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16. Abstract

A five-year study was performed to compare conditions in the Pilchuck River before and after channel reconstruction associated with rerouting highway SR-2. The study focused on sediment particle-size analyses, benthic macroinvertebrates and fish. Substrates comparable to control areas developed in all portions of the new channel within one year after construction. The available data on invertebrates and fish gave no indication of deterioration in diversity, quantity or size in the reconstructed channel. The report provides recommendations for further improvements in the design of stream channel changes should there be no alternative to their construction.

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ABSTRACT

A five-year study was performed to compare conditions in the Pilchuck River before and after channel reconstruction associated with rerouting highway SR-2. The study focused on sediment particle-size analyses, benthic macroinvertebrates and fish. Substrates comparable to control areas developed in all portions of the new channel within one year after construction. The available data on invertebrates and fish gave no indication of deterioration in diversity, quantity or size in the reconstructed channel. The report provides recommendations for further improvements in the design of stream channel changes should there be no alternative to their construction.

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INTRODUCTION

Site Description

Prior to reconstruction of highway SR 2 to bypass Snohomish, Washington, a portion of the Pilchuck River was rechanneled to remove it from the planned right of way. The rechanneled section is approximately 700 m (2300 ft), in length and is located northeast of the town and within 3.2 Km (2 miles) of the river's junction with the Snohomish River. The construction replaced a bend in the river, beginning about 500 m (1650 ft) south of the Bloedel Road bridge with an S-shaped meander to the west of the existing channel. Figure 1 presents a vicinity map indicating the old and new channels.

The revised channel was designed to maintain both stream length and average velocity and to approximate the original substrate to aid the recovery of stream biota (Washington State Highway Department, 1977). The river banks were established on a steep slope of approximately 1:1 and stabilized by large rip-rap placed near the toe of the slopes to protect against erosion during normal and routine high flows. Higher on the slopes, there are some large rocks but no continuous rip-rap for erosion protection during very elevated flows. Grasses were established on the slopes, and small trees were planted along the tops of the slopes to eventually reestablish a natural canopy.

The banks of the new channel contrast with those of the former channel and unaffected upstream and downstream reaches, which generally have very slight slopes and a considerable amount of overhanging riparian vegetation and high growth near the water's edge. This vegetation provides shading and protective habitat for adult fish.

Substrate material in a variety of sizes was placed on the bed of the new channel. The objective was to create habitat variety through a mix of sub

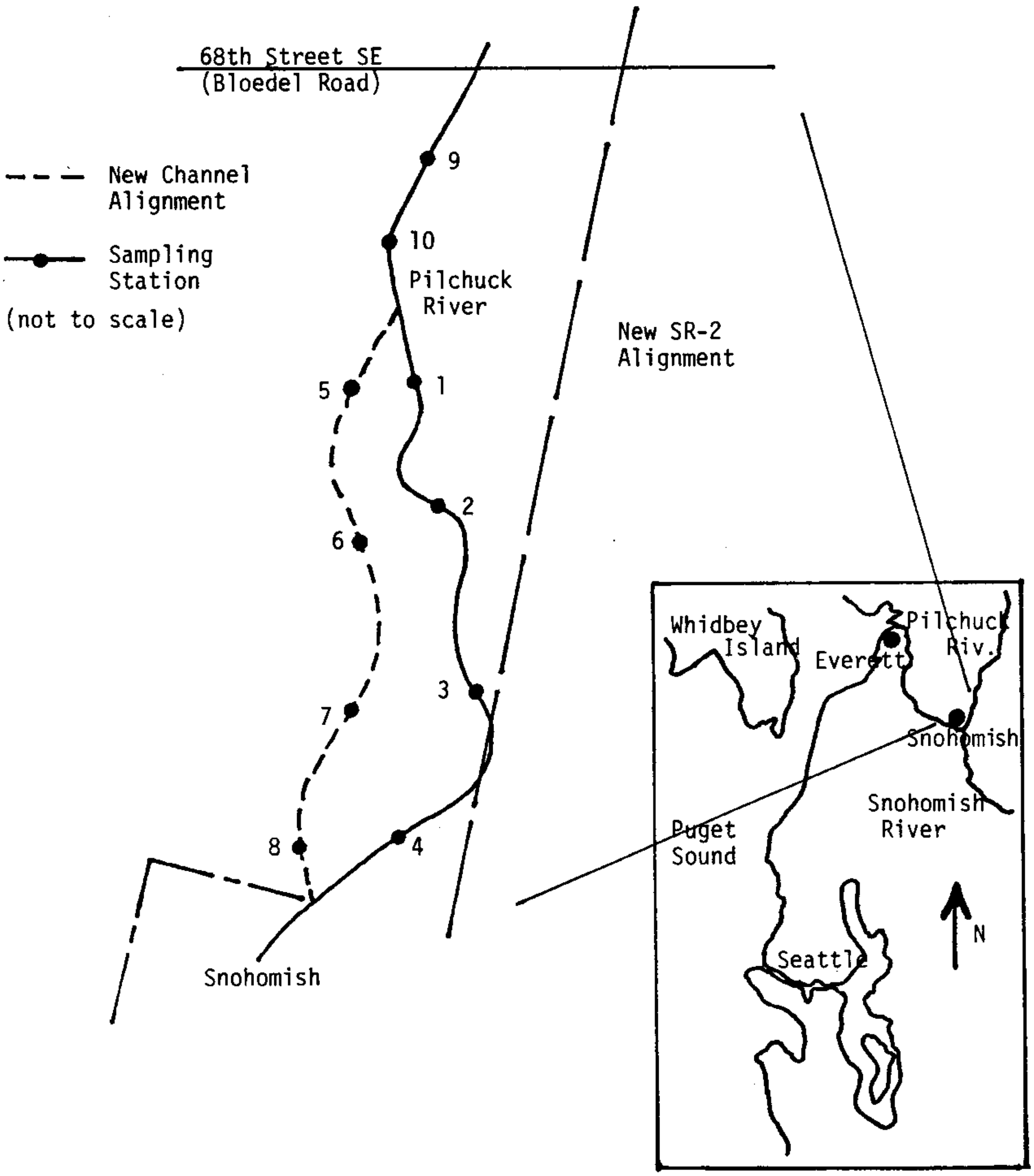

Figure 1: Pilchuck River Channel Reconstruction Vicinity Map and Sampling Sites

strate types and depths. At certain points large rocks were placed near the banks on either side to induce flow into a restricted area such that its energy would be dissipated in digging pools.

The new channel was constructed during the summer of 1979 and left dry over the following winter. A portion of the flow was diverted into it following spring runoff in the early summer of 1980. All flow was directed through the new channel and the old channel was closed off in August, 1980.

The Pilchuck River is a low-to-moderate fertility stream providing a variety of habitats for benthic and fish communities. There is a general alternation between pools and riffles. Rocky, gravelly, and sandy/silty substrates are all common. The Pilchuck serves primarily as a nursery for anadromous salmonids, with the productivity of resident fish apparently limited by low productivity at lower food web levels, a result of low nutrient concentrations.

Potential Impacts of Channel Reconstruction

Channel reconstruction creates acute effects on aquatic biota during dewatering of the original channel and may cause long-term effects on the ecosystem as a result of unfavorable conditions in the new channel relative to those in the original reach. These extended effects would be due to potential reductions in habitat and water quality (Patrick, 1973).

Among the specific possible occurences are the introduction of poor habitat for invertebrate animals and fish spawning and rearing, removal of protective habitat and feeding sites for adult fish, and interference with the migrations of anadromous fish. These impacts may result from uniform geometries which may support some but not all life stages, unsuitable substrates, and/or velocity modifications creating unfamiliar currents. Erosion of unstable banks and beds can increase loadings of suspended sediments and associated pollutants and lead to increased sediment deposition in the river, further degrading habitats.

Often associated with channel reconstruction is riparian vegetation removal, allowing the transmission of more light to the stream. A direct result may be elevated summer temperatures, to the possible detriment of salmonid fish and certain benthic invertebrates.

Rechanneling a stream can also alter its relationship with adjacent terrestrial areas. For example, steeply sloped banks would prevent the spread of high flows on the flood plain, a means of depositing sediments and nutrients on the land. Those quantities would then remain for later deposit within the stream or, through more extensive flooding, on lands downstream. Modification of the temperature, light, velocities, sediment loadings, and nutrient regime can affect the composition and quantity of primary producers which form the base of stream food webs. The result may be to increase or decrease production and, possibly, to change the form of the autotrophic biota. These effects can extend through the food web to consumers ultimately dependent on the primary producers.

Being very dynamic systems, streams have the capacity to physically modify their channels and recover a condition approximating the original following channel reconstruction. That recovery could be rather rapid where construction plans have been sensitive to fluvial processes and biotic requirements. It may, however, be retarded or even prevented when the construction is poorly conceived and when engineering barriers maintain the stream in a condition inimical to biological regeneration.

Scope of the Study

An investigation was undertaken to document the degree and rate of recovery of the Pilchuck River in the rechanneled reach. Accordingly, sampling was performed prior to construction, during the period of dual flow in the old and new channels, and following redirection of all of the flow through the new channel. During the initial two years (1977-78), an effort was made to broadly characterize physical, chemical, and biological conditions in and near the section to be affected by construction. The results of this effort have been documented in an earlier report (Horner and Welch, 1979).

For the remaining years of the study (1979-81), the work was concentrated on intensive sampling of the substrate material, benthic invertebrates, and fish. The substrate was considered to be the element that most directly reflects habitat recovery following rechanneling. The benthic invertebrates and fish were thought to be the most important biota in the ecosystem, as well as those most subject to harm by the construction. This report will discuss the variations in the substrate and these two groups of biota during the years of study.

MATERIALS AND METHODS

Figure 1 indicates the locations of sampling sites. Site numbers 1-4 were in the old channel, 5-8 were in the new channel, and 9-10 were control sites just upstream of the construction area.

Substrates

Substrate samples were collected once during July or August in each of the years 1979-81. Sites 1-4 were sampled in 1979. In the following year, samples were collected at all sites; while in 1981, sites 5-8 and 9-10 were sampled. In each case two samples were collected at each station at depths of 0.5 m or less, where the sampling apparatus could be used. Where possible, these two samples were taken at the center of the channel and half the distance between the center and the west bank.

Figure 2 illustrates the substrate sampler. It was driven into the substrate by a twisting action to a depth of about 15 cm, where the main cylinder touched the river bed. The sediments contained in the core were then removed by hand and placed in the annulus of the main cylinder until the tooth edge was exposed. A plug was placed on the top of the empty core to retain most of the fine particles in the main cylinder. The sampler was then lifted from the river and placed over a bucket lined with two heavy plastic bags. The plug was removed to release the water into the bucket. After the majority of the sediments were drained or poured from the main cylinder, it was rinsed until all visible particles were washed into the bucket. The bags were then labeled and tied and transported to the laboratory.

In the laboratory the substrate samples were rinsed and rubbed by hand through a series of nine sieves with mesh sizes ranging from 26.9 to 0.105 mm. Washings were caught in a garbage can. The material retained on each sieve was poured and thoroughly rinsed into a graduated cylinder of water. The volume of water displaced by the material was measured in ml and recorded. Particles <0.105 mm in size caught in the garbage can were transferred to a graduated settling chamber and allowed to settle until there was no volume change. This volume was also measured in ml and recorded.

Coincidental with the sampling program described, the U.S. Fish and Wildlife Service collected freeze-core samples of the Pilchuck River substrates, also for the purpose of following its recovery from channel reconstruction (Dilley, 1981).

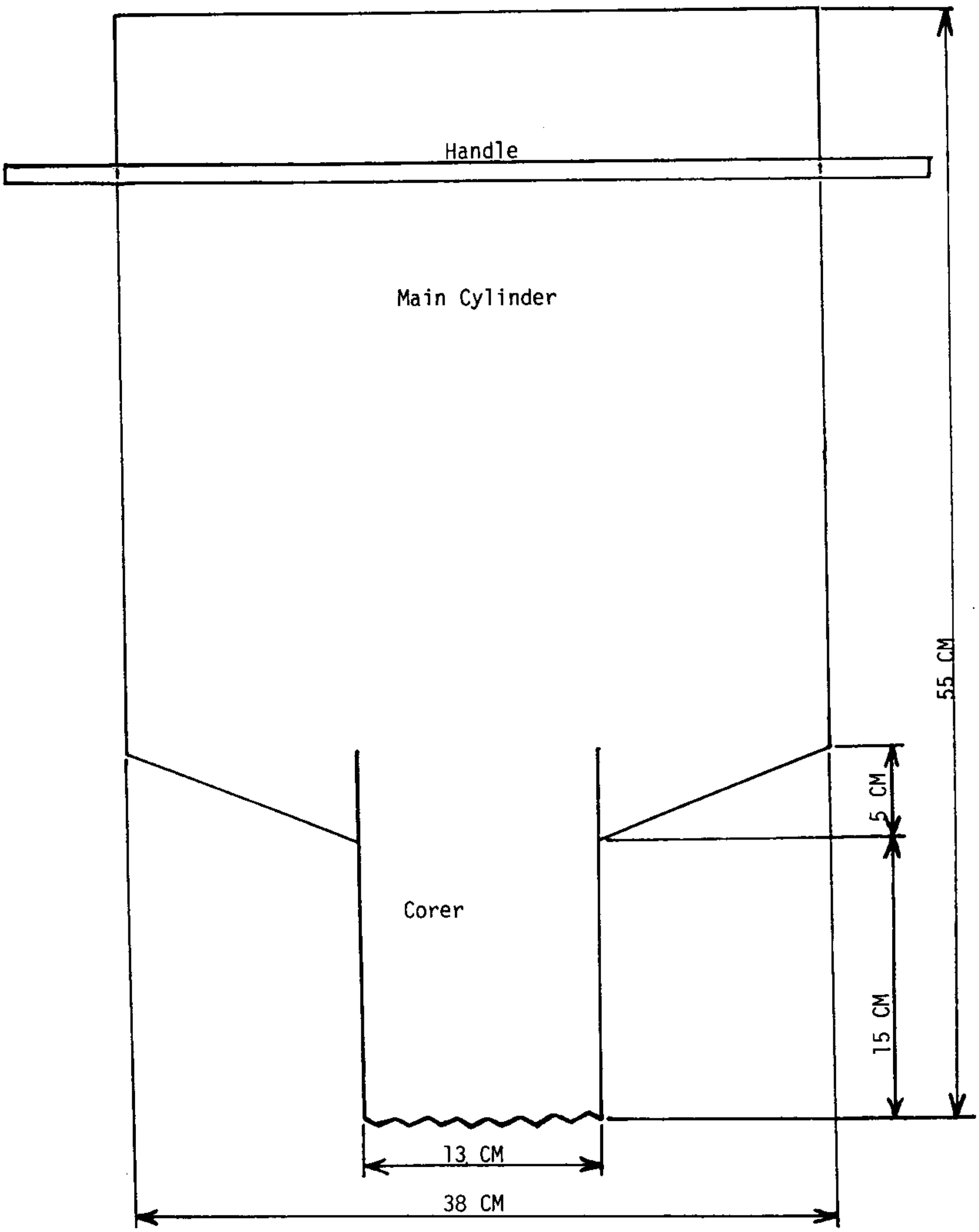

Figure 2: Substrate Sampler

Note: Dimensions are approximate.

Benthic Macroinvertebrates

Included in the benthic (bottom-dwelling) macroinvertebrate community are aquatic life stages of certain insects, crustaceans such as crayfish, freshwater mollusks, nematodes and oligochaete and annelid worms. This diverse community represents a variety of ecosystem functions, including herbivorous and carnivorous predation and consumption and decomposition of dead matter. Stream invertebrates are a crucial food source for fish.

Benthic macroinvertebrates were sampled once during July or August in each of the years 1979-81, as follows:

1978	Sites 1-4
1979	Sites 1-4 and 9-10
1980	Sites 1-10
1981	Sites 5-8 and 9-10

In each case four equally spaced samples were collected along a transect perpendicular to the flow, using a Surber sampler to define square foot areas. The collected invertebrates were preserved in jars to which 95% ethanol was added to provide a final concentration of approximately 30% ethanol. The preserved invertebrates were transported to the laboratory for later identification and enumeration.

Fish

Fish were sampled once during July or August in each of the years 1978-79 and 1981. Sites 1-4 were sampled in 1978 and 1979, while sites 5-8 and 9 were sampled in 1981. In addition to this effort, the U.S. Fish and Wildlife Service conducted fish sampling in the same reach of river in the summers of 1979 and 1980.

Around each sampling site a zone of 30 or 60 m in length was marked. This dimension and several width measurements within the zone were recorded to permit computation of the area sampled. When conditions allowed, block nets were installed to isolate the zone during the sampling period. Three successive passes were made through each zone with Coeffelt Electronics Company model VVP-15 electrofishing gear. All fish netted in each pass were placed in live cars for identification and enumeration. A large subsample of each species in the total catch was measured to produce frequency distributions of lengths.

Population sizes were estimated for each species in each zone using the technique described by Zippin (1958). This method estimates, by the use of a calculated ratio and several probability charts, the percentage of the total population actually captured. The total catch divided by this percentage provides an estimate of the population size.

RESULTS

Substrates

Table 1 summarizes the results of the substrate particle size analyses, which are presented in full in Appendix A. Prior to construction, the channel contained means of 26.0 percent stones (>26.9 mm) and 21.8 percent fines (<0.841 mm). Those percentages remained approximately the same (28.6 and 20.7, respectively) after diversion of a portion of the flow in 1980. The new channel contained a slightly smaller proportion of stones (mean 23.3 percent) and a somewhat higher percentage of fines (mean 24.8 percent) in the first summer after construction. However, analysis of variance (Sokal and Rohlf, 1969) demonstrated no statistically significant differences among the quantities of fines in the new channel (1980) and the old channel (1979 and 1980).

Table 1: Summary of Substrate Particle Size Analyses
(Mean Volume Percent Composition)

Date	Stations	Size Class (mm):	Volume Percent >26.9	0.841-26.9	<0.841
7/20/79	1-4		26.0	52.2	21.8
7/10/80	1-4		28.6	50.7	20.7
	5-8		23.3	51.9	24.8
	9-10		33.4	49.4	17.2
8/13/81	5-8		32.6	44.3	23.1
	9-10		42.2	41.3	16.5

The control sites, located upstream of any construction influence, had higher percentages of stones and lower percentages of fines than the new channel in both 1980 and 1981. The difference in percent fines was statistically significant at $P < 0.05$ in 1981, although not significant in 1980. At both control and new channel sites, the proportion of stones increased fairly substantially in 1981 compared to 1980, while the percentage of fines dropped slightly in both areas. Apparently, the bed of the new channel stabilized fairly rapidly such that it was affected by fluvial processes in a fashion similar to undisturbed zones in the reach.

It may be expected that, for some time to come, substrates in the new channel will continue to exhibit smaller particle sizes overall than those upstream and to be slightly less stable. The evidence available suggests that the differences in the quantities of fine particles and the patterns of fluctuation of those quantities will not be great, however. Since larger bed materials, in general, offer better habitat for fish spawning and rearing and macroinvertebrate production than fines, the comparable bed characteristics in the affected and unaffected areas are an important indication that indigenous biota should be established and maintained in the new channel.

The U.S. Fish and Wildlife Service (USFWS) (Dilley, 1981) conducted substrate sampling by the freeze core technique in 1979-1981 at sites close to those sampled in this study. The most distinctive difference among sites appearing in the USFWS results was the exceptionally high percentage of fines (defined in that work as <1 mm) present in the lower new channel in July 1980 compared to the upper new channel, old channel, and control sites (53 versus $\leq$ 26 percent). The quantity in the lower new channel dropped to 32 percent in October 1980 and 8 percent in August 1981. Comparison of percentage fines (<0.841 mm) in July 1980 at sites 5 (upstream new channel) and 8 (downstream new channel) sampled in this study indicates a substantial difference as well (11.1 versus 32.8 percent). By August 1981, the percentage had declined to 22.8 at site 8, while rising to 27.0 percent at site 5. Although the sites sampled in the two studies and the methods employed were not identical and the magnitudes of the results differed somewhat, the independent findings agree that the lower new channel initially contained a large proportion of fine substrates but that this proportion declined rapidly.

Benthic Macroinvertibrates

Table 2 summarizes the results of the benthic macroinvertebrate surveys, which are presented in full in Appendix B. Prior to construction, the channel contained a mean of 404 invertebrates m^{-2} in 1978 and 788 m^{-2} in 1979, compared to 720 m^{-2} in the upstream control area in 1979. Of the total popula-

Table 2: Summary of Benthic Macroinvertebrate Data

Date	Station	Mean No. m^{-2}								
		Plecoptera	Ephemeroptera	Trichoptera	Coleoptera	Diptera	Oligochaeta	Annelida	Others	Total
8/4/78	1-4	79	126	60	49	82	0	3	5	404
8/10/79	1-4	107	263	64	75	224	0	48	7	788
	9-10	184	27	22	0	481	0	0	6	720
7/10/80	1-4	12	188	31	30	1098	5	0	9	1381
	5-8	8	172	10	9	1670	4	0	1	1873
	9-10	53	188	12	17	436	0	0	4	708
8/13/81	5-8	90	540	16	33	1336	182	0	17	2214
	9-10	130	511	18	42	1067	84	0	6	1858

tions, 65.6 percent were Ephemeroptera (mayflies), Plecoptera (stoneflies) or Trichoptera (caddisflies), which are preferred fish food forms; while 21.0 percent were Diptera (true flies) or worms (Annelida in this case), which can dominate in waters of relatively poor quality. The corresponding percentages in 1979 were 55.1 percent E-P-T and 34.5 percent Diptera or Annelida in the old channel and 32.4 percent E-P-T and 66.8 percent Diptera in the control area.

In 1980, after diversion of a portion of the flow through the new channel, the control area maintained a very similar mean total invertebrate population (708 m^{-2}). The old and new channels, however, housed much larger populations (means of 1381 and 1873 m^{-2}, respectively). These populations included 16.7 percent E-P-T and 79.9 percent Diptera or worms (Oligochaeta) in the old channel, 10.1 percent E-P-T and 89.4 percent Diptera or Oligochaeta in the new channel, and 35.7 percnet E-P-T and 61.6 percent Diptera in the control zone.

In 1981, when the full flow was passing through the new channel, it contained a mean of 2214 invertebrates m^{-2}, of which 29.2 percent were E-P-T and 68.6 percent were Diptera or Oligochaeta. The control sites had a mean population of 1858 m^{-2}, 35.0 percent E-P-T, and 61.9 percent Diptera or Oligochaeta. With patchy distributions, considerable variability occured from site-to-site within the same area in the cases of both total populations and compositions. Analysis of variance demonstrated no statistically significant differences between new channel and controls for any of these statistics in 1981.

The three years of data indicated a tendency towards the development of larger benthic invertebrate populations in the final two years in the construction zone compared to the pre-construction years. That same tendency also appeared in the control area in the final year. The control site populations were quite uniform in composition through the three years, while the percent E-P-T dropped and the percent Diptera or worms increased in the construction area relative to the pre-construction period, perhaps as a consequence of the somewhat greater proportion of fines in the substrates in that area. Since much larger populations existed in the latter years, however, the total numbers of preferred fish food organisms actually increased, although the proportion of such organisms declined. The new channel thus is capable of supporting a diverse invertebrate community useful as a food supply by predators.

Fish

Table 3 summarizes the fish population statistics developed by electrofishing, while Table 4 presents length-frequency distributions for rainbow trout and coho salmon. Appendix C contains the full data set.

The two pre-construction years show contrasting results. Rainbow trout and coho salmon year-class strengths were considerably greater in 1978 compared to 1979. The large 1978 populations were coincident with relatively depressed macroinvertebrate numbers. Mean lengths were comparable in the two years.

Larger populations inhabited the new channel in 1981 than were present in the old channel in 1979, but the yearling salmonid numbers were far beneath those observed in 1978. In contrast, the sculpin population exceeded that observed in any other year. Salmonid populations in the new channel exceeded those at the upstream control site. Mean lengths of rainbow trout and coho salmon were greater in the new channel in 1981 than in both the control area in 1981 and the old channel in previous years, which is probably a reflection

Table 3: Summary of Fish Population Data

		Mean No. Ha^{-1}					
Date	Stations	Rainbow Trout	Coho Salmon	Cutthroat Trout	Sculpin	Whitefish	Lamprey Eel
7/6-7/78	1-4	4538	1545	12	1354	54	210
7/16-17/79	1-4	967	62	8	1018	9	676
8/26-27/81	5-8	1647	799	18	2750	20	499
	9	1367	19	0	3936	0	654

Note: Numerous dace were also collected but not enumerated.

Table 4: Fish Length - Frequency Distributions

Date	Stations	Length Range (mm)	Rainbow Trout (No.)	Coho Salmon (No.)
7/6-7/78	1-4	<40	9	0
		41-45	20	0
		46-50	35	0
		51-55	32	0
		56-60	14	1
		61-65	12	14
		66-70	9	15
		71-75	6	32
		76-80	5	24
		81-85	1	25
		86-90	2	5
		91-95	0	1
		96-100	0	1
		>100	38	2
		Total	183	120
		Mean (mm)	70.4	75.6
7/16-17/79	1-4	<40	0	0
		41-45	3	0
		46-50	6	0
		51-55	9	0
		56-60	8	0
		61-65	10	1
		66-70	15	0
		71-75	8	2
		76-80	4	3
		81-85	3	5
		86-90	3	0
		91-95	0	1
		96-100	0	1
		>100	3	0
		Total	72	13
		Mean (mm)	66.7	80.9

Table 4 - Continued

Date	Stations	Length Range (mm)	Rainbow Trout (No.)	Coho Salmon (No.)
8/26-27/81	5-8	<60	10	0
		60-70	22	4
		71-80	28	29
		81-90	26	57
		91-100	7	13
		101-110	5	2
		111-120	3	0
		121-130	7	0
		131-140	20	0
		141-150	19	0
		151-160	14	0
		161-170	7	0
		171-180	2	0
		181-190	1	0
		Total	172	105
		Mean (mm)	103.7	83.8
	9	<60	7	0
		60-70	9	0
		71-80	11	1
		81-90	6	0
		91-100	5	0
		101-110	2	0
		111-120	0	0
		121-130	1	0
		131-140	0	0
		141-150	1	0
		151-160	0	0
		161-170	1	0
		Total	44	1
		Mean (mm)	84.1	78.0

of later sampling in 1981 than in other years.

The U.S. Fish and Wildlife Service (Dilley, 1981) sampled stations in the new and old channels plus controls by electrofishing and seining in September 1979 and July 1980. A mark and recapture technique was used to make population estimates. Biomass (g m^{-2}) was also determined. Tables 5 and 6 present the results. The FWS survey showed approximately a three-fold increase in total salmonid populations at all sites in 1980 compared to 1979, with the exception of the downstream control site, although biomass quantities were generally comparable in the two years. Total salmonid population was much lower at both control sites than in either the old or new channel in 1980. The largest population was observed in the upper old channel, followed by the lower new channel, the lower old channel, the upper new channel, and then the controls.

The preconstruction variations noted suggest that natural fluctuations easily may obscure the effects of rechanneling. To gain some insight in this regard, the Washington State Department of Fisheries was contacted to obtain data on salmonid stocks in the Snohomish River system in general during the years of study (Flint, personal communication). Estimates of returning adult coho spawners are:

1977	74,000
1978	56,000
1979	99,000
1980	70,000

Spawners produce the juvenile stocks resident in the following year. The estimates indicate that 1979 should exhibit relatively low juvenile numbers, while 1980 stocks should be high. These deductions are consistent with the field observations.

Table 5: Population Estimates and 95% Confidence Intervals (CI) of Salmonids Captured by Electrofishing and Beach Seining by USFWS (Dilley, 1981)

			Population in Reach Fished (±CI)				
Date	Location	River Mile	Coho Salmon	0+Trout (1)	Rainbow Trout	Cutthroat Trout	All Salmonids
9/6-17/79	Upstream Control	4.4	21(31)	51(70)	69(94)	3(7)	143(104)
	Old Upper Channel	3.9	3(6)	17(26)	96(129)	6(11)	124(91)
	Old Lower Channel	3.3	15(14)	105(60)	430(178)	3(6)	590(230)
	Downstream Control	2.0	9(8)	11(9)	337(99)	8(7)	367(103)
7/3-15/80	Upstream Control	4.8	89(42)	256(88)	44(39)	4(5)	392(107)
	Old Upper Control	3.3	428(104)	1859(372)	48(23)	5(7)	2520(468)
	New Upper Channel	3.3	501(182)	249(77)	164(150)	0	877(209)
	Old Lower Channel	3.0	459(116)	516(101)	103(42)	5(6)	1094(161)
	New Lower Channel	3.0	1276(387)	147(112)	31(18)	13(11)	1498(406)
	Downstream Control	2.0	47(37)	257(138)	22(21)	3(6)	362(188)

Note: (1) Rainbow and cutthroat trout of < 70 mm length.

Table 6: Biomass (g m^{-2}) of Salmonids Captured by Electrofishing and Beach Seining by USFWS (Dilley, 1981)

			Biomass (g m^{-2})				
Date	Location	River Mile	Coho Salmon	0+Trout[1]	Rainbow Trout	Cutthroat Trout	All Salmonids
9/6-17/79	Upstream Control	4.4	.18	.19	.69	.09	1.10
	Old Upper Channel	3.9	.08	.33	3.73	.45	4.72
	Old Lower Channel	3.3	.12	.43	7.37	.02	8.60
	Downstream Control	2.0	.12	.05	7.31	.19	7.66
7/3-15/80	Upstream Control	4.8	.22	.09	.59	.08	.99
	Old Upper Channel	3.3	1.20	.90	.67	.14	3.18
	New Upper Channel	3.3	2.72	.24	3.47	.03	6.46
	Old Lower Channel	3.0	2.78	.37	1.50	0	4.64
	New Lower Channel	3.0	4.36	.09	.85	.38	5.68
	Downstream Control	2.0	.10	.27	.45	.06	.88

Note: (1) Rainbow and cutthroat trout of < 70 mm length.

The Department of Fisheries has correlated low summer stream flow to poor salmon production. The Department has defined a flow index as the ratio of the 60-day mean low flow in a given year to the same flow measure over a 17-year period. The index has been applied to 10 streams in the Puget Sound area and summed to produce a regional composite index. Indices available for the study years are:

1978	12.27
1979	6.91
1980	12.14

The low 1979 index provides further evidence that juvenile coho stocks were generally smaller in 1979 than other recent years due to natural conditions.

Annual variations have somewhat obscurred the effects of construction in the fish results. Nevertheless, there is no indication that the reconstructed channel is incapable of providing for populations of rearing salmonids and resident species comparable to those occurring in unaffected reaches.

CONCLUSIONS AND RECOMMENDATIONS

Study of the Pilchuck River channel reconstruction has demonstrated that a substrate comparable to the original was recovered within one year. Sampling of the benthic macroinvertebrate and fish communities was subject to temporal variation unrelated to the construction, but the results gave no indications of deterioration in diversity, quantity or size in the reconstructed channel. These points are evidence that the design and construction of the new channel was relatively effective in promoting the development of favorable habitat for juvenile anadromous salmonids, resident species, and their invertebrate food sources.

Nevertheless, several factors exist which make it prudent to avoid stream rechanneling whenever possible. First, even with relatively careful design and construction, a period of time is required for recovery of a natural substrate. During this period, the overall smaller than normal particle size distribution introduces a degree of instability that would become particularly evident in the event of highly elevated flow. Second, steep bank slopes such as installed in the reconstructed Pilchuck channel, disrupt the relationship between the river and its flood plain. With slighter slopes, suspended particles and contaminants associated with them could be more effectively settled rather than transported in increasing concentrations downstream. Third, the upper portions of the Pilchuck bank slopes are not as well stabilized as portions closer to the normal water surface and may erode substantially in a future flood, especially on outside meanders. Some undercutting on outside meanders was observed recently (September 1982), indicating insufficient rip-rapping in these sections. Finally, vegetation loss is aesthetically detrimental and may result in increased water temperatures and reduced fish productivity if extensive.

Should river channel reconstruction have to be undertaken in conjunction with a future highway project, certain aspects of the Pilchuck River application can serve as a model. The layout maintained the original length, a meander pattern, and flow velocities approximating the original. Placement of the new substrate resulted in the occurrence of both pools and riffles and fairly rapid recovery of a bed similar to the original. These effective features are apparently responsible for relatively rapid development of extensive and diverse macroinvertebrate and fish populations in the new channel.

On the other hand, any future channel reconstruction should be engineered with bank slopes comparable to neighboring reaches. In addition, greater attention should be given to replacement of riparian vegetation and bank stabilization which will assure erosion protection on outside meanders and under bank-full flow conditions.

Flow was introduced to the new Pilchuck River channel in the early part of the summer 1980, low-flow period; and development of a substrate comparable to unaffected areas was essentially complete within a year. Summer low flows apparently did not remove fines effectively, since Dilley (1981) observed a high proportion of fines remaining in October, 1980. It can be hypothesized that fine removal may be advanced and substrate recovery hastened further by introducing flow into reconstructed channels just before the highest annual flows are expected. The scheduling, of course, must also be based on other considerations, such as avoidance of interference with fish migrations. Nevertheless, this modification in operating procedure should be considered in future similar projects.

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APPENDIX

APPENDIX A:
Substrate Particle Size Analyses
(Volume Percent Composition)

Date	Station	Sample	Size Class (mm):	> 26.9	26.9-13.25	13.25-6.73	6.73-3.36	3.36-1.68	1.68-0.841	0.841-0.420	0.420-0.210	0.210-0.105	< 0.105
				Volume Percent									
7/20/79	1	1		45.6	8.1	8.7	6.9	6.9	3.9	4.7	7.1	3.1	5.2
		2		21.4	21.9	14.4	8.1	6.5	5.1	10.6	7.2	1.7	3.0
	2	1		21.0	12.4	14.5	8.5	6.8	14.5	16.2	3.9	0.6	1.7
		2		32.4	10.0	9.9	10.3	11.6	7.2	6.0	7.7	1.6	3.3
	3	1		27.0	13.9	12.1	10.0	9.4	8.3	8.8	6.0	1.4	3.1
		2		26.2	13.6	12.6	9.5	8.1	8.9	12.7	5.8	0.9	1.7
	4	1		20.6	29.0	11.9	5.0	4.3	2.7	10.5	10.9	2.1	2.9
		2		15.7	25.2	14.2	9.8	7.8	3.6	11.0	9.5	1.7	1.5
	1-4			26.0	16.7	12.3	8.5	7.7	6.9	10.2	7.2	1.6	2.8
7/10/80	1	1		31.3	17.8	13.4	9.5	9.4	6.7	3.8	2.1	0.7	5.2
		2		41.3	11.4	6.4	6.6	6.0	3.1	9.8	7.6	2.4	5.4
	2	1		30.7	16.9	11.0	7.1	7.2	10.9	11.3	2.4	0.3	2.2
		2		15.6	20.0	13.4	7.6	3.8	10.3	18.2	5.3	1.0	4.8
	3	1		27.9	17.7	11.3	8.1	7.0	9.8	10.7	4.1	1.1	2.3
		2		33.8	9.2	10.4	9.5	10.3	10.6	9.4	2.9	0.6	3.3
	4	1		17.3	28.8	13.6	6.8	3.7	2.9	14.0	8.5	2.0	2.4
		2		30.7	17.6	10.1	3.1	6.6	11.0	10.1	9.1	0.6	1.2
	1-4			28.6	17.4	11.2	7.3	6.8	8.2	10.9	5.3	1.1	3.4
	5	1		34.6	14.1	13.7	4.7	10.1	9.1	6.3	4.8	0.3	2.4
		2		35.7	21.2	16.5	4.4	8.0	5.7	3.4	3.2	0.2	1.6
	6	1		11.5	25.5	17.4	10.2	8.2	7.8	8.0	5.7	1.3	4.4
	7	1		9.0	15.0	14.9	10.7	10.6	10.9	13.5	6.4	2.2	6.7
		2		12.3	13.9	11.4	7.8	7.5	9.0	12.9	8.6	3.9	12.7
	8	1		26.4	16.4	8.9	2.5	6.4	7.8	7.0	11.3	2.7	10.6
		2		33.5	12.9	7.5	2.6	5.6	3.9	11.5	17.9	1.5	3.0
	5-8			23.3	17.0	12.9	6.1	8.1	7.7	8.9	8.3	1.7	5.9
	9	1		39.6	12.7	9.9	9.8	10.3	10.5	7.2	5.1	0.3	1.1
		2		36.6	13.8	11.2	3.7	8.6	7.5	8.7	6.7	0.6	2.6
	10	1		23.9	21.2	14.7	5.3	12.0	3.5	3.6	11.3	1.3	3.2
	9-10			33.4	15.9	11.9	6.3	10.3	7.2	6.5	7.7	0.7	2.3

APPENDIX A - Continued

Date	Station	Sample	Size Class (mm):	Volume Percent > 26.9	26.9-13.25	13.25-6.73	6.73-3.36	3.36-1.68	1.68-0.841	0.841-0.420	0.420-0.210	0.210-0.105	< 0.105
8/13/81	5	1		20.4	11.8	16.0	14.3	7.7	3.9	12.9	9.3	1.6	2.1
		2		23.4	10.9	13.0	10.2	7.2	7.3	18.9	5.4	0.8	3.0
	6	1		30.9	16.6	12.0	9.5	5.3	2.8	12.6	6.8	1.3	2.1
		2		47.2	16.7	6.5	2.9	2.0	2.2	10.6	8.1	1.8	1.9
	7	1		43.2	22.5	7.5	4.8	3.5	2.2	7.6	6.3	1.6	1.0
		2		45.4	15.9	5.7	2.9	3.5	3.2	8.5	10.4	2.2	2.3
	8	1		25.4	15.6	12.5	9.5	8.3	4.7	11.2	7.3	1.9	3.6
		2		24.6	22.8	17.1	8.3	3.2	2.5	12.0	6.0	0.8	2.7
	5-8			32.6	16.6	11.3	7.8	5.1	3.6	11.8	7.5	1.5	2.3
	9	1		41.2	12.2	8.3	6.9	5.6	6.8	13.0	3.7	0.9	1.4
		2		29.5	22.3	15.2	5.9	3.9	3.0	11.2	5.4	1.2	2.3
	10	1		36.8	16.2	12.2	10.1	7.7	2.6	6.6	4.3	1.2	2.4
		2		61.3	11.3	7.6	4.7	2.1	0.3	2.5	4.7	2.0	3.5
	9-10			42.2	15.5	10.8	6.9	4.8	3.2	8.3	4.5	1.3	2.4

Appendix B: Benthic Macroinvertebrate Data

No. m^{-2}

Date	Station	Sample	Plecoptera	Ephemeroptera	Trichoptera	Coleoptera	Diptera	Oligochaeta	Annelida
8/04/78	1	1-4	97	116	102	48	62	0	8
	2	1-4	108	188	30	97	124	0	0
	3	1-4	67	129	64	26	140	0	3
	4	1-4	46	70	43	21	3	0	3
	1-4	1-4	79	126	60	49	82	0	3
8/10/79	1	1	400	605	43	0	378	0	151
		2	11	151	22	76	97	0	11
		3	0	227	11	162	173	0	0
		4	140	367	11	32	43	0	11
		1-4	128	338	22	68	173	0	43
	2	1	205	464	43	97	680	0	86
		2	76	194	54	130	324	0	194
		3	54	216	22	11	54	0	0
		4	140	486	313	0	0	0	0
		1-4	119	340	108	60	265	0	70
	3	1	108	54	0	11	119	0	216
		2	76	97	43	86	173	0	32
		3	43	108	54	54	194	0	0
		4	11	32	0	0	22	0	0
		1-4	60	73	24	38	127	0	62
	4	1	216	346	65	151	378	0	0
		2	43	302	86	119	238	0	11
		3	54	216	22	76	421	0	0
		4	173	335	227	184	281	0	54
		1-4	122	300	100	133	330	0	16
	1-4		107	263	64	75	224	0	48
	9	1	86	11	0	0	378	0	0
	10	1	281	43	43	0	583	0	0
	9-10		184	27	22	0	481	0	0
7/10/80	1	1	0	65	11	11	237	0	0
		2	11	204	22	11	5046	0	0
		3	0	54	11	76	399	0	0
		4	32	247	0	43	1614	22	0
		1-4	11	143	11	35	1824	6	0
	2	1	11	44	54	33	205	0	0
		2	0	75	43	22	506	0	0
		3	0	33	11	65	387	0	0
		4	33	204	22	97	2700	0	0
		1-4	11	89	33	45	950	0	0

Appendix B continued

Date	Station	Sample	Odonata	Lepidoptera	Hydrocarina	Zygoptera	Amphipoda	Hirudinea	Mollusca	Nematoda	Total
			No. m^{-2}								
8/04/78	1	1-4	0	3	0	0	0	0	0	0	436
	2	1-4	0	5	0	0	0	0	0	0	552
	3	1-4	8	0	0	0	0	0	0	0	441
	4	1-4	3	0	0	0	0	0	0	0	189
	1-4		3	2	0	0	0	0	0	0	404
8/10/79	1	1	0	0	0	0	0	0	0	0	1577
		2	0	0	43	0	0	0	0	0	411
		3	0	0	0	0	0	0	0	0	573
		4	0	0	0	0	0	0	0	0	604
		1-4	0	0	11	0	0	0	0	0	791
	2	1	0	0	22	0	0	0	0	0	1597
		2	0	0	22	0	11	0	0	0	1005
		3	0	0	0	0	0	0	0	0	357
		4	0	0	0	0	0	0	0	0	939
		1-4	0	0	11	0	3	0	0	0	975
	3	1	0	0	0	0	0	0	0	0	508
		2	0	0	0	0	0	0	0	0	507
		3	0	0	0	0	0	0	0	0	453
		4	0	0	0	0	0	0	0	0	65
		1-4	0	0	0	0	0	0	0	0	383
	4	1	0	0	0	0	0	0	0	0	1156
		2	0	0	0	0	0	0	0	0	799
		3	0	0	0	0	0	0	0	0	789
		4	0	0	0	0	0	0	0	0	1254
		1-4	0	0	0	0	0	0	0	0	1000
	1-4		0	0	6	0	1	0	0	0	788
	9	1	0	0	0	0	0	0	0	0	475
	10	1	0	0	0	11	0	0	0	0	961
	9-10		0	0	0	6	0	0	0	0	720
7/10/80	1	1	0	0	0	0	0	0	0	0	324
		2	0	0	22	0	0	0	0	0	5316
		3	0	0	0	0	0	0	0	0	540
		4	0	0	54	0	0	0	0	0	2012
		1-4	0	0	19	0	0	0	0	0	2049
	2	1	0	0	0	0	0	0	0	0	347
		2	0	0	0	0	0	0	0	0	646
		3	0	0	11	0	0	0	0	0	507
		4	0	0	0	0	0	0	0	0	3056
		1-4	0	0	3	0	0	0	0	0	1131

Appendix B. continued

Date	Station	Sample	Plecoptera	Ephemeroptera	Trichoptera	Coleoptera	Diptera	Oligochaeta	Annelida
			No. m^{-2}						
7/10/80	3	1	11	506	33	33	1700	0	0
		2	22	441	65	43	979	0	0
		3	33	280	75	11	764	0	0
		4	22	173	22	11	757	22	0
		1-4	22	350	49	25	1050	6	0
	4	1	0	161	54	65	914	0	0
		2	0	65	0	43	538	22	0
		3	11	86	33	76	627	0	0
		4	0	366	33	22	194	0	0
		1-4	3	170	30	52	568	6	0
	1-4		12	188	31	39	1098	5	0
	5	1	0	495	54	22	2647	22	0
		2	11	301	11	11	893	11	0
		3	0	65	0	11	215	0	0
		4	11	377	0	33	2969	11	0
		1-4	6	310	16	19	1681	11	0
	6	1	0	98	11	22	4040	0	0
		2	11	377	43	0	3077	0	0
		3	0	65	11	0	377	0	0
		4	0	108	0	0	323	11	0
		1-4	3	162	16	6	1954	3	0
	7	1	0	151	0	0	699	0	0
		2	0	140	0	11	2410	0	0
		3	0	344	22	0	1216	0	0
		4	0	65	0	0	2087	0	0
		1-4	0	175	6	3	1603	0	0
	8	1	0	108	0	0	1625	0	0
		2	0	22	11	11	1990	0	0
		3	0	22	0	11	1754	0	0
		4	86	11	0	0	397	0	0
		1-4	22	41	3	6	1442	0	0
	5-8		8	172	10	9	1670	4	0
	9	2	11	108	0	11	108	0	0
		3	22	75	0	11	140	0	0
		4	33	151	11	32	1291	0	0
		1-4	22	111	4	18	513	0	0
	10	1	33	387	0	0	420	0	0
		2	0	161	11	0	172	0	0
		3	22	463	22	65	258	0	0
		4	281	43	43	0	583	0	0
		1-4	84	264	19	16	358	0	0
	9-10		53	188	12	17	436	0	0

Appendix B. continued

No. m^{-2}

Date	Station	Sample	Odonata	Lepidoptera	Hydrocarina	Zygoptera	Amphipoda	Hirudinea	Mollusca	Nematoda	Total
7/10/80	3	1	0	0	11	0	0	0	0	0	2294
		2	0	0	11	0	0	0	0	0	1561
		3	0	0	0	0	0	0	0	0	1163
		4	0	0	0	0	0	22	0	0	1029
		1-4	0	0	6	0	0	6	0	0	1514
	4	1	0	0	0	0	0	0	0	0	1194
		2	0	0	0	0	0	0	0	0	668
		3	0	0	0	0	0	0	0	0	833
		4	0	0	0	0	0	0	0	0	615
		1-4	0	0	0	0	0	0	0	0	829
	1-4		0	0	7	0	0	2	0	0	1381
	5	1	0	0	0	0	0	0	0	0	3240
		2	0	0	0	0	0	0	0	0	1238
		3	0	0	0	0	0	0	0	0	291
		4	0	0	0	0	11	0	0	0	3412
		1-4	0	0	0	0	3	0	0	0	2046
	6	1	0	0	0	0	0	0	0	0	4171
		2	0	0	0	0	0	0	0	0	3508
		3	0	0	0	0	0	0	0	0	453
		4	0	0	0	0	0	0	0	0	442
		1-4	0	0	0	0	0	0	0	0	2144
	7	1	0	0	0	0	0	0	0	0	850
		2	0	0	0	0	0	0	0	0	2561
		3	0	0	0	0	0	0	0	0	1582
		4	0	0	0	0	0	0	0	0	2152
		1-4	0	0	0	0	0	0	0	0	1787
	8	1	0	0	0	0	0	0	0	0	1733
		2	0	0	0	0	0	0	0	0	2034
		3	0	0	0	0	0	0	0	0	1787
		4	0	0	0	0	0	0	0	0	494
		1-4	0	0	0	0	0	0	0	0	1514
	5-8		0	0	0	0	1	0	0	0	1873
	9	2	0	0	0	0	0	0	0	0	238
		3	0	0	0	0	0	0	0	0	248
		4	0	0	0	0	0	0	0	0	1518
		1-4	0	0	0	0	0	0	0	0	668
	10	1	0	0	0	0	0	0	0	0	840
		2	0	0	0	0	0	11	0	0	355
		3	0	0	0	0	0	0	0	0	830
		4	0	0	0	11	0	0	0	0	961
		1-4	0	0	0	3	0	3	0	0	747
	9-10		0	0	0	2	0	2	0	0	708

Appendix B continued

No. m^{-2}

Date	Station	Sample	Plecoptera	Ephemeroptera	Trichoptera	Coleoptera	Diptera	Oligochaeta	Annelida
8/13/81	5	1	0	0	0	0	301	0	0
		2	11	215	0	0	613	33	0
		3	0	215	0	33	441	11	0
		4	140	398	0	22	559	0	0
		1-4	38	207	0	14	479	11	0
	6	1	33	312	43	11	742	65	0
		2	11	312	11	0	592	11	0
		3	11	86	11	0	323	22	0
		4	0	301	11	22	785	43	0
		1-4	14	253	19	8	611	35	0
	7	1	75	463	0	33	2442	65	0
		2	151	2485	43	161	4432	118	0
		3	323	624	11	86	2657	11	0
		4	151	828	33	65	2679	65	0
		1-4	175	1100	22	86	3053	65	0
	8	1	140	452	33	22	1237	172	0
		2	118	678	11	33	1033	764	0
		3	140	592	33	22	1420	1054	0
		4	129	678	11	22	1119	473	0
		1-4	132	600	22	25	1202	616	0
	5-8		90	540	16	33	1336	182	0
	9	1	33	366	11	54	1108	151	0
		2	33	516	0	22	979	0	0
		3	43	355	0	43	1033	183	0
		4	420	323	0	97	1442	204	0
		1-4	132	390	3	54	1141	135	0
	10	1	269	613	33	33	1108	43	0
		2	161	581	0	22	710	11	0
		3	22	753	43	43	839	22	0
		4	54	581	54	22	1313	54	0
		1-4	127	632	33	30	993	33	0
	9-10		130	511	18	42	1067	84	0

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No. m^{-2}

Date	Station	Sample	Odonata	Lepidoptera	Hydrocarina	Zygoptera	Amphipoda	Hirudinea	Mollusca	Nematoda	Total
8/13/81	5	1	0	0	0	0	0	0	0	0	301
		2	0	0	0	0	0	0	0	0	877
		3	0	0	0	0	0	0	0	0	700
		4	0	0	0	0	0	0	0	0	1119
		1-4	0	0	0	0	0	0	0	0	749
	6	1	0	0	0	0	0	0	0	0	1206
		2	0	0	0	0	0	0	0	0	937
		3	0	0	0	0	0	0	0	0	453
		4	0	0	0	0	0	0	0	0	1162
		1-4	0	0	0	0	0	0	0	0	940
	7	1	0	0	140	0	0	0	0	0	3218
		2	0	0	33	0	0	0	22	0	7445
		3	0	0	22	0	0	0	22	0	3756
		4	0	0	0	0	0	0	22	0	3843
		1-4	0	0	49	0	0	0	17	0	4567
	8	1	0	0	0	0	0	0	0	11	2067
		2	0	0	0	0	0	0	0	0	2637
		3	0	0	0	0	0	0	0	0	3261
		4	0	0	0	0	0	0	0	0	2432
		1-4	0	0	0	0	0	0	0	3	2600
	5-8		0	0	12	0	0	0	4	1	2214
	9	1	0	0	0	0	0	0	0	0	17231
		2	0	0	22	0	0	0	0	0	1572
		3	0	0	0	0	0	0	0	0	1657
		4	0	0	0	0	11	0	0	0	2497
		1-4	0	6	0	3	0	0	0	0	1864
	10	1	0	0	0	0	0	0	0	0	2099
		2	0	0	0	0	0	0	0	0	1485
		3	0	0	0	0	0	0	0	0	1722
		4	0	0	11	0	0	0	0	0	2089
		1-4	0	0	3	0	0	0	0	0	1851
	9-10		0	0	5	0	1	0	0	0	1858

Appendix C: Fish Population Data

No. Ha^{-1}

Date	Station	Rainbow Trout	Coho Salmon	Cutthroat Trout	Sculpin	Whitefish	Lamprey Eel	Sunfish	Catfish
7/6-7/78	1	(1)	2976	48	0	21	56	0	0
	2	4081	1131	0	2047	140	466	0	0
	3	5990	1477	0	1620	(1)	0	0	0
	4	3543	594	0	1748	0	317	0	0
7/16-17/79	1	708	0	10	1164	0	90	0	0
	2	833	18	0	145	0	540	0	0
	3	1673	83	21	2145	0	83	0	0
	4	654	148	0	617	37	1989	0	0
8/26-27/81	5	2418	653	21	2563	0	104	0	0
	6	1301	482	0	2925	53	24	0	0
	7	2160	1240	52	889	26	0	0	0
	8	362	505	0	4644	0	1867	117	80
	9	1367	19	0	3936	0	654	0	0

Notes: (1) Insufficient catch in first pass precluded use of Zippen (1958) method.
(2) Numerous dace were also collected but not enumerated.