 2012. There was no change in embeddedness at transects 9, 13, 15, or 67 from that in 2010. Embeddedness at transect 7 in 2012 declined 10% from that in 2010 and declined by 30% at transect 3 from that in 2010.

Table 1. Values for sorting and porosity (mean ± 1 SE) in three areas of the glide transects. East, center, and west refer to the locations in the river when facing north. N = 18 for the Salmon River; N = 12 for the Little Salmon River for each year.

	Salmon River			Little Salmon River		
	East	Center	West	East	Center	West
Sorting 2002	0.99 ± 0.19	0.84 ± 0.08	0.68 ± 0.09	1.09 ± 0.08	0.93 ± 0.13	0.87 ± 0.08
Sorting 2010	1.11 ± 0.10	0.8 ± 0.05	0.95 ± 0.06	0.91 ± 0.02	0.95 ± 0.08	0.99 ± 0.09
Sorting 2012	1.08 ± 0.71	0.89 ± 0.12	1.02 ± 0.12	0.86 ± 0.02	0.85 ± 0.16	0.8 ± 0.02
Porosity 2002	0.49 ± 0.03	0.54 ± 0.02	0.48 ± 0.04	0.52 ± 0.04	0.52 ± 0.04	0.5 ± 0.03
Porosity 2010	0.45 ± 0.03	0.61 ± 0.01	0.42 ± 0.03	0.42 ± 0.03	0.5 ± 0.02	0.43 ± 0.04
Porosity 2012	0.38 ± 0.02	0.53 ± 0.01	0.42 ± 0.03	0.34 ± 0.03	0.51 ± 0.01	0.38 ± 0.01

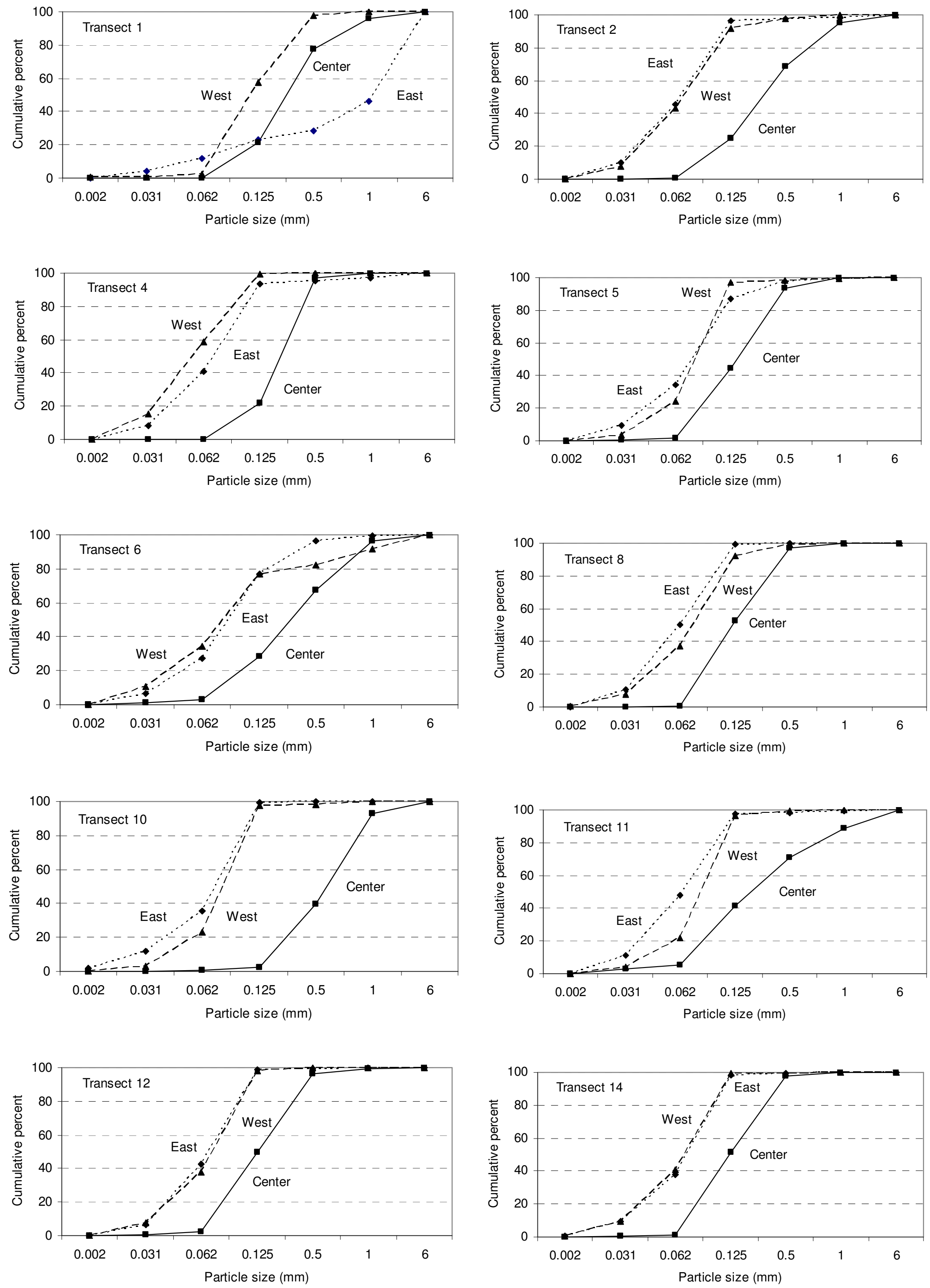


Figure 4. Cumulative percent of sediment fractions from the glide transects in 2012. Particle sizes (mm) were: clay = 0.002, silt = 0.031, very fine sand = 0.062 to 0.125, fine and medium sand >0.125 to 0.5, coarse sand >0.5 to 1, and pebble = 6.

Pebble counts. The riffle transects were composed primarily of cobble, ranging from 43% at transect 9 to 83% at transect 13. Transect 9 was the only riffle that had a substantial percentage of bedrock (20%; Figure 5) and more than 2% coarse sand.

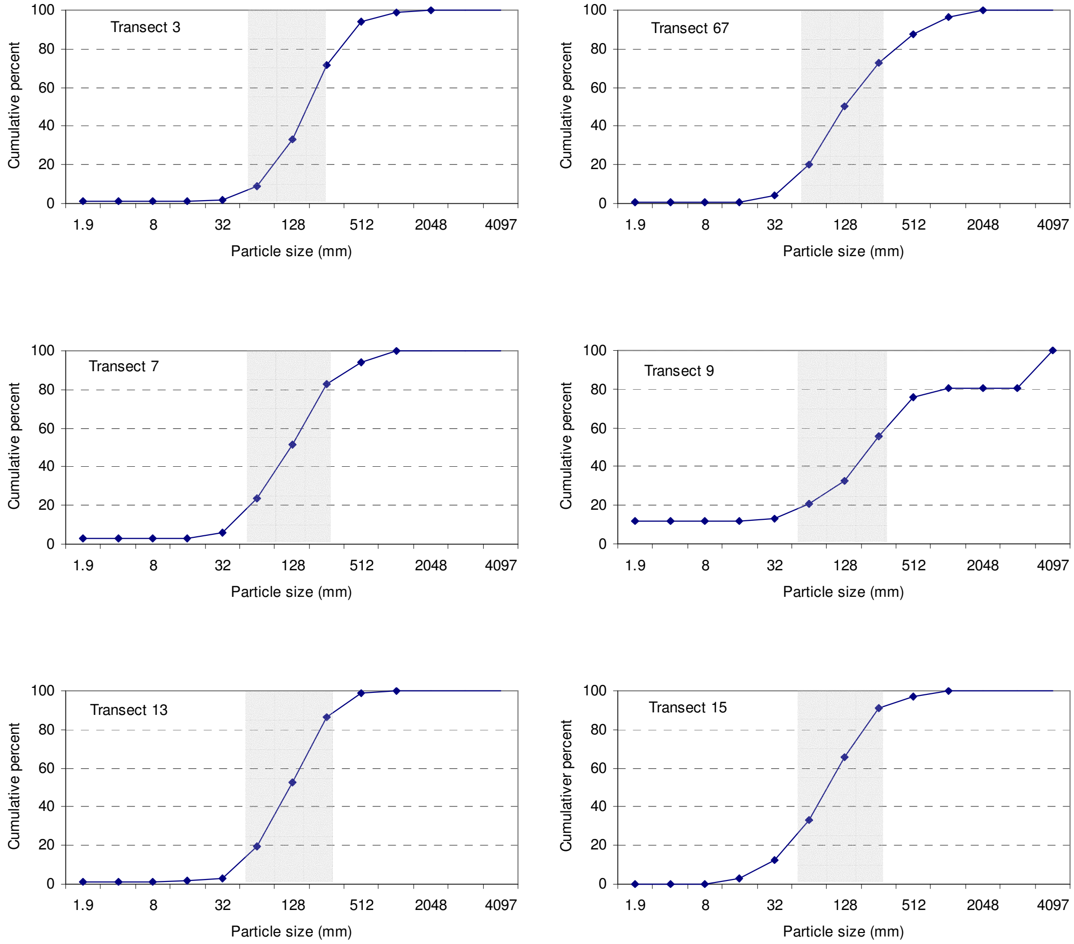


Figure 5. Distribution of particle sizes in six riffles of the Salmon and Little Salmon rivers. Particle sizes (mm) were 1.9 = coarse sand, 4 to 63 = pebble, 64 to 256 = cobble (gray boxes), 257 to 4096 = boulder, and 4097 = bedrock.

Physical contours of transects. The maximum depth of the former impoundment transects increased from 2010 to 2012 as did the depth at transects 1 and 2 (Table 2). Scouring of sediments in transects 4 through 67 shifted the wetted area westward in 2012 and increased the maximum width of these transects by 2 to 4 meters. Plots of stream contours at those transects affected by dam removal (Figure 6) show that the sand deposited after dam removal was scoured out, which reformed channels similar to pre-dam removal condition with the exception of transect 2, which had a new channel on the east side whereas the old channel was located on the west side. The riffles at transects 3 and 7 were similar in length and width to that in 2010. The average bank height was

Table 2. Maximum width and depth of transects: changes occurred only at transects 1, 2, and 4 to 6 in 2012. Pre- and Post- correspond to pre- and post-dam removal conditions in the year indicated. Transect 67 was a glide prior to dam removal and became a riffle after dam removal.

	Salmon River					Little Salmon River		
	Width (m)		Depth (m)					
Transect	Pre-2003	Post-2012	Pre-2003	Post-2010	Post-2012	Transect	Width (m)	Depth (m)
1, glide	25	25	3	0.5	1.5	10, glide	17	3
2, glide	50	50	2	0.5	1	11, glide	34	1
3, riffle	34	32	0.5	0.5	0.5	12, glide	21	2
4, glide	25	23	3	0.5	0.8	13, riffle	13	0.5
5, glide	30	24	2	0.2	0.7	14, glide	38	1
6, glide	50	52	1	0.5	0.7	15, riffle	30	0.5
67, glide, riffle	25	27	2	0.5	0.5	Lewis Marine, glide	28	2
7, riffle	70	70	0.5	0.5	0.5			
8, glide	34	34	1	1	1			
9, riffle	40	40	0.5	0.5	0.5			
Deer Creek, riffle	10	10	<0.5	<0.5	<0.5			

greater in the Salmon River (2.1 m) than in the Little Salmon River (1.5 m; Appendix Table 1) but the average bank angle was similar between the two rivers. The west side of transects in both rivers was steeper, on average, than the east side.

Discharge and water level. Discharge values were not available from the Salmon River for 2012 but comparisons of historical discharge records from the USGS gage at Chasm Falls (Salmon River; gage 04270000), and the USGS gage at Bombay (Little Salmon River; gage 04270200), showed that the response to precipitation was similar in the two rivers, although the Salmon River discharged at a greater rate. Discharge in the Little Salmon River (USGS gage) in 2012 (Figure 7) was similar to the records of the monitoring locations (Figure 8) and showed rapid, although brief, water level changes. Higher than average air temperature in early March (4 days > 10 °C) combined with more than 1.3 cm of rain (NOAA 2012), resulted in a sharp increase in discharge. These conditions were repeated in the latter part of March (air temperature more than 18 °C greater than average combined with 1.2 cm of rain), but the resulting increase in discharge was less than half that of early March. Neither event caused flooding on the scale of October, 2010, which had a discharge that was 20% greater.

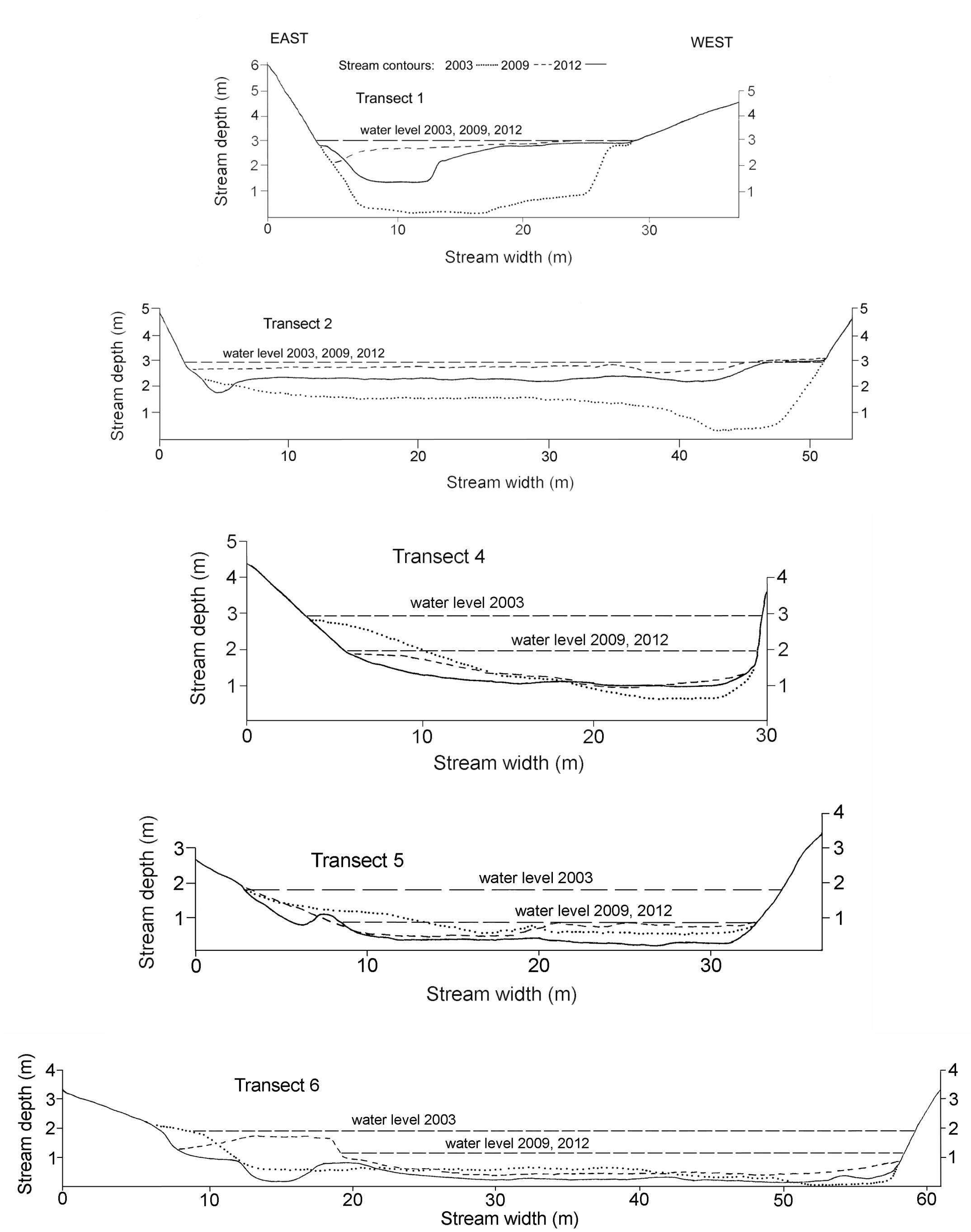


Figure 6. Stream width and depth from Salmon River transects affected by the removal of the Fort Covington Dam in 2009. Water level at transects 1 and 2 was not measurably different before and after dam removal at low discharge rates; water level at transects 4 through 6 was reduced by about 1 meter after dam removal. Discharge was 3.1–5.5 m^3/s when contours were measured.

Water velocity. Measurements were taken at discharge rates between 0.6 and 5.5 m^3/s but the measured velocity could not be estimated from recorded discharge. Mean velocity was greatest at transect 3 and least in transect 2 (Table 3), however, the differences were small.

Table 3. Mean measured water velocity at selected transects in 2012. Means are ranked from fastest to slowest from left. N is the number of estimations.

	Transect						
	3	7	13	15	9	Deer Creek	2
Mean velocity (m/s ± 1 SE)	0.78 ± 0.09	0.75 ± 0.16	0.71 ± 0.06	0.69 ± 0.09	0.68 ± 0.09	0.33 ± 0.03	0.32 ± 0.05
N	6	7	14	12	11	12	9

Water temperature. Ice cover formed in early December, 2011, broke up in early March, 2012, in the Little Salmon River (Figure 7), and then reformed in mid-December. Water temperature increased rapidly in both rivers in late March and varied by as much as 13 ºC until July. The highest water temperature was 27 ºC in both rivers in June. The seasonal temperature profile (Figure 8) was similar in both rivers although the Salmon River was about 2 ºC colder than the Little Salmon River. Water temperature at Lewis Marine averaged 0.5 ºC colder than at transects 12 and 15.

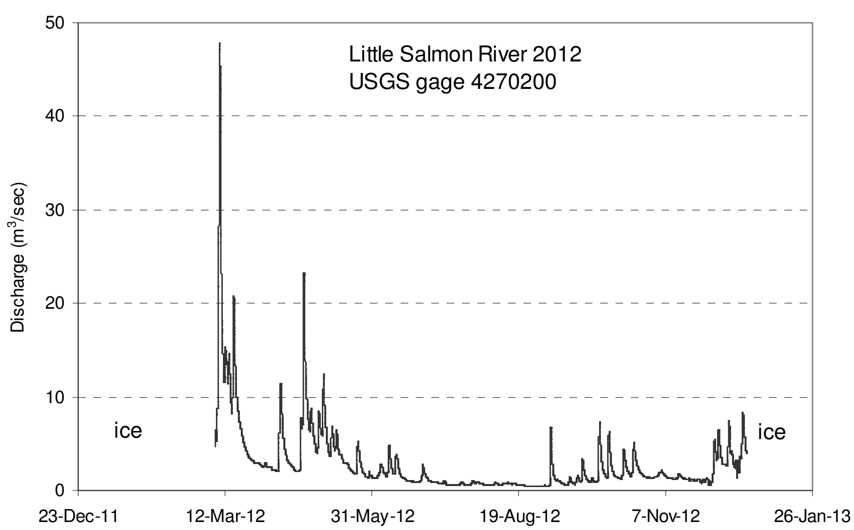


Figure 7. Mean daily discharge of the Little Salmon River during 2012 measured at Bombay (USGS gage 04270200). The gaging station is approximately 7 river km upriver of the study area.

Dissolved oxygen ranged from 5.1 to 11.8 mg/L (58.5% to 108% saturation) from May through October 2012, and the mean measured saturation was 89.7%. Dissolved oxygen and percent saturation were similar between the two rivers. Transects 10 and Deer Creek had lower percent saturation than other transects (Table 4). The range of pH was from 6.6 to 9.1 during the study period and mean pH showed little difference by month.

Total dissolved solids (TDS) ranged from 100 to 390 μS and were generally greater in the Little Salmon River. Measured TDS was greater in Deer Creek than at other transects. TDS values increased from May through August and then decreased except in Deer Creek where values continued to increase into October. Alkalinity ranged from 60 to 148 mg/L and was greater in Deer Creek. The greater TDS and alkalinity levels in Deer Creek might be the influence of groundwater: several groundwater seeps had TDS levels of 260 to 380 μS and alkalinity levels of 188 to 288 mg/L. The range in alkalinity values was similar to that in 2010. Alkalinity did not show any seasonal trends. Total alkalinity was from bicarbonates as phenophthalein titrations were always zero. Chloride concentrations ranged from 0 to 0.65 mg/L but were generally less than 0.27 mg/L. High values of chloride were recorded on two occasions, one at transect 13 in August (0.64 mg/L) and one at transect 15 in September (0.65 mg/L), which resulted in greater mean concentrations at these two transects than at other transects. Sulfate concentrations ranged from 0 to 71 mg/L with a mean of 7.9 mg/L. High values for sulfate were recorded on two occasions, one at Deer Creek in September (68 mg/L) and one at transect 13 in October (71 mg/L); these two measurements were repeated with similar results. Three of the high values could be associated with rain in August (2.54 cm) and September (1.4 cm) but not the high value for sulfate in October. Ammonia concentrations were variable with no seasonal trends and were generally less than 0.9 mg/L with two exceptions: 0.12 mg/L at transect 2 (June) and 0.13 mg/L at transect 13 (August). Nitrate ranged from 0.1 to 1.4 mg/L (mean = 0.82 mg/L) and showed a seasonal pattern of greater values in May, decreasing in July, increasing in September and lower values in October. Nitrate values were variable and ranged by 0.6 to 0.9 mg/L in each month. Mean turbidity by transect ranged from 6.5 to 10 FAU with greater values resulting from precipitation in May (1.6 cm) and September (1.4 cm).

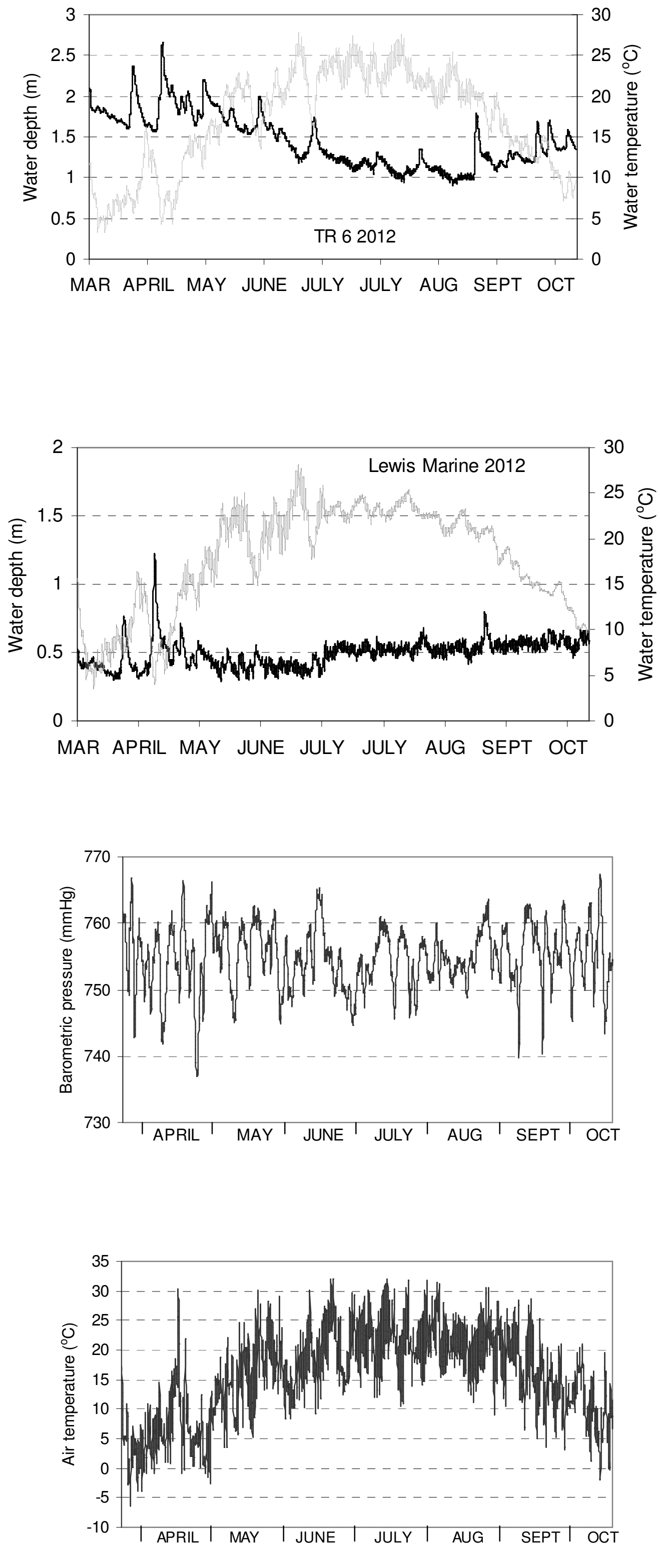


Figure 8. Water depth (black line) and water temperature (gray line) recorded in 2012 at transect 6 and at Lewis Marine near transect 10 (upper panels); barometric pressure recorded at Lewis Marine (middle panel); and air temperature at Lewis Marine (bottom panel). The high air temperature in April was 27 °C greater than the average for that month.

Macroinvertebrates in 2012. Out of the 90 families (not including unionid mussels) that have been collected during the study (2002 to 2012), 64 were collected in 2012 and used in the construction of indices (Appendix table 2). The indices used various combinations of the collected families.

Table 4. Mean concentration (± 1 SE) of water chemistry parameters taken as grab samples (N = 6) from May through October, 2012. DC = Deer Creek.

	Salmon River				Little Salmon River		
Transect	2	7	9	DC	10	13	15
Dissolved oxygen (mg/L)	8.7 (0.6)	9.8 (1.1)	9.8 (0.6)	7.4 (0.9)	7.4 (0.8)	9.3 (0.5)	8.5 (0.7)
Percent saturation	88.8 (1.9)	103.2 (7.6)	102.3 (2.8)	76 (0.9)	77.5 (4.9)	98.8 (2.6)	96.5 (6.9)
pH	8.1 (0.1)	8.1 (0.06)	8.3 (0.1)	7.6 (0.09)	8.0 (0.03)	8.5 (0.2)	7.2 (0.1)
Total dissolved solids (µS)	173.3 (10.8)	160 (11.2)	148.3 (12.2)	310 (20)	201.7 (7.9)	200 (8.6)	181.7 (7.5)
Alkalinity (mg/L$CaCO_3$)	79.3 (2.4)	80 (4)	69 (4.1)	124.7 (7.3)	86 (3.1)	85.3 (2.2)	87.3 (3.3)
Chloride (mg/L, Cl^-)	0.16 (0.03)	0.15 (0.02)	0.13 (0.02)	0.12 (0.01)	0.13 (0.01)	0.21 (0.02)	0.19 (0.09)
Nitrate (mg/L, NO_3-N)	0.83 (0.06)	0.61 (0.15)	1.04 (0.09)	0.89 (0.10)	0.62 (0.12)	0.7 (0.1)	1.04 (0.09)
Sulfate (mg/L, SO_4)	3.2 (0.7)	3.8 (0.9)	3.5 (0.9)	19.5 (10.5)	4.8 (2.1)	15.2 (11.2)	5.5 (2.1)
Turbidity (FAU)	10 (1.1)	7.8 (1.1)	9.5 (2.0)	9.7 (1.9)	8.3 (1.6)	6.5 (1.1)	8 (1.6)
Nitrogen, Ammonia (mg/L, NH_3-N)	0.04 (0.02)	0.01 (0.005)	0.03 (0.01)	0.02 (0.008)	0.02 (0.01)	0.03 (0.01)	0.05 (0.02)
Water temperature (°C)	16.6 (2.1)	17.3 (2.3)	16.6 (2.3)	17.7 (2.1)	18.5 (2.4)	18.7 (2.8)	17.9 (2.0)

A total of 67,438 macroinvertebrate organisms was collected in 2012 (an increase of 45% from 2010) equivalent to 4,362 organisms/m^2: 60,618 of these organisms were used in the indices. Chironomidae dominated the glide transects in abundance (mean = 60% of organisms collected) but Chironomidae accounted for only 11.8% in the riffles. Baetidae was more abundant at five of six riffle transects (mean = 34% of all organisms) but Chironomidae was dominant at transect 9 (29.4 %). Chironomidae were dominant in mean density at 9 of 10 glides (range = 620–7,642/m^2) followed by oligochaetes (645/m^2), Baetidae (494/m^2), Hydropsychidae (315/m^2), and Elmidae (251/m^2). There was considerable variation in density in the center of the glide transects ranging from

193.5 organisms/m^2 at transect 8 to 5,495 organisms/m^2 at transect 2 (coefficient of variation = 26%). Mean density of all organisms was significantly less in the center of the glides (lsmeans = 0.03) than in the east areas of the glides but not different from that in the west areas. Mean density in the former impoundment (transects 4, 5, and 6) was not significantly different from glide transects 1, 2, and 8 in the Salmon River (lsmeans = 0.75). There was no significant difference in areas of the riffles (lsmeans >0.26) and no significant difference in mean density between riffles and glides ($F = 0.47$; $P = 0.49$).

The number of EPT families was significantly greater ($F = 15.61$; $P = 0.0003$) in the riffles (mean = 6.5) than in the glides (mean = 2.7) in 2012 (Figure 9). The number of EPT families collected at transect 67 was similar to that collected at other riffle transects. Stoneflies were collected at transects 67 and 9 in 2012 but not in 2010.

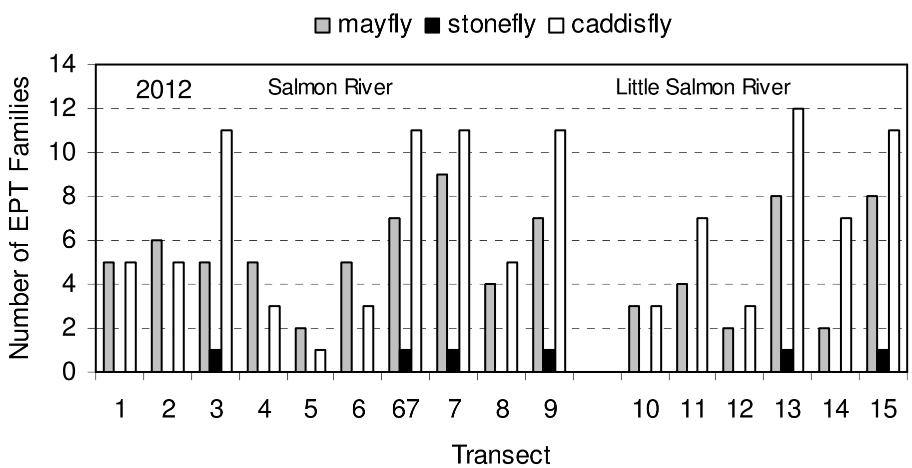


Figure 9. Number of EPT families collected in 2012. Transects 4 through 67 are in the former impoundment.

Values for Total Families at transects 4 and 5 were less than values at all other transects. Riffles supported more families than glides did with the exception of glide transect 6 where the number of families doubled from that in 2010. Scores for the family biotic index (FBI) clearly distinguish the riffles (lower scores) from the glides due to lower pollution tolerance values of riffle-dwelling macroinvertebrates (Figure 10).

Percent Dominants had an index value of 80% or greater in 15 of the 16 transects and glide transects 1, 2, 4, 5, and 6 had scores >97% primarily due to the abundance of

Chironomidae (Figure 10). Percent Chironomidae was greater in the glide transects of the lower Salmon River (>80%) and least in the riffle transects (mean = 13.7%).

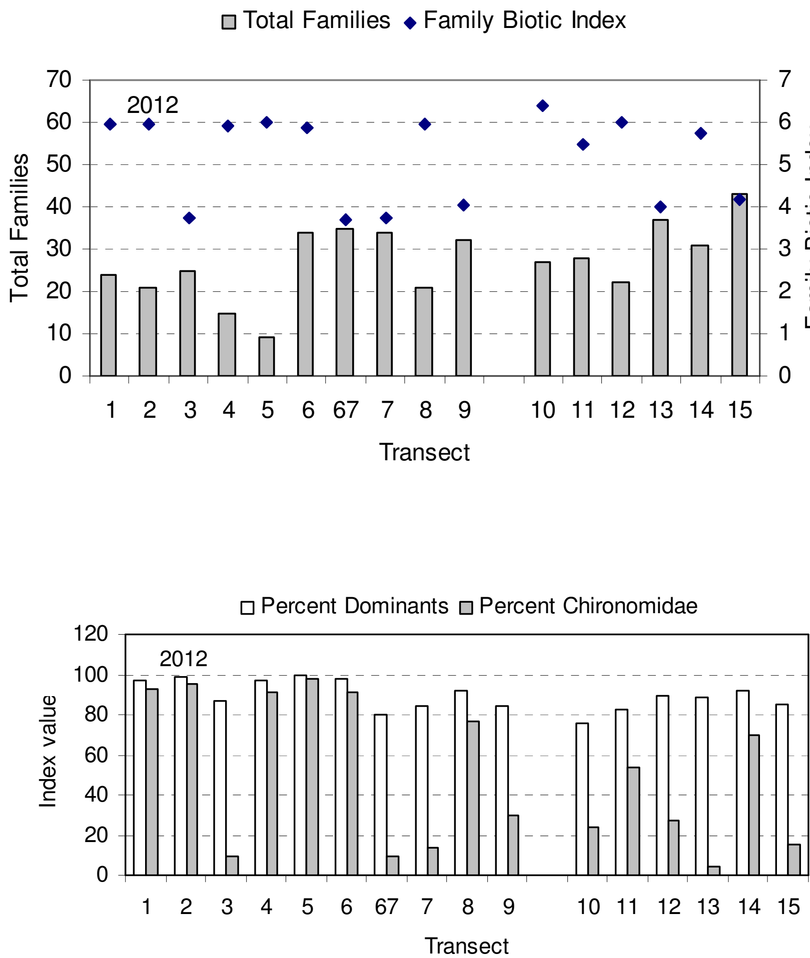


Figure 10. Total families index and family biotic index for the Salmon (transects 1–9, 67) and Little Salmon (10–15) rivers in 2012 (upper panel). Lower scores for the FBI indicate more organisms with lower pollution tolerance values; and percent dominants index and percent Chironomidae index for the Salmon (transects 1–9, 67) and Little Salmon (transects 10–15) rivers in 2012 (lower panel).

Percent Model Affinity (briefly defined as similarity to an undisturbed community) was developed from riffle samples (Novak and Bode 1992) but has been applied to glide samples here as well as a useful comparison method. Glide transects in the Salmon River had less model affinity than did glide transects in the Little Salmon River (Figure 11), and Salmon River transects 1, 2, and 4 had declined from percentages in 2010. Riffle transects increased in model affinity in 2012 with the exception of transect 13 where model affinity declined by 7.3%. Calculation of this index is shown in

Appendix Table 3.

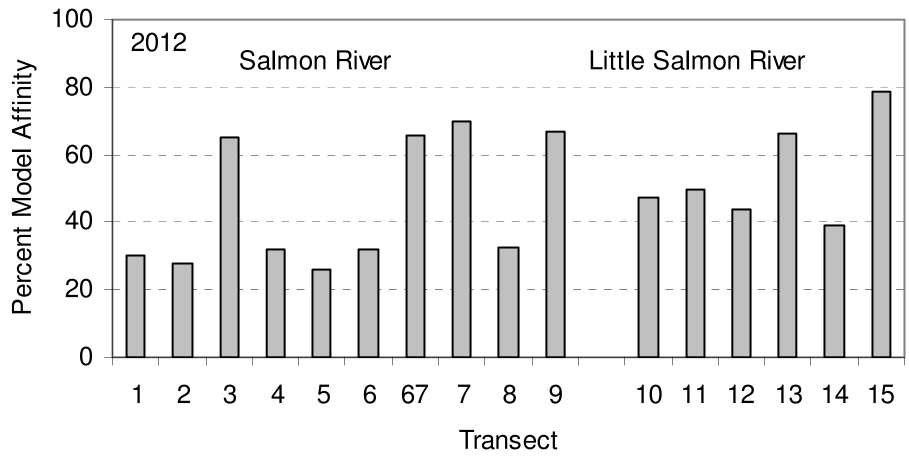


Figure 11. Percent model affinity for the Salmon (transects 1–9, and 67) and Little Salmon (transects 10–15) rivers in 2012.

Macroinvertebrate comparisons in pre- and post-removal periods. Transect 4 showed the only significant difference ($F = 6.56$; $P = 0.02$) in EPT families when comparing transects in pre- and post dam removal periods (Figure 12) due largely to the increase in mayfly families (Figure 13). There were no significant differences between the pre-dam removal period and the post-dam removal period for the number of mayfly families (lsmeans = 0.32) or caddisfly families (lsmeans = 0.25). The number of stonefly families was not compared statistically due to the low number of families.

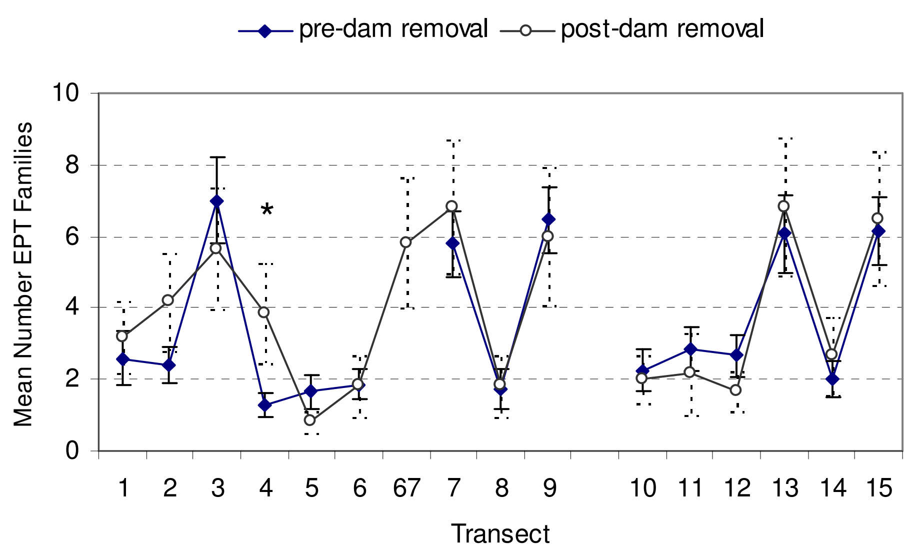
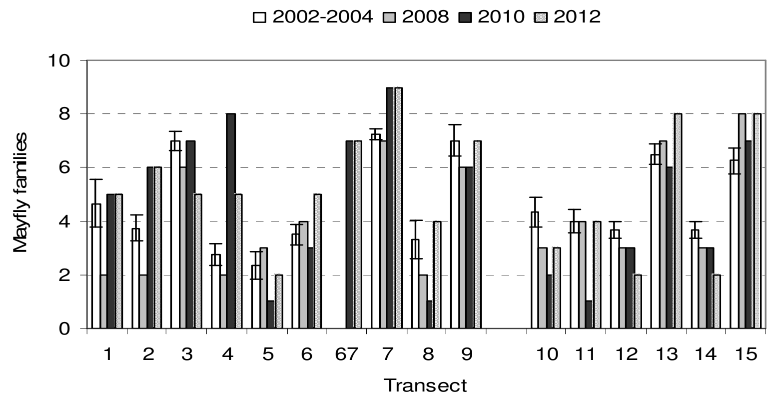
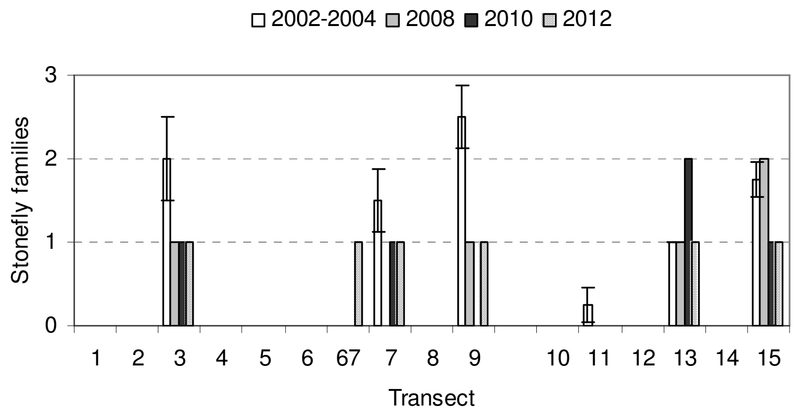


Figure 12. Mean number of EPT families from the pre-dam removal period and the number collected in post-dam removal period (mean ± 1 SE). The asterisk signifies a significant difference.





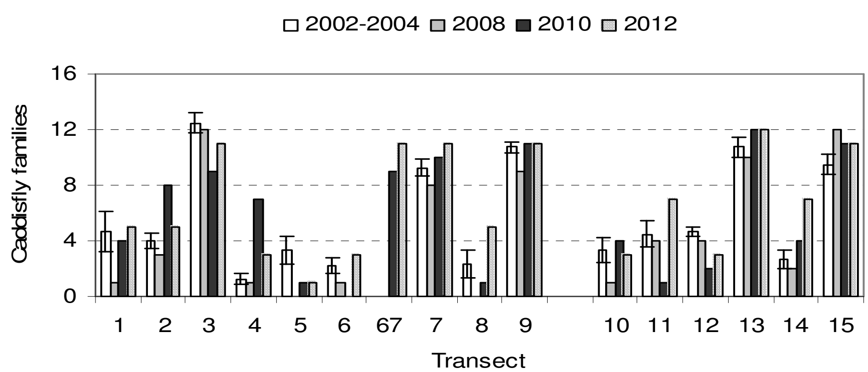


Figure 13 . Number of mayfly, stonefly, and caddisfly families by transect. Four sampling months occurred from 2002 to 2004 thus these values are means (± 1 SE); 2008, 2010, and 2012 have family number for one sampling month in each year. Transects 1 to 9 are in the Salmon River and transects 10 to 15 are in the Little Salmon River. Transect 67 was not sampled from 2002 to 2008.

The four indices of total families, family biotic index, percent dominants, and percent Chironomidae (Figure 14) showed varied responses in 2012 compared to 2010

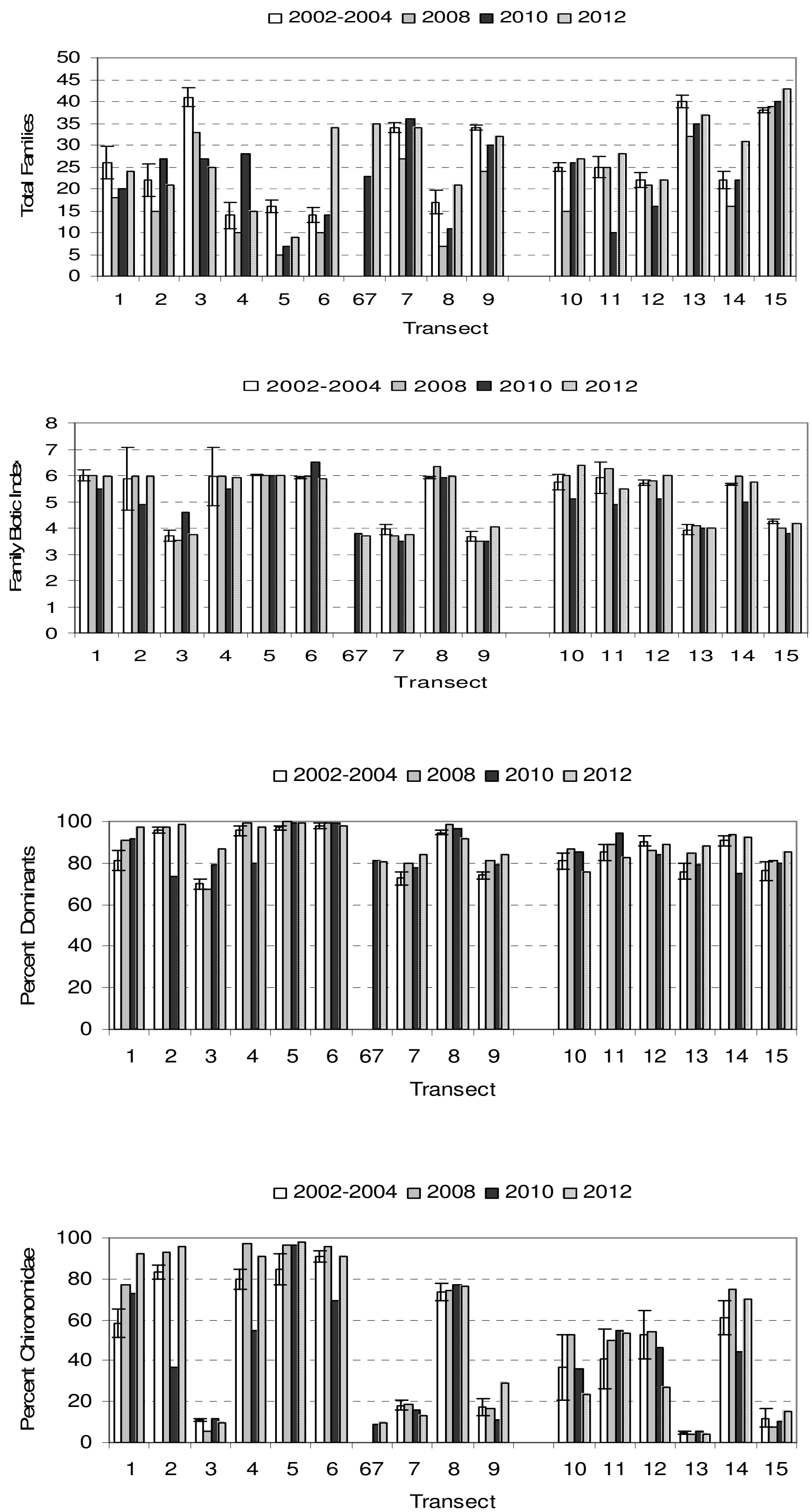


Figure 14. Macroinvertebrate indices for each transect and river calculated from 64 families. Four sampling months occurred from 2002 to 2004 thus these values are means (± 1 SE); the other years are represented by a single value for one sampling month in each year.

but all were relatively stable in pre- and post-dam removal periods. Year-to-year variations occurred in total families (transects 3, 6, and 11) and in percent Chironomidae (transects 2, 4, and 14) from pre- to post-dam removal.

Changes in the indices for pre- and post-dam removal for each transect were examined with least-squares means using the seven sampling periods (from 2002 through 2012) as a covariate. The number of EPT families by transect was not significantly different among the seven sampling periods ($F = 0.66$; $P = 0.58$) but the riffle transects had significantly more EPT families than the glide transects ($P < 0.0003$ with Bonferroni correction; Figure 15).

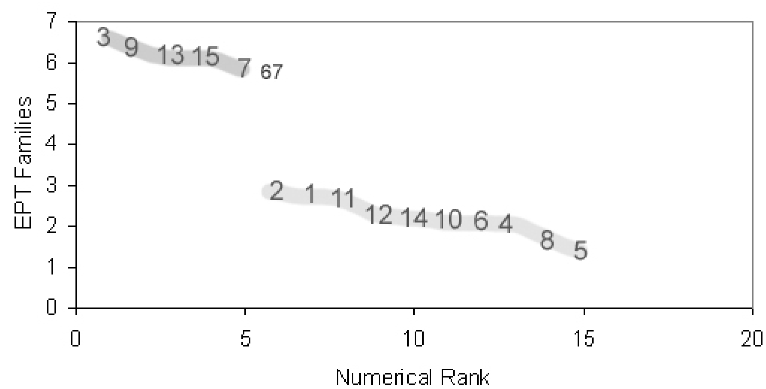


Figure 15. Numerically ranked value of EPT families at transects for seven sampling periods from 2002 to 2012. Numbers refer to transects. Transects that do not share a common color shade are statistically different: note that transect 67 was sampled only in 2010 and 2012 and was not used in statistical tests.

Transects segregated into three groups by numerical rank for total families (Figure 16): riffle transects had statistically greater number of total families than did glide transects 1 and 2 and 10 to 14. Transects of the former impoundment (4, 5, and 6), and transect 8, formed a third statistically distinct group ($P < 0.0001$). Transect 15 had greater number of total families than did transect 9 but the difference was not significant (Bonferroni correction $P > 0.01$). There was no significant difference in pre- and post-dam removal in total families ($F = 0.0$; $P = 0.99$). Transects segregated into three groups by rank for percent Chironomidae: riffle transects had significantly lower percent chironomids than did glide transects 10 to 14 in Little Salmon River or glide transects in the former impoundment and lower Salmon River ($P < 0.0001$). There was no significant difference in pre- and post-dam removal in percent Chironomidae ($F = 0.0$; $P = 0.96$).

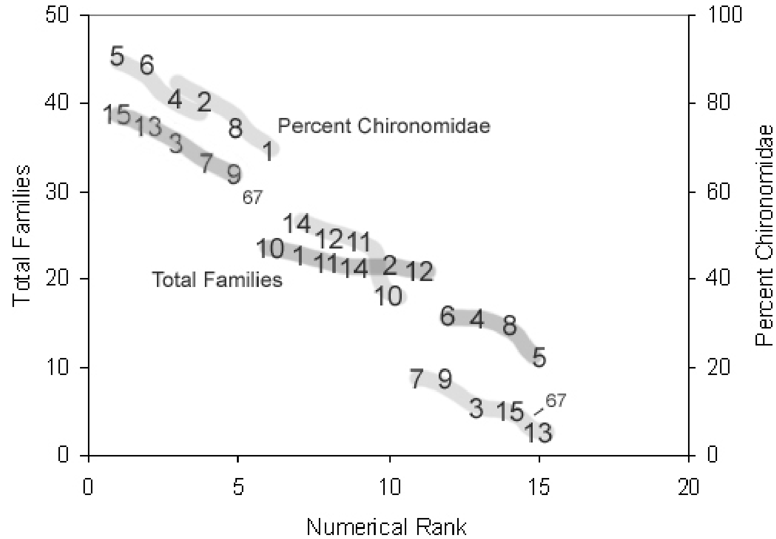


Figure 16. Numerically ranked value of total families and percent Chironomidae at transects for seven sampling periods from 2002 to 2012. Numbers refer to transects. Transects that are not connected with a common color shade are statistically different: transect 67 was not used in statistical tests.

Riffle transects shared some similarity in percent dominants with transect 10, which also shared similarity to glide transects of the Little Salmon River, and transect 1 of the Salmon River. Glide transects in the former impoundment were split into two groups (transects 5 and 6; transect 4) with transect 8 sharing similarity with both groups (Figure 17). There was no significant difference in pre- and post-dam removal in percent dominants ($F = 0.79$; $P = 0.38$).

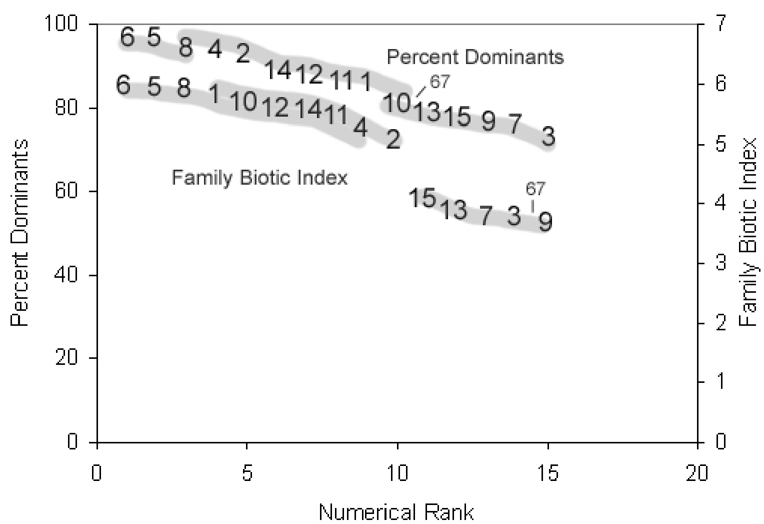


Figure 17. Statistical relationship of transects for percent dominants and family biotic index with the numerically ranked index value of each transect. Numbers refer to transect. Those transects that do not share a color shade are significantly different ($\alpha = 0.003$). Transect 67 was not used in statistical tests.

Values for the family biotic index did not share any similarity between riffle transects and glides, but glides did share similarity, particularly those glides in the Little Salmon River. There was no significant difference in pre- and post-dam removal in family biotic index ($F = 0.32$; $P = 0.58$).

Unionid mussels. Nine species of living mussels were collected in 2012 from 1000 quadrats of 0.25 m^2 area. A ratio estimator (Strayer and Smith 2003) was used to estimate the mussel population within each transect. *Elliptio complanata*, *Lampsilis radiata*, and *Lampsilis cariosa* were the more abundant species accounting for 97% of the total collected. *Elliptio complanata* was collected at all transects and had the greatest density, more than 22 times greater than *L. radiata*. *Lampsilis cariosa* was collected in Deer Creek and transect 12 (Table 5) but *L. ovata* was not collected in 2012 although individuals were observed outside of the sampling area at transect 5. One living *Margaritifera margaritifera* was collected at transect 9, which represented the first occurrence of that species in the mussel surveys.

Table 5. Density (all transects combined) and population estimates of living adult mussels collected in the mussel survey in 2012. Relative abundance is based on mussels collected. Population estimates and density are based on the total area of transects, not extrapolated to the entire study area.

Species	Number collected	Population estimate	Population 95% CI	Relative abundance (%)	Density (no./m^2)	Density SE
All species	215	651	649–652	—	0.17	0.18
Alasmidonta marginata	1	3	2.9–3.0	0.5	0.001	0.002
Elliptio complanata	198	594	591–597	91.2	0.15	0.52
Lampsilis cariosa	3	9	8.9–9.1	1.4	0.002	0.01
Lasmigona costata	2	6	5.9–6.0	0.9	0.002	0.005
Margaritifera margaritifera	1	3	2.9–3.0	0.5	0.001	0.002
Lampsilis radiata	9	27	26.8–27.2	4.1	0.007	0.03
Pyganodon cataracta	1	3	2.9–3.0	0.5	0.001	0.003
Pyganodon grandis	1	3	2.9–3.0	0.5	0.001	0.02
Strophitus undulatus	1	3	2.9–3.0	0.5	0.001	0.003

Lewis Marine and transect 8 had greater density of mussels (Lewis Marine = 1.86/m^2; transect 8 = 0.84/m^2) in 2012. The remaining transects had mussel densities of less than 0.3/m^2. Mean density of all mussels was greater in the Little Salmon River

($0.64/m^2$) than in the Salmon River ($0.18/m^2$).

The cumulative distribution of mussels (all years) was significantly different between glide transects and riffle transects (Kolmogorov-Smirnov D = 0.98, maximum difference = 44.5, $\alpha = 0.01$). Mussels in glides were collected more frequently on the east side of both rivers but mussels in riffles were more abundant on the west side (Figure 18).

Overall mussel density was not significantly different from 2005 through 2012 ($F = 0.62$; $P = 0.74$) but Lewis Marine had a greater density of mussels ($1.14/m^2$) than other transects (lsmeans <0.0001). Mussel density at transect 8 was significantly greater than at other transects in 2012 other than Lewis Marine and transect 12 ($F = 13.7$; $P < 0.0001$). Pre- and post-dam removal comparisons (Figure 19) showed that mussel density decreased at transect 6 by 88% (lsmeans = 0.01), and increased at transects 12 (lsmeans = 0.0002) and 15 (lsmeans = 0.74). The increase at transect 12 was partly due to collecting more juveniles from increased excavation: a similar number of adults were collected.

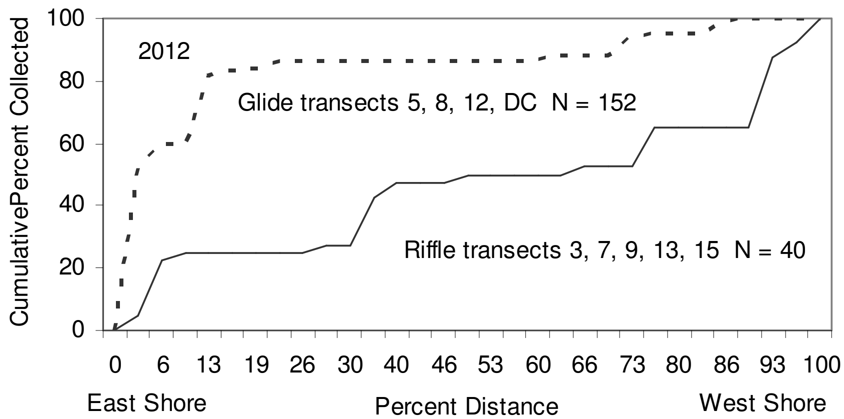


Figure 18. Cumulative percent distribution of adult mussels in glide and riffle transects, excluding Lewis Marine in 2012. Mussels were sampled from a glide portion of Deer Creek (DC). Percent distance refers to the distance across the river starting from the east shore.

Juvenile mussels (defined as having a shell length <40 mm). Quadrat excavation produced 37 juvenile mussels from three transects (Table 6) with three additional mussels coming from benthic samples. *Elliptio complanata* juveniles had the greatest density at Lewis Marine, nearly twice that at transect 12. The number of juveniles collected in 2012 was 39% less than that in 2010.

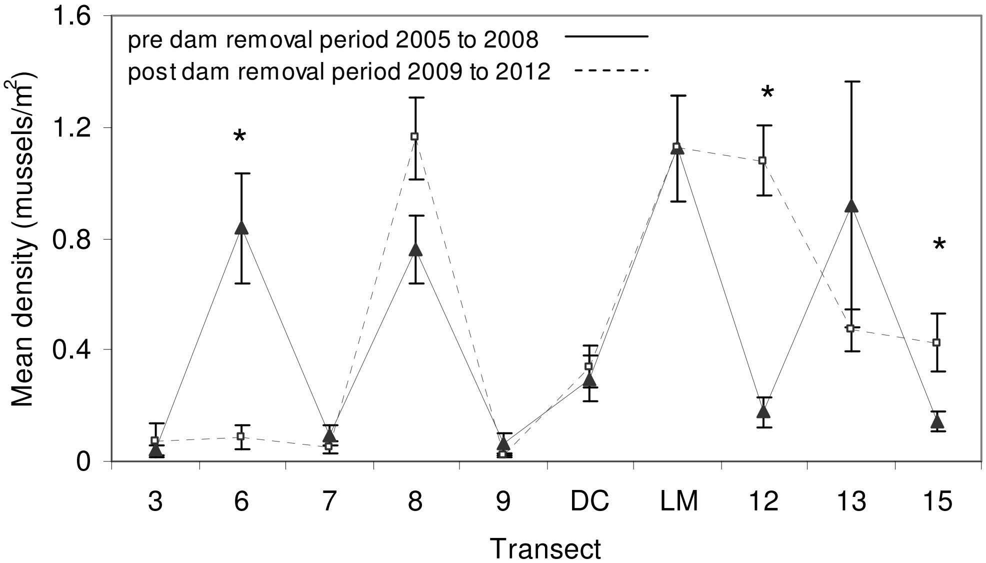


Figure 19. Mean adult mussel density (± 1 SE) by transect in pre-dam removal years (solid line, 2005–2008) and post-dam removal years (dashed line, 2009–2012). An asterisk refers to a significant difference. DC = Deer Creek and LM = Lewis Marine.

Table 6. Number and shell length of juvenile mussels collected in the mussel survey and benthic samples in 2012. Mussels from transects 11 and 15 were collected in benthic samples.

Species	Transect 6	Lewis Marine	Transect 11	Transect 12	Transect 15	SL (mm)	%
	Number collected						
Elliptio complanata	1	19	2	11	1	7.5–36.1	91.9
Lampsilis radiata	1					20.9	2.7
Pyganodon grandis		1				19.3	2.7
Lampsilis cariosa				1		31.1	2.7
Total	2	20	2	12	1		
%	5.4	54	5.4	32.4	2.7		

More than 200 living juvenile mussels of seven species were collected in the study period from 2002 to 2012. *Elliptio complanata* was dominant at nearly 91% of all juveniles with *Lampsilis radiata* at 3.9%: the remaining five species (*L. ovata*, *L.cariosa*, *Lasmigona compressa*, *Pyganodon grandis*, and *Strophitus undulatus*) were collected at less than 2% of the total. Juvenile mussels were collected from 13 transects (including benthic and sediment samples) but not at Deer Creek or transects 4, 6, and 7. Lewis Marine and transect 12 accounted for nearly 89% of the total.

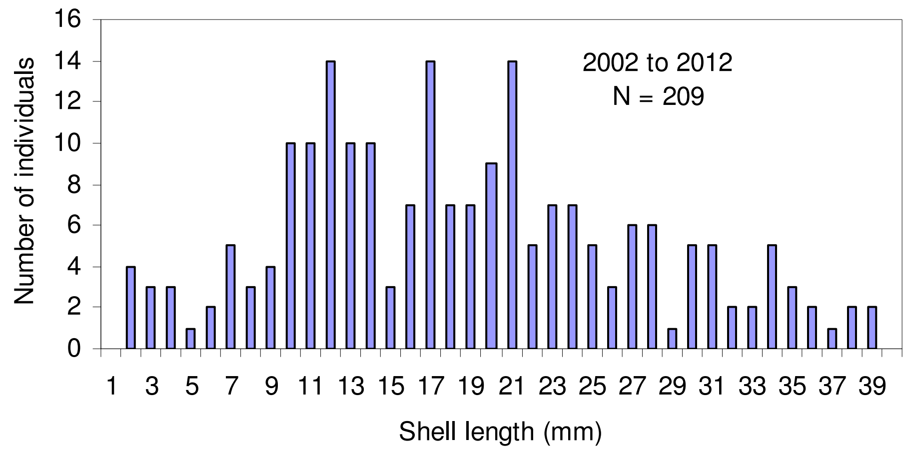


Figure 20. Shell length distribution of juvenile mussels collected from 2002 to 2012 from mussel surveys, benthic samples, and sediment samples. Juvenile mussels were defined as having shell lengths of less than 40 mm.

Middens. Eighteen middens were located in 2012 that were not seen in previous years, 13 in the Salmon River and five in the Little Salmon River. Most of these middens were in two areas that had not been examined before: from transect 7 to transect 8 and between transects 13 and 15. These middens yielded 594 mussels of 10 species (Table 7), including two *M. margaritifera*, a species not seen in earlier surveys. The middens in the Salmon River were not distributed evenly but occurred in two areas; one from the mouth of Deer Creek downriver to transect 7 and the other between transects 8 and 9. Four of the five new middens in the Little Salmon River were located between transects 14 and 15, one was located upriver of transect 15, and none were located between transects 13 and 14.

Mussels were collected from 37 middens from 2005 to 2012 resulting in 10 species and 2,559 complete shells. The species were dominated by *E. complanata* (79.6% of all collected) with *L. radiata* at 7.8% and *S. undulatus* at 3.5%. Three species that were collected alive in the study area were not found in any midden: *Lasmigona compressa*, *Anodontoides ferussacianus*, and *Pyganodon grandis*. A summary of living mussels and those from middens is given in Appendix Table 4.

Table 7. Number and mean shell length (SL) of mussel species collected in 13 middens in the Salmon River and from five middens in the Little Salmon River in 2012.

	Salmon River		Little Salmon River			
Species	Collected	Mean SL	Collected	Mean SL	Total	Percent
Alasmidonta marginata			4	60	4	0.7
Alasmidonta undulata	3	49.0			3	0.5
Elliptio complanata	467	81.3	82	69.4	549	92.4
Lampsilis cariosa			4	84.1	4	0.7
Lampsilis ovata			1	74.9	1	0.2
Lampsilis radiata	1	74.2	3	71.9	4	0.7
Lasmigona costata			19	82	19	3.2
Margaritifera margaritifera	2	114.5			2	0.3
Strophitus undulatus	3	66.2	5	65.3	8	1.4
Total	476		118		594	100

Fish. Hoop nets were fished for 444 hr at seven locations in 2012: four locations in the Salmon River and three locations in the Little Salmon River. Sixteen species were collected with hoop nets (N = 225). Brown Bullhead was the most abundant in CPUE (Table 8), followed by Pumpkinseed and Longnose Gar; these three species accounted for 73% of the total catch in hoop nets.

Twenty-seven seine hauls were made at 21 locations covering 304 m and collected 348 fish of 14 species. Seine haul distance ranged from 9 m to 13 m. Tessellated Darter and Rock Bass were the more abundant species (Table 8). Eastern Sand Darter was 5th in CPUE with the largest catch (N = 25) being made on a sand deposit in the Salmon River between transects 1 and 2. Eastern Sand Darter was also collected at the confluence of the two rivers and at transects 1 and 5. Round Goby (*Neogobius melanostomus*) was collected in two locations in the Little Salmon River and one location in the Salmon River.

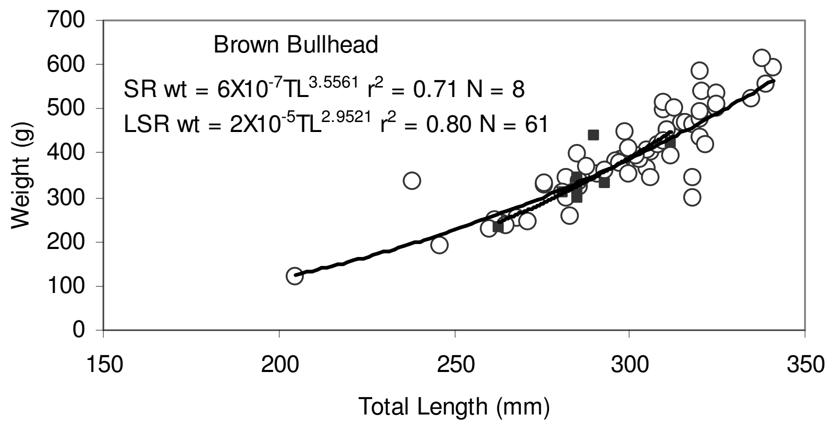
Thirty-two species of fishes (N = 590) were collected in the study area in 2012 (all gear combined; Appendix Table 5). A greater percentage of fish was caught in the Little Salmon River (67%) than in the Salmon River (32%). Longnose Gar, Walleye, and Northern Pike were the more abundant predators (from trapnets): Longnose Gar was ranked third in CPUE, Walleye and Northern Pike ranked 10th, and Largemouth Bass ranked 11th. No Sea Lamprey was collected in the study. Silver Lamprey was the only parasitic lamprey collected in 2012 (15th in relative abundance) and only from the Salmon River, however, Silver Lamprey was collected from both rivers in other years. Summaries of the fish species collected for all years of the study are given in Appendix Tables 6 and 7.

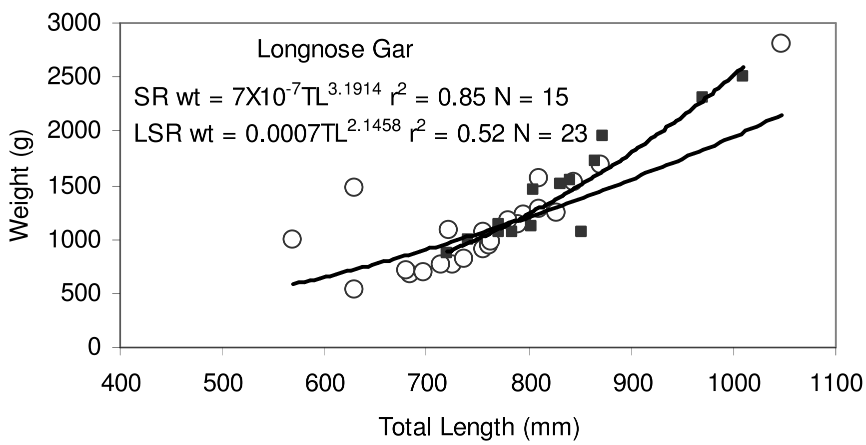
Table 8. Catch-per-unit-effort of 10 more abundant fish species collected in hoop nets and seine in 2012. CPUE for hoop net was based on total hours fished, and CPUE for seine was based on total distance.

	Hoop net (444 hours)		Seine (304 m)
Species	catch/hr	Species	catch/m
Brown Bullhead	0.155	Tessellated Darter	0.26
Pumpkinseed	0.117	Rock Bass	0.24
Longnose Gar	0.095	Pumpkinseed	0.197
Rock Bass	0.068	Spottail Shiner	0.18
Greater Redhorse	0.011	Eastern Sand Darter	0.11
Black Crappie	0.011	Brook Silverside	0.08
White Sucker	0.011	Smallmouth Bass	0.05
Fallfish	0.009	Mimic Shiner	0.04
Yellow Perch	0.007	Rosyface Shiner	0.03
Northern Pike	0.005	White Sucker	0.003

Logarithmic regressions of length and weight resulted in relationships with good predictive characteristics for Brown Bullhead and Rock Bass but not for Longnose Gar (Figure 21). Longnose Gar was caught only during the spring spawning period (although they were observed at other times) and the catch most likely included post-spawning adults, which would affect the length-weight relationship. Regressions showed that the length-weight relationship of Longnose Gar and Rock Bass were similar between the Salmon and Little Salmon rivers (Longnose Gar lsmeans = 0.40; Rock Bass lsmeans = 0.16). The length-weight regressions of Brown Bullhead were also similar but were not tested statistically due to uneven sample size. Pumpkinseed was collected in great enough numbers but windy conditions prevented making weight determinations in 2012.

Length frequency plots of the more abundant fish species collected by seine showed a wide range of sizes (Figure 22) but the majority were young-of-year. The majority of Tessellated Darter, Rock Bass, Brook Silverside, and Round Goby were collected in October, Eastern Sand Darter and Pumpkinseed were collected evenly in August and October; and Fallfish, Smallmouth Bass, and Largemouth Bass were collected primarily in August.





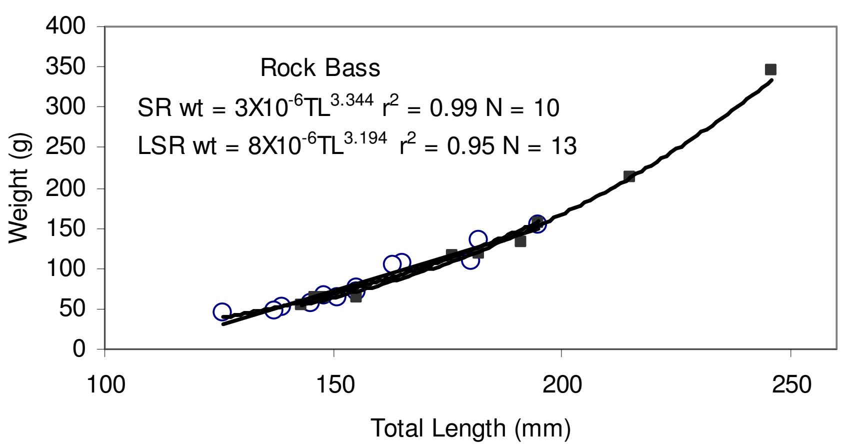


Figure 21. Length-weight relationships for three more abundant fishes collected in trap nets in the Salmon and Little Salmon rivers in 2012. Solid squares represent fish from the Salmon River (SR) and open circles represent fish from the Little Salmon River (LSR).

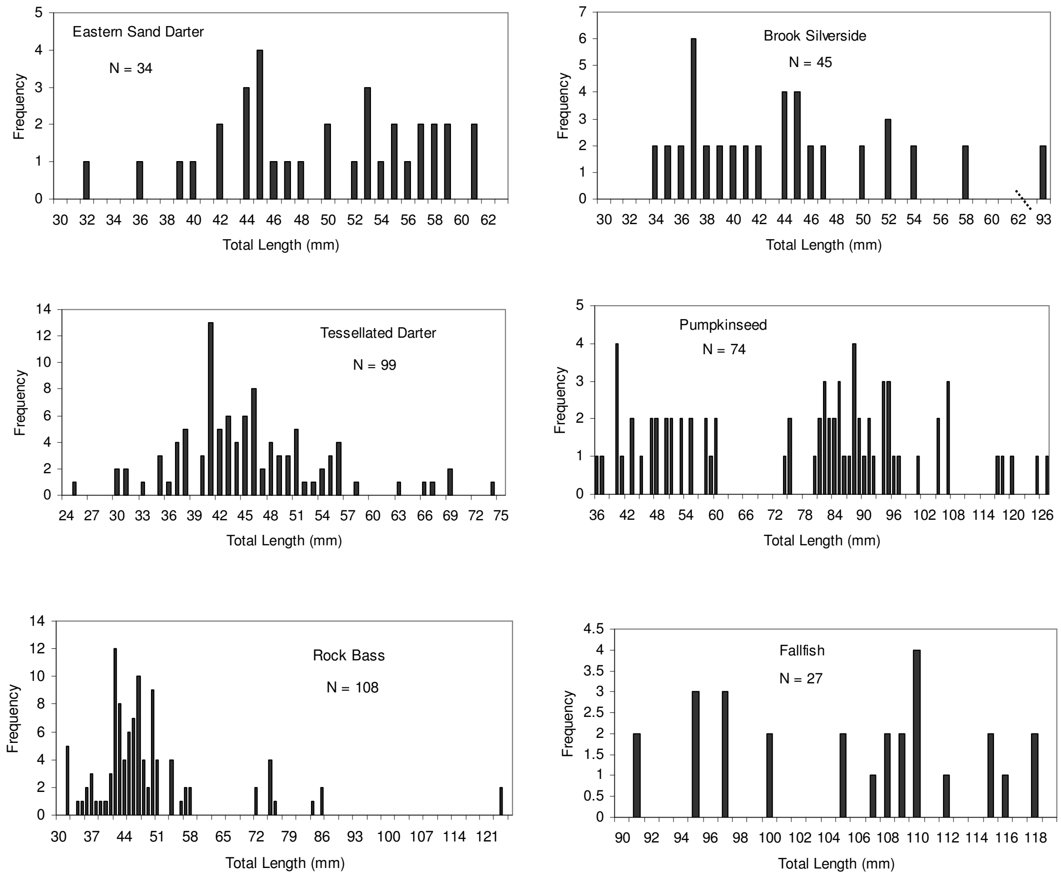


Figure 22. Length frequency plots of six fish species collected by seining in the Salmon and Little Salmon rivers. Not all fish collected were measured.

Growth of Brown Bullhead and Rock Bass was compared at locations upriver and downriver of the dam site for pre-dam removal years and post-dam removal years. Brown Bullhead were greater in weight downriver of the dam in pre-dam removal years and remained greater after the dam was removed (lsmeans <0.0001 in both comparisons). Rock Bass weight in relation to total length was similar upriver and downriver in pre-dam and post-dam removal years (pre-dam lsmeans = 0.44; post-dam lsmeans = 0.29). Longnose Gar could not be compared since only two individuals were collected upriver of the former dam site.

There were 14 species not collected in 2012 that were collected in previous years (summarized in Appendix Tables 6 and 7), and several of these species were collected infrequently in the past. One Bowfin was collected in the Little Salmon River for the first time in 2012. Longnose Gar and Silver Lamprey were the only species caught upstream of the former dam site that had not been collected there in previous years. No American Eel has been collected since 2003.

Index of biotic integrity. Scores in richness and composition metrics were similar between the Salmon River and Little Salmon River in 2012 although the percentage of dominants was less in the Salmon River. Both rivers showed a decline in trophic composition metrics: percent insectivores declined in the Salmon River and percent omnivore species declined in the Little Salmon River compared to 2010 (Table 10). The Little Salmon River had lower scores for fish health (greater percent tumors and lesions) in every year of the study. The IBI score was 'very good' for the Salmon River and 'good'

Table 10. Metric scores for 2012 for fish index of biotic integrity (IBI) following Daniels et al. (2002) based on a watershed of 2838 km^2.

		Scoring			Salmon River		Little Salmon River	
Metric	Description	5	3	1	value	score	value	score
	Resident fish species richness and composition							
1	Total number of species	>13	6–12	<6	15	5	15	5
2	Number of benthic insectivores	>4	2–4	<2	5	5	7	5
3	Water column species	>5	2.5–5	<2.5	6	5	6	5
4	Number of terete minnow species	>4.5	2–4.5	<2	4	3	4	3
5	% dominant species	<40%	40–55%	>55%	50.3	3	65	1
6	% total white sucker	<3%	3–15%	>15%	2.1	5	0.5	5
	Trophic composition							
7	% total omnivores	<20%	20–45%	>45%	45.5	1	64	1
8	% total insectivores	>50%	25–50%	<25%	37	3	17.6	1
9	% carnivores	>5%	1–5%	<1%	16.4	5	10.2	5
	Fish abundance and condition							
10	fish abundance (no./100m^2)	>10	5–10	<5	36	3	164	5
11	% with 2 age groups	>40%	15–40%	<15%	19	3	31.6	3
12	% with tumors, lesions, parasites	0%	>0<1%	>1%	0	5	2.6	1

Total score	46	40

for the Little Salmon River in 2012 but these scores have varied between 37 to 46 in the Salmon River and between 40 and 44 for the Little Salmon River for the four sampling periods of 2002–2004, 2008, 2010, and 2012.

Aquatic plants. Twelve genera of aquatic plants were identified but only four genera occurred in the Salmon River and these were in small, isolated patches. In contrast, ten genera of aquatic plants occurred in the Little Salmon River in large, dense patches that were composed primarily of *Potamogeton*, *Myriophyllum*, and *Vallisneria* (Figure 22). Northern wild rice (*Zizania palustris*) was found in one small area at Lewis Marine as was the exotic flowering rush (*Butomus umbellatus*). *Elodea* dominated the plant cover at transect 8 (not shown) but the area covered was restricted to the east side of the river. The former impoundment was devoid of any submerged aquatic plants with the exception of water cress at transect 4 and *Vallisneria* at transect 67. The few colonies of the exotic European frogbit (*Hydrocharis morsus-ranae*) that had been present near transect 5 in 2004 were absent. A stand of wild rice that was present downstream of the former dam

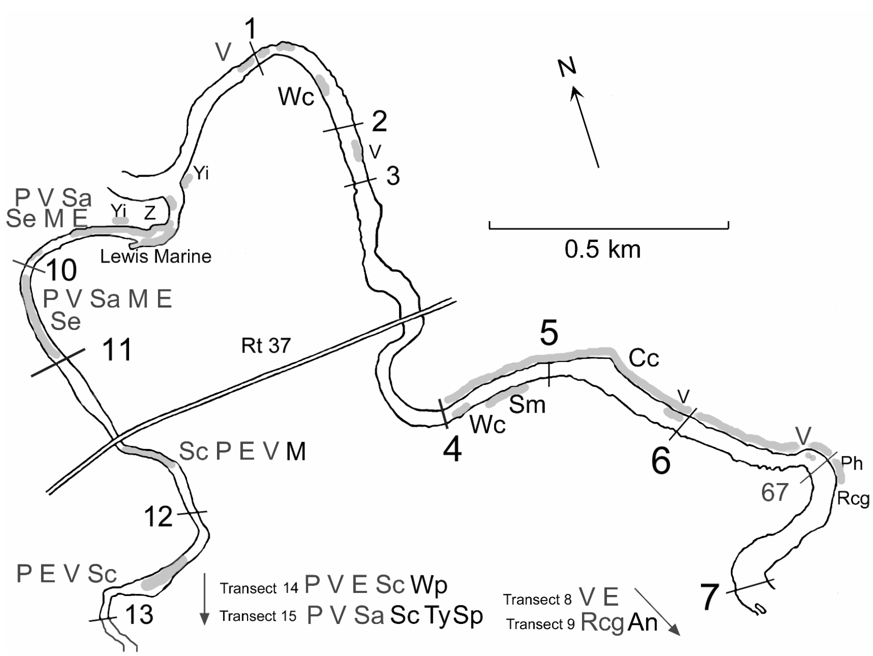


Figure 22. Plant genera identified in 2012. The letter abbreviations for plants are: An = *Angelica*, Cc = common cocklebur, E = *Elodea*, M = *Myriophyllum*, P = *Potamogeton*, Ph = *Phragmites*, Sa = *Sagitarria*, Sc = *Scirpus*, Se = sedges, Sm = swamp marigold, Sp = *Sparganium*, Ty = *Typha*, V =*Vallisneria*, Wc =

water cress, Wp = wild parsnip, Yi = yellow iris, and Z = *Zizania*. Flowering rush *Butomus umbellatus* was present along the north side of transect 10, and Rice cut-grass (Rcg) was present at transects 9 and 67. Gray areas show the extent of the vegetation. Transects 8, 9, 14, and 15 are not shown on the figure.

site was replaced by lawn grass in 2010 and has not returned. There was no apparent change in the aquatic plant coverage in the Little Salmon River. The only vegetated areas that would serve as fish larvae nurseries were in the Little Salmon River. Other plants associated with wet or damp soils were wild parsnip (*Pastinaca sativa*, invasive), yellow iris (*Iris pseudocorus*, invasive), common reed (*Phragmites australis*, invasive), Angelica (*Angelica atropurpurea*, native), swamp marigold (*Bidens coronata*) and rice cut-grass (*Leersia oryzoides*). Common cocklebur (*Xanthium strumarium*) has colonized most of the east shore of the former impoundment.

Discussion

The Salmon and Little Salmon rivers cut through a glacial moraine deposit of fine to coarse sand on the north side of Malone, New York. This sand has been deposited in the rivers and remains the dominant physical feature of glide substrate while cobble is dominant in the riffles. Downstream movement of sediment would be of critical importance in assessing the risks of dam removal (Shuman 1995) and several studies have documented alterations of the habitat due to deposition of sediments (Stanley et al. 2002; Burroughs et al. 2010): the erosion of upriver sediments led to an increased gradient and water velocity in the former impoundments and formation of new channels with steeper banks. All of these physical changes occurred in the former impoundment of the Salmon River and the eroded sediment (primarily sand) accumulated in the lower river. The deposited sand continued to move downriver but at a much slower rate than in the former impoundment. Three conceptual models have been proposed for the transport of sediments (reviewed in Lisle et al. 1997) where the sediment can 1) move as a discrete mass with little change in shape, 2) move as a diffuse stream of particles over time, and 3) remain in place with only a small proportion moving downstream. The sand that passed through the former impoundment of the Salmon River was most similar to conceptual model 1; the leading edge of the sand was apparent from July to November, 2009. The movement of the sand was similar to that described by Simons and Simons (1991; cited in Doyle et al. 2000) after the removal of the Newaygo Dam on the Muskegon River, Michigan, where sediment moved as a wave at about 1.6 km/year. The average rate observed in the Salmon River was equivalent to 2.3 km/year.

The increased water velocity increased the dimensions of the riffles at the upper end of the former impoundment as well as at the former dam site. An additional riffle was exposed after dam removal: pebble counts in these riffles show that the riffles were similar in that they were composed primarily of cobble with less than 10% finer particles. These riffles were similar in composition to those in the Great Chazy River, New York (NYSDEC 2008), which lies to the east of the Salmon River. Erosion has continued to widen the river on the west side through undercutting of the river bank. The deposition of eroded material downriver has not resulted in a change in mean sorting or porosity with removal of the dam. This was not surprising since the substrate in the Salmon River was primarily sand in all areas and similar-sized particles were only redistributed. Mean particle size in a Pennsylvania stream was reduced after dam removal (Thomson et al. 2005) but that substrate was primarily pebble with an increase in sand following dam removal.

The deposition of sand downstream reached beyond the confluence of the Salmon and Little Salmon rivers by May, 2010, and formed a bar adjacent to the mouth of the Little Salmon River. This bar was partially removed by flooding in October, 2010, reformed by November, 2010, but was reduced in length in 2012. The channel in the Salmon River at the confluence was more defined in 2012 and was similar in depth to the pre-dam removal depth but regained only about 30% of the pre-dam removal width.

Alteration of the habitats did not cause major changes in any of the macroinvertebrate indices although the number of macroinvertebrates increased dramatically in 2012. The macroinvertebrate assemblage within the former impoundment remains much as it was prior to dam removal. Glide transects were dominated by midges (Chironomidae) while caddisflies, mayflies, and riffle beetles were more abundant in riffle transects. This was similar to that described by Stanley et al. (2002) in the Baraboo River. Transects 4, 5, and 6 in the former impoundment, and transect 8, shared similar ranks derived from the macroinvertebrate indices, which indicated that these areas supported less diverse communities in pre- and post-dam removal years. These transects have a nearly uniform sand substrate that would reduce habitat diversity (Hill et al. 1993).

The Salmon and Little Salmon rivers can be classified as soft water with moderate buffering capacity. Chloride, sulfate, and ammonia levels were lower than would be expected in natural freshwater and had similar levels in pre- and post-dam removal years, and to those determined in previous studies over the past 50 years (USGS), although some samples showed elevated concentrations. Dissolved oxygen levels and temperature were not affected by the dam and did not change appreciably after dam removal. Velinsky et al. (2006) did not find any change in levels of pH, alkalinity, or conductivity in a Pennsylvania stream after dam removal.

Dam removal was more disruptive for mussels. The lowering of the water level in the impoundment stranded, and subsequently killed, approximately 77% of the impoundment population of mussels (Cooper 2011) in 2009, and this was reflected in a decline in impoundment mussel density in all years after dam removal. A similar result was described by Sethi et al. (2004) for a dam removal in Wisconsin, although mortality there was not as great. Deposition of sand in downstream areas would have buried mussels but there are no estimates of the population. The potential for burial of downstream mussels can be drawn from the contents of two mussel middens near transect 1. These two middens contained six mussel species (246 complete shells) of which two species, *Lampsilis ovata* and *Lampsilis cariosa*, accounted for 34%. These two species are listed as those in greatest conservation need by the New York Heritage Program. It is possible that these shells represented a dense mussel bed that was covered by sand. Dissolution rates of shell material (Strayer and Malcolm 2007) could be fairly high in the low-calcium water of the Salmon River (mean = 10.5 mg/L; USGS), thus midden contents would not represent a long-term accumulation. A small cluster of living mussels, including *L. ovata*, was observed near transect 1 where scouring of the sand along the east river bank had revealed part of the original shoreline.

The fish IBI has varied over the years in the Salmon River, which might not reflect a true change in the fish community. Changes in fishing efficiency (lower water depth, fewer effective fishing sites) as well as the presence of the dam in the early part of the study would affect catches to varying degrees. The dam could act as a barrier, which prevented fish from moving upstream and could have increased the catch, especially of spring migrants such as redhorse suckers. Under post-dam removal conditions, the redistribution of sand rendered many areas of the river too shallow for hoop nets and those areas that had sufficient water depth also had greater water velocity, which prevented some anchored hoop nets from remaining in place despite additional anchors and weights. The formation of a sand bar adjacent to the mouth of the Little Salmon River might have reduced water flow from that river allowing silt and algae to accumulate in the sand habitat at Lewis Marine and transect 11, which reduced the presence of fish. Eastern sand darter was not collected at Lewis Marine in 2010 or 2012 after silt and algae became prevalent but sand darters were collected there in pre-dam removal seining when the substrate was clean sand. Sand darters were collected only over clean sand substrate in all years of this study, which conforms to the findings of Daniels (1993) that sand darter selected sand substrates where vegetation and accumulated debris were no closer than 5 m. Brook Silverside, Bluntnose Minnow, Common Shiner, and Spotfin Shiner were not collected at transect 11 where they were common prior to 2010; Brook Silverside was collected several miles upriver where silt and algae was less prevalent but the other species were not.

The fish collections revealed an assemblage that was similar to that collected in 1930 (NY Cons. Dept. 1931). The 1930 survey covered a wider area, including the headwaters of the Salmon River and collected 12 species that were not collected in either the pre-dam removal study or post-removal study. Nine of the 12 species were considered to be headwater species and would not be found in the lower Salmon River. Three fish species collected in the 1930 survey were not collected from 2002 to 2012: Blacknose Shiner, Channel Darter, and Johnny Darter, although Blacknose Shiner was collected in the St. Regis River in 2004 (Dawn Dittman, USGS, pers. comm). Five fish species not collected in the 1930 study were collected in the present study: Longnose Gar, Carp, Central Mudminnow, American Eel, and Brook Silverside, but Central Mudminnow was not collected after dam removal, and no American Eel was collected since 2003. Largemouth Bass was collected in the Salmon River in 1998 and 2001 (Morrill and Tyson 2001), 2002 (Cooper et al. 2004), 2012 (this study), and in the St. Regis River in 2004 (Dawn Dittman, USGS, pers. comm). The exotic Round Goby was collected for the first time in 2010 in the Salmon River and in both rivers in 2012 but no evidence of spawning by Round Goby was found. Inclusion of more upriver sampling areas would likely result in an increased IBI (as IBI scores generally decrease in a downriver direction; Gammon and Simon 2000) and might have characterized fish movements more clearly.

Predicted changes. The baseline report (Cooper et al. 2004) predicted changes to the river following dam removal. It was correctly predicted that there would not be any effect upriver from transect 7 (upriver limit of the impoundment) and that this riffle would expand downriver; transects 5 and 6 would remain as glide-type habitats, similar to transect 8; transect 4 would experience the most change in flow velocity and in the macroinvertebrate community; and the riffle at transect 3 would expand upstream. Those predictions that were incorrect came about primarily as a result of the unanticipated increase in sand erosion and deposition downriver: all of the existing sand bars within the former impoundment were scoured out by water flow and were not colonized by aquatic vegetation; transects 1 and 2 downriver of the dam were predicted to receive additional sediment after dam removal but that any deposition would be for a short time: sand deposition has reduced the water depth at these transects by about 80% and will require many years to move the sand downriver; the mussel population was incorrectly predicted to not be affected in the lower river but was covered by sand; and that fish might gain access to the ponds from the river if a channel was eroded through the sill at the downstream end. Both ponds have dried completely and there is little reason to expect fish gaining access to either pond from the river: the erosion of the sill has occurred but remains much higher in elevation than the river.

Fish migration upriver is now possible for American Eel, Walleye, Longnose Gar, and carp for the first time in 91 years, although the benefit to American Eel and Walleye remains limited due to their low population level in the river. Predation on forage fish by Longnose Gar and Smallmouth Bass was predicted to increase, particularly if access to the ponds was possible. This was expected to increase the growth rate of Smallmouth Bass as was seen in the Milwaukee River after dam removal (Kanehl et al. 1997). Pond access by fish was not possible and few Longnose Gar and Smallmouth Bass were collected upriver of the former dam site. Carp were of concern upriver of the former dam as they might reduce spawning success of some forage fish by disturbing sediments and vegetation (Roberts et al. 1995) but there were few habitats of this type, except in Deer Creek, and river flow velocity is generally greater than that preferred by Carp.

The habitat for the Eastern Sand Darter was predicted to not change appreciably and it would appear that this prediction was accurate in the Salmon River but not in the Little Salmon River where the best habitat (Lewis Marine) was covered by silt and algae. New migrants, such as Sea Lamprey and Lake Sturgeon, are possible although Sea Lamprey has not been collected in the Salmon River. Lake Sturgeon was stocked in upriver areas of the Salmon River in 2012 after the fish sampling period was finished. Stocking appears to be successful in the St. Regis River and might lead to colonization of the Salmon River.

Acknowledgements

I would like to thank Sue Sabik for help with sampling and data collection, and Patricia Manchester, Supervisor for the Village of Fort Covington. I also thank the operators of the Lewis Marine for their help with equipment. My friend and colleague, Dr. Ronald J. Klauda, Maryland Department of Natural Resources, provided an in-depth review of this report.

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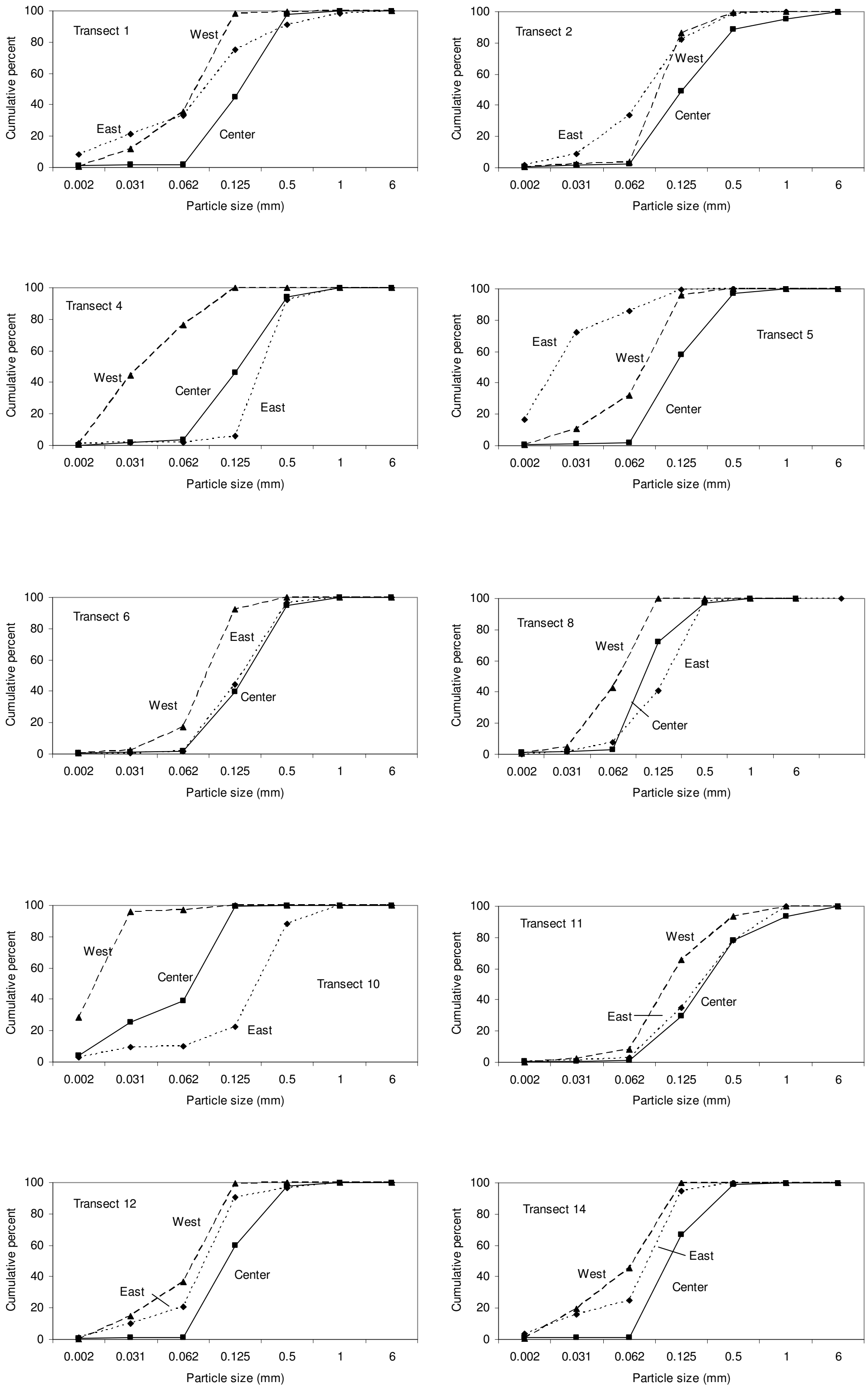


Appendix Figure 1. Cumulative percent of particle size from re-screened sediment samples from glide transects taken in 2002.

Appendix Table 1. Estimate of distance of transects from the confluence of the Salmon and Little Salmon rivers; and bank height and angle from transects in the Salmon and Little Salmon rivers in 2012.

Transect	Distance from confluence (km)	Bank height (m)		Bank angle Degrees from horizontal	
		east	west	east	west
1	0.36	3	1.5	60	20
2	0.66	1.8	1.7	60	60
3	0.91	3	3	30	60
dam	0.94				
4	1.09	2.4	1.7	40	80
5	1.55	1.8	2.3	20	55
6	1.91	1.8	2.4	20	60
67	2.01	1.6	2.4	15	80
7	2.26	1.5	2.3	15	40
8	9.25	1.8	2.7	80	80
9	10.13	1.2	2.3	80	40
10	0.43	2.4	1.8	70	50
11	0.66	1.5	1.5	40	70
12	0.91	1.5	2.1	60	80
13	1.3	1.2	1.1	20	60
14	2.41	1.8	1.1	85	30
15	4.72	1.2	1.4	15	30
Deer Creek	5.38	1.2	1.8	70	60
Lewis Marine	0.13	1.2	0.8	40	60
			average	by river	
Salmon River		1.99	2.23	42	57.5
L. Salmon River		1.54	1.4	47.1	54.3

Appendix table 2. Number of macroinvertebrates by transect for 2012. Only those families collected were used to construct the indices.

		Transect																
	Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**67**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**TOTAL**
caddisfly	Hydroptilidae	0	1	15	0	0	0	39	33	0	25	1	29	2	90	1	25	261
	Philopotamidae	0	0	110	0	0	0	26	16	0	16	0	0	0	155	0	106	429
	Hydropsychidae	1	1	1784	1	0	5	1445	1866	5	1020	0	0	0	2080	0	2337	10545
	Molannidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	3
	Limnephilidae	2	3	1	1	0	0	0	0	1	3	0	1	0	3	0	1	16
	Phyrganeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	Helicopsychidae	0	0	10	0	0	1	18	49	0	6	0	1	0	120	1	237	443
	Brachycentridae	1	0	430	0	0	0	314	284	4	767	0	0	0	7	0	9	1816
	Polycentropodidae	3	0	3	0	0	0	24	36	2	8	8	20	18	29	4	5	160
	Leptoceridae	0	5	0	8	9	29	1	5	4	0	3	1	2	57	14	62	200
	Glossosomatidae	0	0	28	0	0	0	82	337	0	14	0	1	0	14	0	112	588
	Rhyacophilidae	0	2	1	0	0	0	9	5	0	1	0	0	0	15	0	1	34
	Psychomyiidae	1	0	20	0	0	0	44	60	0	3	0	0	0	0	0	0	128
	Odontoceridae	0	0	1	0	0	0	2	4	0	4	0	0	0	6	2	3	22
	Lepidostomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
mayfly	Heptageniidae	0	0	137	1	0	0	333	207	5	118	0	2	0	392	0	235	1430
	Baetidae	3	1	1859	3	0	0	1906	1974	2	856	3	0	0	5346	2	4643	16598
	Isonychiidae	0	0	485	0	0	1	961	316	0	409	0	0	0	100	0	75	2347
	Ephemeridae	2	10	0	7	7	16	1	0	0	0	1	3	12	0	3	0	62
	Polymitarcyidae	0	1	16	0	0	1	15	3	0	6	0	0	0	11	0	15	68
	Ephemerellidae	0	2	58	0	0	0	62	43	0	58	0	0	0	444	0	686	1353
	Caenidae	2	23	0	9	3	8	0	3	1	0	4	2	0	1	0	6	62
	Baetiscidae	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2
	Leptophlebiidae	0	0	0	0	0	0	1	0	0	3	0	0	0	2	0	1	7
	Tricorythidae	2	2	0	3	0	2	3	10	9	27	0	5	5	86	0	496	650
stonefly	Perlidae	0	0	12	0	0	0	6	7	0	6	0	0	0	37	0	20	88
	Taeniopterygidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nemouridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Leuctridae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1

Appendix table 2. Number of macroinvertebrates by transect for 2012, continued.

		Transect																
	Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**67**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**TOTAL**
beetles	Elmidae	4	16	194	10	11	8	237	302	9	491	80	70	67	2245	189	1504	5437
	Psephenidae	8	0	6	2	0	0	5	1	0	5	0	0	0	16	0	47	90
	Hydrophilidae	0	1	0	0	0	0	0	1	0	0	4	1	0	0	6	4	17
	Dryopidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gyrinidae	1	0	0	0	1	0	0	1	0	2	0	6	2	2	0	4	19
	Dytiscidae	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	1	4
	Noteridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Staphylinidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Haliplidae	1	0	0	0	0	0	0	0	0	1	9	0	0	0	0	0	11
	Chrysomelidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Curculionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
amphipods	Gammaridae	20	4	0	0	0	0	0	1	0	0	27	11	6	5	21	33	128
	Hyalellidae	0	0	0	0	0	0	0	0	0	0	157	0	0	0	10	0	167
snails	Viviparidae	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	1	5
	Pleuroceridae	0	0	0	0	0	0	0	0	0	0	1	35	63	0	0	0	99
	Valvatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	Physidae	7	0	1	1	0	0	4	0	2	0	81	2	0	8	4	59	169
	Hydrobiidae	0	0	0	0	0	0	0	0	1	0	181	21	235	1	40	2	481
	Ancylidae	4	2	21	0	0	0	22	34	3	34	0	3	4	0	3	9	139
	Planorbidae	0	0	0	0	0	0	0	0	0	0	48	2	3	2	1	1	57
	Lymnaeidae	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	3
	Bithynidae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
clams	Sphaeriidae	15	5	0	2	5	4	29	1	42	18	46	9	26	11	73	166	452

Appendix table 2. Number of macroinvertebrates by transect for 2012, continued.

		Transect																
	Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**67**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**TOTAL**
diptera	Simuliidae	0	0	42	0	0	0	27	6	0	17	0	0	0	188	0	143	423
	Tipulidae	0	2	79	0	0	2	71	120	4	95	0	0	0	14	0	20	407
	Tabanidae	0	1	0	0	0	0	0	0	3	0	1	0	1	0	8	0	14
	Ceratopogonidae	2	1	0	1	6	1	0	0	14	0	10	10	4	1	32	0	82
	Empididae	1	2	7	0	1	2	3	7	0	15	1	0	0	10	0	48	97
	Stratiomyidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Athericidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	Dolichopodidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ephydridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	Culicidae	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	3
	Muscidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
chironomids	Chironomidae	1101	1833	570	540	2132	822	872	616	372	1677	228	285	173	530	1048	2038	14837
spongillafly	Sisyridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
damselfly	Protoneuridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Coenagrionidae	0	0	0	0	0	0	0	0	0	0	15	1	0	2	2	1	21
	Lestidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Calopterygidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dragonfly	Libellulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gomphidae	0	0	0	0	0	0	0	0	1	0	0	0	4	0	6	2	13
	Aeshnidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cordulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Macromiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
moths	Pyralidae	0	0	0	0	0	0	2	2	0	0	15	1	0	3	1	1	25
	Nepticulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Noctuidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix table 2. Number of macroinvertebrates by transect for 2012, continued.

Family		Transect 1	2	3	4	5	6	7	67	8	9	10	11	12	13	14	15	TOTAL
isopod	Asellidae	4	0	0	3	0	0	2	13	1	0	27	1	1	0	11	2	65
megaloptera	Sialidae	1	0	0	0	0	0	0	0	1	0	5	7	2	0	9	0	25
	Corydalidae	0	0	1	0	0	0	1	1	0	0	0	0	0	2	0	0	5
bugs	Corixidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Belastomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gerridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Aphididae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Notonectidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nepidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Saldidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hebridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Veliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wasp	Mymaridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Braconidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL		1188	1918	5891	592	2175	902	6569	6367	486	5708	961	531	632	12037	1497	13164	60618

Appendix Table 3. Values calculated for the Percent Model Affinity index (Novak and Bode 1992) combining all sampling periods. Taxa listed as 'other' include Simuliidae, Gammaridae, Asellidae, Physidae, and Empididae. Levels of effect are 'none' = 65% or greater, 'slight' = 50 to 64%, 'moderate' (mod) = 35 to 49%, and 'severe' <35%.

		Absolute difference between mean percent abundance and model percent															
		Transect															
Taxa	Model percent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	67
Trichoptera	10	8.7	2.7	34.7	6.5	9.4	9.0	31.1	8.9	34.6	7.5	3.7	6.7	14.3	6.7	18.0	45.6
Ephemeroptera	40	35.2	33.7	7.9	32.7	39.1	38.1	10.2	38.7	16.2	34.8	37.3	36.4	10.0	38.2	1.3	11.5
Plecoptera	5	5.0	5.0	4.7	5.0	5.0	5.0	4.8	5.0	4.9	5.0	5.0	5.0	4.4	5.0	4.8	4.9
Coleoptera	10	5.1	6.3	4.1	8.4	8.7	8.9	3.8	8.0	2.0	2.1	1.7	3.3	4.7	1.1	3.6	6.5
Oligochaeta	5	1.8	6.7	4.2	2.9	8.8	8.8	3.0	26.0	4.1	18.5	19.6	32.9	4.8	12.8	4.4	3.5
Chironomidae	20	51.7	47.5	10.0	55.4	61.1	61.1	3.3	41.1	0.9	22.2	25.2	17.9	15.2	37.3	8.3	10.6
Other	10	5.6	8.3	5.0	7.9	10.0	9.9	7.8	9.6	8.0	0.9	8.4	9.0	5.7	4.0	7.6	8.4
	sum difference	113.0	110.0	70.7	118.8	142.0	140.7	64.0	137.4	70.6	91.0	100.8	111.2	59.1	105.1	48.0	91.1
	sum diff X 0.5	56.5	55.0	35.4	59.4	71.0	70.4	32.0	68.7	35.3	45.5	50.4	55.6	29.6	52.6	24.0	45.6
	100 - sum diff	43.5	45.0	64.6	40.6	29.0	29.6	68.0	31.3	64.7	54.5	49.6	44.4	70.4	47.4	76.0	54.4
	Effect	mod	mod	slight	mod	severe	severe	slight	severe	slight	slight	slight	mod	none	mod	none	slight

Appendix Table 4. Unionid mussels collected from 10 transects in the Salmon and Little Salmon rivers and the number of complete shells collected in 37 middens from 2005 to 2012. SR = Salmon River, LSR = Little Salmon River.

	Collected alive				Collected in middens			
Species	SR	LSR	Total	Percent	SR	LSR	Total	Percent
Alasmidonta marginata	0	5	5	0.4		8	8	0.2
Alasmidonta undulata	1	0	1	0.1	4	1	5	0.2
Anodontoides ferussacianus	1	0	1	0.1				0
Elliptio complanata	709	534	1243	88.5	790	1247	2037	79.6
Lampsilis cariosa	9	3	12	0.8	72	9	81	3.2
Lampsilis ovata	2	12	14	1.0	63	6	69	2.7
Lampsilis radiata	14	47	61	4.3	79	120	199	7.8
Lasmigona compressa	6	4	10	0.7				0
Lasmigona costata	0	6	6	0.4	11	44	55	2.1
Margaritifera margaritifera	1	0	1	0.1	2	0	2	0.08
Pyganodon cataracta	3	8	11	0.8	0	14	14	0.5
Pyganodon grandis	0	3	3	0.2				0
Strophitus undulatus	12	24	36	2.6	11	78	89	3.5
Total	758	646	1404		1032	1527	2559	

Appendix Table 5. Total catch of fishes by sampling gear in 2012. Fish from trapnet and seine were used to construct the index of biotic integrity.

Salmon River

Species	trapnet	seine	benthos	total
Brown Bullhead	8			8
Eastern Sand Darter		34		34
Fallfish	4	28		32
Greater Redhorse	3			3
Longnose Dace			1	1
Longnose Gar	14			14
Northern Pike	1			1
Pumpkinseed	2	26		28
Rock Bass	11		2	13
Rosyface Shiner		9		9
Round Goby		1		1
Silver Lamprey	1	3	1	5
Smallmouth Bass		11		11
Spottail Shiner			1	1
Tessellated Darter		21	8	29
Walleye	1			1
White Sucker	4			4
Yellow Perch	1			1
Total	50	133	13	196

Little Salmon River

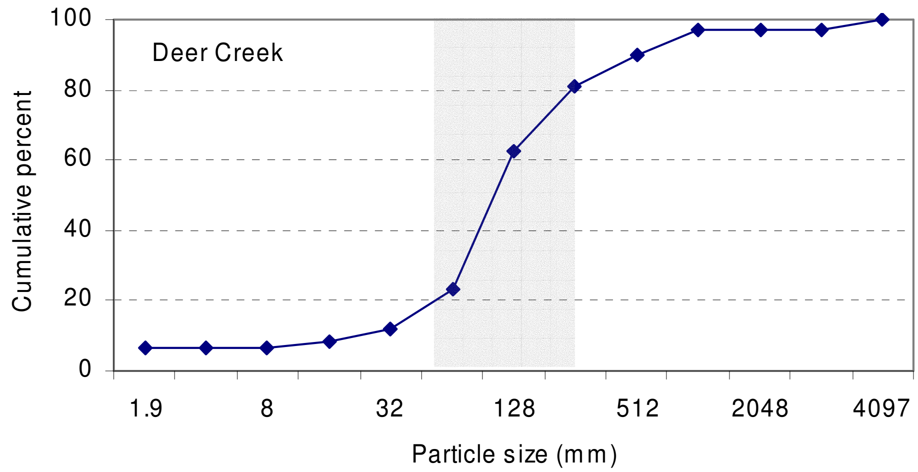
Species	trapnet	seine	benthos	total
Black Crappie	5			5
Bowfin	1			1
Brook Silverside		23		23
Brown Bullhead	61			61
Carp	1			1
Greater Redhorse	2			2
Largemouth Bass	1	3		4
Longnose Gar	28			28
Mimic Shiner		11		11
Northern Pike	1			1
Pumpkinseed	50	34		84
Rock Bass	19	73		92
Round Goby		2		2
Silver Redhorse	1			1
Smallmouth Bass	1	5		6
Spottail Shiner		6		6
Stonecat			3	3
Tessellated Darter		57		57
Walleye	1			1
White Sucker	1	1		2
Yellow Perch	2			3
Total	175	215	3	393

Appendix Table 6. Fish species collected by trapnet for all years of the study. Trapnets were fished in late October in 2002. SR = Salmon River, LSR = Little Salmon River. CPUE is based on 2083.3 fishing hours. Species and number caught from other gear were: American brook lamprey–2, bridle shiner–1, fantail darter–7, fathead minnow–3, logperch–1, longnose dace–2, pumpkinseed–2, rock bass–2, silver lamprey–2, smallmouth bass–2, spottail shiner–4, stonecat–7, tessellated darter–28, and tiger muskellunge–1.

Trapnets	2002		2003		2004		2008		2010		2012		Total				
Species	SR	LSR	SR	LSR	SR	LSR	SR	LSR	SR	LSR	SR	LSR	SR	LSR	Total	%	CPUE
Am Brook Lamprey			1										1	0	1	0.1	<0.001
American Eel			1										1	0	1	0.1	<0.001
Black Bullhead					1								1	0	1	0.1	<0.001
Black Crappie				4								5	0	9	9	0.6	0.004
Bowfin												1	0	1	1	0.1	<0.001
Brown Bullhead			82	10	136	40	264	228	16	18	8	61	506	357	863	52.8	0.414
Brown Trout							1						1	0	1	0.1	<0.001
Carp						1	1			2		1	1	4	5	0.3	0.002
Fallfish	1		2				1				4		8	0	8	0.5	0.004
Greater Redhorse			19		3	1	6	3		2	3	2	31	8	39	2.4	0.019
Largemouth Bass		2										1	0	3	3	0.2	0.001
Longnose Gar			11	13		1		44	5	104	14	28	30	190	220	13.5	0.106
Northern Pike	1	1		1	1	1	1	1		1	1	1	4	6	10	0.6	0.005
Pumpkinseed		1	10	16	4	1	23	2		23	2	50	39	93	132	8.1	0.063
Rock Bass	1	3	76	9	3	1	28	46	17	21	11	19	136	99	235	14.4	0.113
Shorthead Redhorse	3			1		2							3	3	6	0.4	0.003
Silver Lamprey				1	1			1	1		1		3	2	5	0.3	0.002
Silver Redhorse			1		2		1	1	1			1	5	2	7	0.4	0.003
Smallmouth Bass	2		9	5			4	2	2	1		1	17	9	26	1.6	0.012
Walleye	1							1			1	1	2	2	4	0.2	0.002
White Sucker	1		19	3	1		8	4	1		4	1	34	8	42	2.6	0.020
Yellow Perch		1	2		1		3	2	2		1	2	9	5	14	0.9	0.007
Total	10	8	233	63	153	48	341	335	45	172	50	175	832	801	1633		0.784

Appendix Table 7. Fish species collected by seining for all years of the study in the Salmon (SR) and Little Salmon rivers (LSR). CPUE is based on a linear seining distance of 1262 meters. No seining was done in 2004.

Seine	2002		2003		2004	2008		2010		2012		Total				
Species	SR	LSR	SR	LSR	no data	SR	LSR	SR	LSR	SR	LSR	SR	LSR	Total	%	CPUE
Bluegill		2	1	1								1	3	4	0.18	0.003
Bluntnose Minnow	6		121	33								127	33	160	7.08	0.127
Brook Silverside	8			15			10				23	8	48	56	2.48	0.044
Central Mudminnow				6								0	6	6	0.27	0.005
Common Shiner			14									14	0	14	0.62	0.011
Cutlips Minnow	2		1	2			1					3	3	6	0.27	0.005
Eastern Sand Darter	1		19					69	1	34		123	1	124	5.49	0.098
Fallfish			97	3		1	1	16		28		142	4	146	6.46	0.116
Golden Shiner				2								0	2	2	0.09	0.002
Grass Pickerel									1			0	1	1	0.04	0.001
Greater Redhorse			4				3					4	3	7	0.31	0.006
Largemouth Bass		6									3	0	9	9	0.40	0.007
Logperch			14	34		3			37			17	71	88	3.89	0.070
Longnose Gar		1										0	1	1	0.04	0.001
Mimic Shiner			10	219				53	9		11	63	239	302	13.36	0.239
Northern Pike			1									1	0	1	0.04	0.001
Pumpkinseed		25	19	6			2		50	26	34	45	117	162	7.17	0.128
Rock Bass	1	9	73	12			12	4	41		73	78	147	225	9.96	0.178
Rosyface Shiner	36		83	24			3	69	3		9	188	39	227	10.04	0.180
Round Goby								2		1	2	3	2	5	0.22	0.004
Silver Lamprey										3		3	0	3	0.13	0.002
Silver Redhorse			2						1			2	1	3	0.13	0.002
Smallmouth Bass			9	5			4	1	49	11	5	21	63	84	3.72	0.067
Spotfin Shiner	1		15	23			6					16	29	45	1.99	0.036
Spottail Shiner	13		93	44		1		22	1		6	129	51	180	7.96	0.143
Tessellated Darter	17		89	3		9	19	25	76	21	57	161	155	316	13.98	0.250
White Sucker		1	14				2	11	52		1	25	56	81	3.58	0.064
Yellow Perch				1					1			0	2	2	0.09	0.002
Total	85	44	679	433		14	63	272	322	124	224	1174	1086	2260		1.791



Appendix Figure 2. Distribution of particle sizes in Deer Creek determined on 15 June 2017. Particle sizes (mm) were 1.9 = coarse sand, 4 to 63 = pebble, 64 to 256 = cobble (gray box), 257 to 4096 = boulder, and 4097 = bedrock.

Appendix Table 8. Percent organic matter determined by loss on ignition in 2002 for glide transects.

Salmon River				Little Salmon River			
Transect	% organic	Transect	% organic	Transect	% organic	Transect	% organic
1 east	0.77	5 east	0.53	10 east	0.16	12 east	0.45
1 center	0.32	5 center	0.17	10 center	0.99	12 center	0.10
1 west	1.01	5 west	0.58	10 west	0.31	12 west	0.75
2 east	0.55	6 east	0.09	11 east	0.47	14 east	0.40
2 center	0.93	6 center	0.15	11 center	0.13	14 center	0.08
2 west	0.13	6 west	0.17	11 west	0.83	14 west	0.85
4 east	0.16	8 east	0.23				
4 center	0.29	8 center	0.11				
4 west	1.08	8 west	0.09				