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Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

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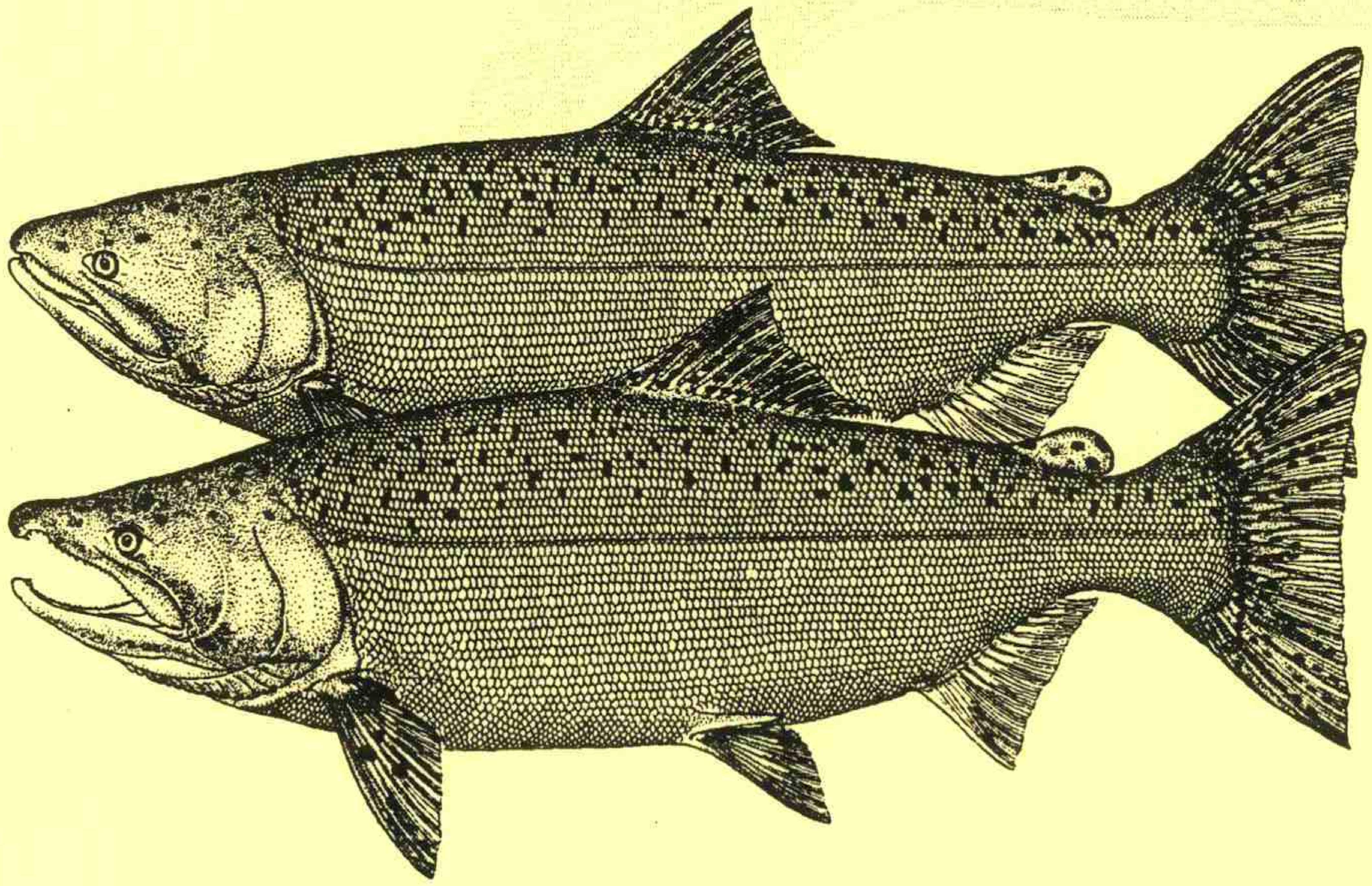
Seattle, Washington



BENTHIC INVERTEBRATES AND SEDIMENT CHARACTERISTICS IN WAHKIAKUM COUNTY FERRY CHANNEL, WASHINGTON, BEFORE AND AFTER DREDGING

by

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EXECUTIVE SUMMARY

In 1993, the Portland District of the U.S. Army Corps of Engineers contracted with the National Marine Fisheries Service to study benthic invertebrates and sediments in the Wahkiakum County Ferry Channel, Washington (River Mile 43.2), before and after dredging. Although the area of the dredging project was small, there was concern that benthic invertebrates, particularly the amphipods *Corophium* spp. (*C. salmonis* and *C. spinicorne*), would be adversely impacted. *Corophium* spp. are abundant in intertidal and shallow subtidal habitats of the Columbia River estuary and are seasonally important in the diets of juvenile salmonids and other fishes. The goals of the study were 1) to describe benthic invertebrate communities in the dredged portion of the ferry channel before and after dredging and 2) to assess recolonization of benthic invertebrates in the dredged portion of the ferry channel. We collected samples in a control area located about 3.2 km (2 mi) upstream from the ferry channel to help assess the effects of dredging. Specifically, we assessed benthic invertebrate species composition, standing crops, diversity, and equitability in both the ferry channel and the upstream control area.

Benthic invertebrate and sediment samples were collected with a 0.1-m^2 Van Veen grab sampler at seven stations in the Wahkiakum County Ferry Channel and at an upstream control area in October 1993, January, February, April, July, and October 1994, and January and April 1995. Sampling in October 1993 and January 1994 was conducted prior to dredging in the ferry channel, and sampling in February 1994 was conducted 6 days after dredging was completed. No significant effect ($P > 0.05$) of the ferry channel dredging project on benthic invertebrate densities (total) was detected in the statistical analysis,

although benthic invertebrate densities were significantly different (P < 0.05) between surveys and areas. Benthic invertebrate densities were significantly higher (P < 0.05) in the control area than in the ferry channel.

During all eight surveys, *Corbicula fluminea*, *Corophium* spp., and Ceratopogonidae (Diptera) larvae were generally the most common benthic invertebrates in both the ferry channel and the control area. No significant effect (P > 0.05) of the ferry channel dredging project on densities of *Corbicula fluminea*, Ceratopogonidae larvae, or *Corophium* spp. was detected in the statistical analysis. However, densities of *Corbicula fluminea* and Ceratopogonidae larvae were significantly different (P < 0.05) between surveys and areas, with densities significantly higher (P < 0.05) in the control area than in the ferry channel. *Corophium* spp. densities were significantly different (P < 0.05) between surveys, but not between areas.

Two measures of community structure, Diversity (H) and Equitability (E), were calculated for each area for each survey. No significant effect (P > 0.05) of the ferry channel dredging project on the benthic invertebrate community structure, as measured by H and E, was detected in the statistical analysis. Both H and E were significantly different (P < 0.05) between surveys, but not between areas.

Three sediment characteristics--median grain size, percent silt/clay, and percent volatile solids--were determined and compared for each area and survey. No significant effect (P > 0.05) of the ferry channel dredging project on median grain size or percent volatile solids was detected in the statistical analysis. Median grain size was significantly smaller in the ferry channel than in the control area (P < 0.05). No statistical comparisons for percent silt/clay were made because of the non-normal distribution of the data and the lack of an adequate data transformation.

CONTENTS

INTRODUCTION

In 1993, the Portland District of the U.S. Army Corps of Engineers (COE) contracted with the National Marine Fisheries Service (NMFS) to conduct benthic invertebrate and sediment studies in the Wahkiakum County Ferry Channel, Washington (River Mile (RM) 43.2), before and after dredging of the channel. The Wahkiakum County Ferry, which is owned and operated by Wahkiakum County and subsidized by the State of Washington, operates between Westport, Oregon, and Puget Island, Washington. Prior to the NMFS surveys, shoaling in the ferry channel between Puget Island and the main navigation channel of the Columbia River forced the ferry to operate at one-half capacity during part of the year (U.S. Army Corps of Engineers 1992). Clamshell dredging was conducted in about 244 m (800 ft) of the ferry channel, from 24 January to 17 February 1994. About 14,258 m^3 (18,650 yd^3) of sediments were removed from the channel and disposed of at an in-water disposal site about 4 km (2.5 mi) downstream from the ferry channel. Although the ferry channel is about 579 m (1,900 ft) long, only about 244 m (800 ft) had to be dredged, as the remainder of the channel is naturally deep. The ferry channel is 61 m (200 ft) wide.

Although the area of the dredging project was small, there was concern that benthic invertebrates, particularly the amphipods *Corophium* spp. (*C. salmonis* and *C. spinicorne*), would be adversely impacted. *Corophium* spp. are frequently found in intertidal and shallow subtidal habitats of the Columbia River estuary and are seasonally important in the diets of juvenile salmonids and other fishes (McCabe et al. 1983, 1986; Kirn et al. 1986; Muir et al. 1988). *Corophium salmonis* and *C. spinicorne* were the dominant prey for juvenile salmonids collected during the spring of 1984 at Bonneville Dam, the lowermost dam on the Columbia River (Muir and Emmett 1988).

The goals of the present study were 1) to describe benthic invertebrate communities in the dredged portion of the ferry channel before and after dredging and 2) to assess recolonization of benthic invertebrates in the dredged portion of the ferry channel. We collected samples in a control area located about 3.2 km (2 mi) upstream from the ferry channel to help assess the effects of dredging. Specifically, we assessed benthic invertebrate species composition, standing crops, diversity, and equitability in both the ferry channel and the upstream control area. Results from the present study will provide useful information to aquatic resource agencies who assess the potential environmental effects of dredging in similar habitats of the lower Columbia River.

METHODS

Sampling

Benthic invertebrate and sediment samples were collected at seven stations each in the Wahkiakum County Ferry Channel and an upstream control area in October 1993, January, February, April, July, and October 1994, and January and April 1995 (Fig. 1). Sampling in October 1993 and January 1994 was conducted prior to dredging in the ferry channel, and sampling in February 1994 was conducted 6 days after dredging was completed. Sampling stations were located using a radar range-finder and the Global Positioning System (GPS) (Appendix Table 1).

At each of the 14 stations, a 0.1-m^2 Van Veen grab sampler was used to collect four samples; three were analyzed for benthic invertebrates and one for sediment type. Each benthic invertebrate sample was initially preserved in a buffered formaldehyde solution ($\geq$4%) containing rose bengal, an organic stain. Later each benthic invertebrate sample was washed

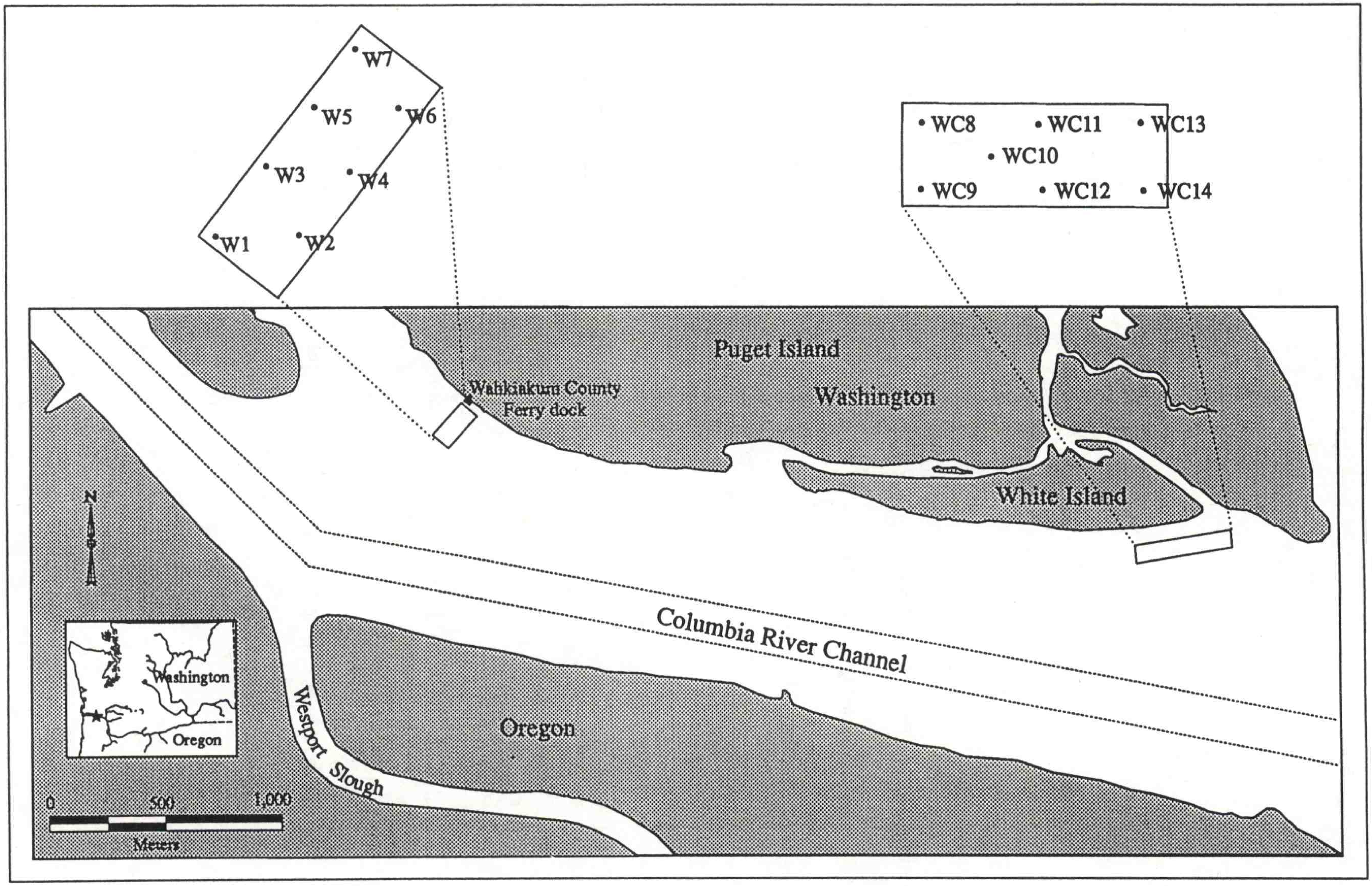

Figure 1. Locations of the Wahkiakum County Ferry Channel, Washington, and the upstream control area. Locations of benthic invertebrate and sediment sampling stations in the dredged portion of the ferry channel and control area are shown in the insets.

with water through a 0.5-mm screen. All benthic invertebrates were sorted from each sample, identified to the lowest practical taxon, counted, and stored in 70% ethanol. The sediment sample from each station was placed in a labeled plastic bag and refrigerated for analysis of grain size, percent silt/clay, and percent volatile solids by the COE North Pacific Division Materials Laboratory, Troutdale, Oregon.

Data Analyses

Benthic Invertebrates

Benthic invertebrate data were analyzed by station to determine species composition, densities (by taxon and total), and community structure (diversity and equitability). The Shannon-Wiener function (H) was used to determine diversity (Krebs 1978), which was expressed as:

$$H = - \sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where $p_i = n_i/N$ (n_i is the number of individuals of the *i*th taxon in the sample, and N is the total number of all individuals in the sample) and s = number of taxa. Equitability (E) was the second community structure index determined; E measures the proportional abundances among the various taxa in a sample (Krebs 1978) and ranges from 0.00 to 1.00, with 1.00 indicating all taxa in the sample are numerically equal. Equitability is expressed as:

$$E = H/\log_2 s$$

where H = Shannon-Wiener function and s = number of taxa. Both H and E were calculated for each sampling station.

Total benthic invertebrate densities, *Corbicula fluminea*, *Corophium* spp., and Ceratopogonidae (Diptera) larval densities, H, and E were each compared between areas (i.e., the ferry channel and control area) and surveys using two-way analysis of variance (ANOVA) (Cruze and Hartzell 1991); invertebrate densities were tested for normality, and if necessary, transformed ($\log_{10}$) prior to performing ANOVA. Normality was tested by calculating normal scores of the data, then conducting a correlation test between the normal scores and the data (Cruze and Hartzell 1991). Means from the three samples collected at each sampling station provided the basic data entries for all statistical tests.

Sediments

Median grain size and percent volatile solids were each compared between areas (i.e., the ferry channel and control area) and surveys using two-way analysis of variance (Cruze and Hartzell 1991); median grain size and percent volatile solids were tested for normality and transformed ($\log_{10}$) prior to performing ANOVA. One low outlying value for median grain size (Station W3, July 1994) was removed prior to using ANOVA. No statistical comparisons for percent silt/clay were made because of the non-normal distribution of the data and the lack of an adequate data transformation.

RESULTS

Benthic Invertebrates

The total numbers of taxa/categories collected in the ferry channel and control area (data combined for both areas) ranged from 11 in April 1994 to 27 in October 1994

(Appendix Table 2). Mean numbers of taxa/categories (by survey) in the ferry channel and control area were similar, ranging from 6 to 11 (Table 1).

No effect of the ferry channel dredging project on benthic invertebrate densities (total) was detected in the statistical analysis, as indicated by the nonsignificant interaction ($P = 0.08$) between survey and area in the ANOVA (Table 2). However, benthic invertebrate densities were significantly different between surveys (ANOVA, $P = 0.00$) and areas (ANOVA, $P = 0.01$). Benthic invertebrate densities were significantly higher ($P < 0.05$) in the control area than in the ferry channel. In the control area, mean densities (by survey) ranged from 2,307 organisms/m^2 in July 1994 to 25,436 organisms/m^2 in April 1994 (Table 3). Mean densities (by survey) in the ferry channel ranged from 2,017 organisms/m^2 in February 1994 to 23,954 organisms/m^2 in January 1995.

During all eight surveys, *Corbicula fluminea*, *Corophium* spp., and Ceratopogonidae larvae were generally the most common benthic invertebrates in both the ferry channel and the control area. In both areas, *Corophium* spp. were generally the most abundant benthic invertebrates (Fig. 2). We estimated that about 98% of the *Corophium* spp. were *C. salmonis* and the remainder *C. spinicorne*. Summaries by station for all eight benthic invertebrate surveys are available upon request from NMFS, Northwest Fisheries Science Center, Point Adams Biological Field Station, P.O. Box 155, Hammond, Oregon 97121.

No effect of the ferry channel dredging project on *Corbicula fluminea* densities was detected in the statistical analysis, as indicated by the nonsignificant interaction ($P = 0.42$) between survey and area in the ANOVA (Table 2). *Corbicula fluminea* densities were significantly different between surveys (ANOVA, $P = 0.03$) and areas (ANOVA, $P = 0.00$). *Corbicula fluminea* densities were significantly higher ($P < 0.05$) in the control area than in

Table 1. Mean numbers of benthic invertebrate taxa/categories identified in samples collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. Each value for a station is the mean of three replicate samples. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
				FERRY CHANNEL				
W1	7	5	6	6	8	11	6	6
W2	6	6	7	6	9	7	6	9
W3	7	5	7	4	7	8	9	7
W4	7	7	5	5	9	10	9	5
W5	7	5	7	7	8	13	4	4
W6	5	7	6	7	8	15	16	6
W7	9	6	7	8	10	16	14	11
	--	--	--	--	--	--	--	--
Mean	7	6	6	6	8	11	9	7
				CONTROL AREA				
WC8	10	8	8	7	10	13	9	8
WC9	6	8	5	6	9	9	6	6
WC10	6	7	10	6	9	8	7	6
WC11	7	8	11	8	9	8	7	8
WC12	6	5	5	8	9	7	10	5
WC13	9	8	11	7	10	11	8	9
WC14	6	5	7	5	8	8	10	6
	--	--	--	--	--	--	--	--
Mean	7	7	8	7	9	9	8	7

Table 2. Results of two-way analysis of variance for selected benthic invertebrate parameters measured in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. Results from eight surveys--October 1993, January, February, April, July, and October 1994, and January and April 1995--were used in the analyses. A significant difference ($P \leq 0.05$) is indicated with an *.

Parameter	Source	Degrees of freedom	F	P value
Benthic invertebrate density ($\log_{10}$), total	Survey	7	5.40	0.000*
	Area	1	6.23	0.014*
	Survey x area	7	1.90	0.078
	Total	111		
Corbicula fluminea density ($\log_{10}$)	Survey	7	2.39	0.027*
	Area	1	13.07	0.000*
	Survey x area	7	1.03	0.415
	Total	111		
Corophium spp. density ($\log_{10}$)	Survey	7	5.07	0.000*
	Area	1	0.25	0.615
	Survey x area	7	1.53	0.166
	Total	111		
Ceratopogonidae larvae density	Survey	7	3.39	0.003*
	Area	1	22.12	0.000*
	Survey x area	7	1.65	0.129
	Total	111		
Diversity (H)	Survey	7	11.76	0.000*
	Area	1	2.04	0.156
	Survey x area	7	1.00	0.438
	Total	111		
Equitability (E)	Survey	7	6.24	0.000*
	Area	1	0.35	0.554
	Survey x area	7	0.81	0.579
	Total	111		

Table 3. Mean densities (number/m^2) of benthic invertebrates collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. Each value for a station is the mean of three replicate samples. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	2,238	1,491	898	11,571	991	14,971	448	4,789
W2	2,961	5,227	1,772	4,597	2,229	4,952	1,967	5,573
W3	3,995	1,399	2,408	1,803	1,775	17,447	37,925	9,043
W4	6,218	19,818	2,069	3,297	1,281	32,655	2,319	5,137
W5	3,804	9,926	2,226	4,063	1,639	29,222	3,628	3,621
W6	7,910	30,722	1,639	6,449	1,346	23,618	79,264	10,142
W7	8,194	3,192	3,109	6,582	7,752	20,830	42,130	59,095
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Mean	5,046	10,254	2,017	5,480	2,430	20,528	23,954	13,914
CONTROL AREA								
WC8	9,176	66,399	26,570	33,674	3,495	25,072	50,194	3,896
WC9	3,745	7,564	3,875	22,238	1,155	39,648	633	1,991
WC10	3,841	14,693	13,563	5,983	2,056	23,170	15,171	2,263
WC11	6,128	17,036	40,049	51,799	3,850	23,982	37,233	23,933
WC12	4,023	2,084	5,397	4,739	1,899	21,868	6,968	1,707
WC13	6,916	55,063	40,101	57,215	2,729	11,201	28,305	43,766
WC14	3,822	2,266	5,026	2,405	963	6,629	5,063	1,979
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Mean	5,379	23,586	19,226	25,436	2,307	21,653	20,510	11,362

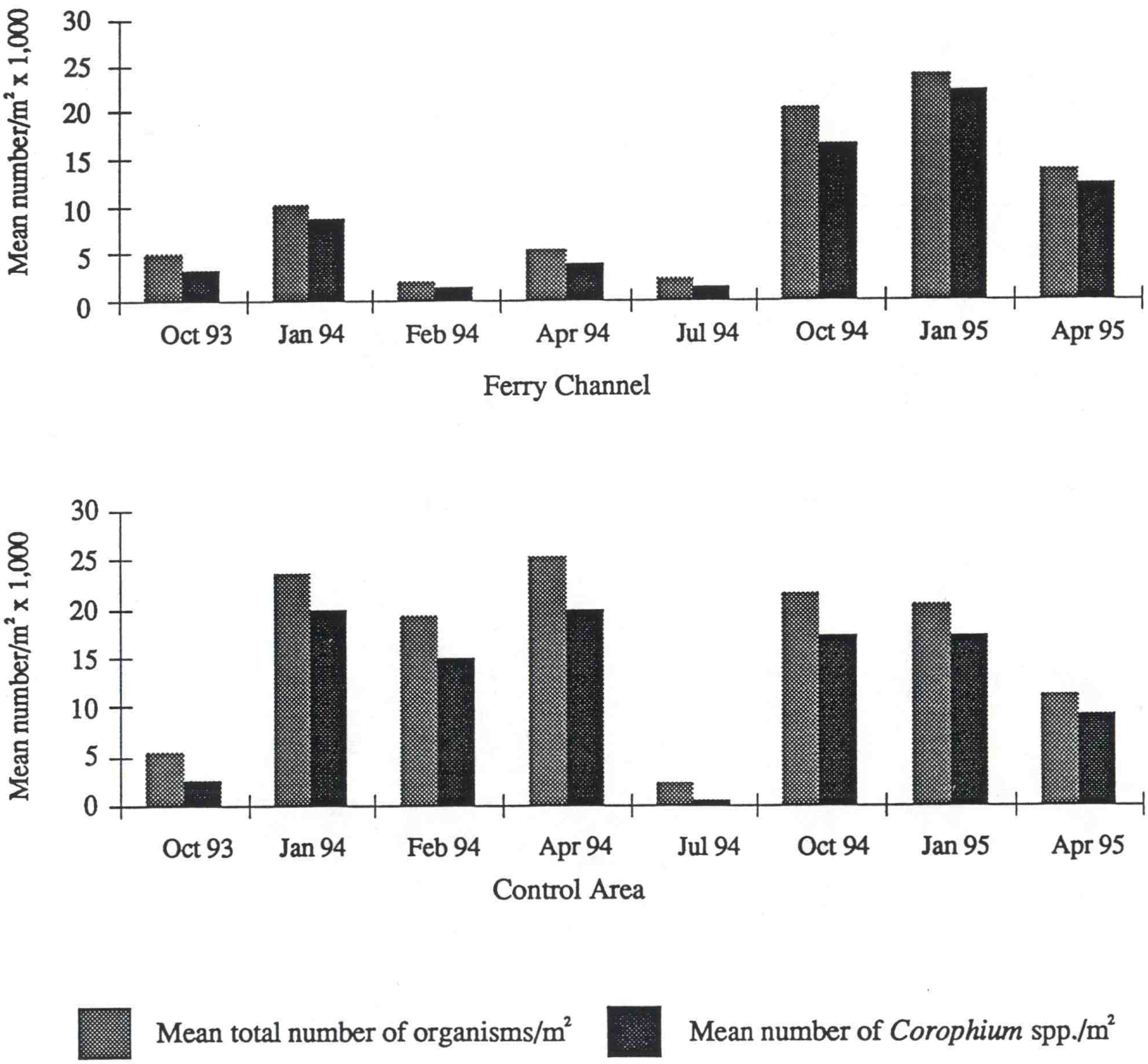

Figure 2. Mean densities of benthic invertebrates (total) and *Corophium* spp. in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

the ferry channel. In the control area, mean densities (by survey) ranged from 636 organisms/m^2 in April 1995 to 2,783 organisms/m^2 in April 1994 (Table 4). Mean densities (by survey) in the ferry channel ranged from 196 organisms/m^2 in February 1994 to 1,370 organisms/m^2 in October 1994.

No effect of the ferry channel dredging project on *Corophium* spp. densities was detected in the statistical analysis, as indicated by the nonsignificant interaction ($P = 0.17$) between survey and area in the ANOVA (Table 2). *Corophium* spp. densities were significantly different between surveys (ANOVA, $P = 0.00$), but not between areas (ANOVA, $P = 0.62$). In the control area, mean densities (by survey) ranged from 545 organisms/m^2 in July 1994 to 20,022 organisms/m^2 in April 1994 (Table 5). Mean densities (by survey) in the ferry channel ranged from 1,373 organisms/m^2 in February 1994 to 22,307 organisms/m^2 in January 1995.

No effect of the ferry channel dredging project on densities of Ceratopogonidae larvae was detected in the statistical analysis, as indicated by the nonsignificant interaction ($P = 0.13$) between survey and area in the ANOVA (Table 2). Densities of Ceratopogonidae larvae were significantly different between surveys (ANOVA, $P = 0.00$) and areas (ANOVA, $P = 0.00$). Densities of Ceratopogonidae larvae were significantly higher ($P < 0.05$) in the control area than in the ferry channel. In the control area, mean densities (by survey) ranged from 525 organisms/m^2 in July 1994 to 2,174 organisms/m^2 in October 1994 (Table 6). Mean densities (by survey) in the ferry channel ranged from 399 organisms/m^2 in February 1994 to 1,123 organisms/m^2 in January 1994.

No effect of the ferry channel dredging project on the benthic invertebrate community structure, measured by H and E, was detected in the statistical analysis, as indicated by the

Table 4. Mean densities (number/m^2) of *Corbicula fluminea* collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. Each value for a station is the mean of three replicate samples. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	509	139	62	994	284	1,003	25	142
W2	466	337	99	392	364	534	83	278
W3	485	80	337	198	352	976	1,223	420
W4	645	945	256	300	266	1,701	139	164
W5	256	235	204	272	219	1,822	219	238
W6	676	639	151	482	296	976	1,476	364
W7	559	389	262	497	256	2,575	1,358	1,201
Mean	514	395	196	448	291	1,370	646	401
CONTROL AREA								
WC8	1,630	4,742	7,975	3,137	991	4,153	2,285	954
WC9	670	380	1,210	1,179	318	1,281	62	151
WC10	945	766	420	1,612	843	1,547	1,541	151
WC11	1,568	1,951	6,147	8,351	1,355	1,899	3,174	2,331
WC12	614	111	250	262	266	701	179	56
WC13	1,985	5,391	1,241	4,631	698	1,179	5,233	713
WC14	763	31	86	312	269	287	93	93
Mean	1,168	1,910	2,476	2,783	677	1,578	1,795	636

Table 5. Mean densities (number/m^2) of *Corophium* spp. collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. Each value for a station is the mean of three replicate samples. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
				FERRY CHANNEL				
W1	957	275	426	9,228	182	13,103	114	4,313
W2	1,226	3,535	1,139	2,482	1,013	2,908	1,257	4,622
W3	2,664	756	1,683	658	670	14,486	35,773	6,428
W4	4,091	17,860	1,287	1,689	494	29,882	1,090	4,010
W5	2,180	7,814	1,010	2,556	834	26,601	1,998	3,010
W6	5,591	28,987	1,380	5,326	543	19,240	76,350	8,666
W7	6,842	1,130	2,689	5,097	6,317	10,123	39,564	54,723
Mean	3,364	8,622	1,373	3,862	1,436	16,620	22,307	12,253
				CONTROL AREA				
WC8	6,619	60,379	17,697	28,598	1,124	18,240	47,372	2,473
WC9	846	5,600	701	17,996	262	34,473	120	114
WC10	1,176	12,220	11,602	1,309	537	18,962	11,732	519
WC11	2,254	13,368	32,300	40,632	849	18,830	32,170	19,500
WC12	2,664	343	936	1,207	315	18,191	5,659	275
WC13	3,378	47,567	37,764	49,823	580	8,580	21,117	41,837
WC14	312	213	3,782	590	151	3,424	2,220	658
Mean	2,464	19,956	14,969	20,022	545	17,243	17,199	9,339

Table 6. Mean densities (number/m^2) of Ceratopogonidae larvae collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. Each value for a station is the mean of three replicate samples. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	710	1,053	371	1,155	395	741	238	269
W2	1,220	1,334	488	1,676	636	1,439	571	145
W3	812	509	333	917	645	1,840	614	2,047
W4	1,389	803	500	1,294	404	698	886	932
W5	1,334	1,812	960	1,152	426	355	1,402	367
W6	1,621	908	74	482	414	68	9	1,003
W7	500	1,445	68	151	324	102	31	46
Mean	1,084	1,123	399	975	463	749	536	687
CONTROL AREA								
WC8	417	704	562	689	642	704	40	170
WC9	2,096	1,368	1,834	2,661	479	3,628	312	1,676
WC10	1,599	1,559	929	2,637	423	2,056	1,655	1,491
WC11	2,013	1,176	874	1,133	519	2,634	1,389	1,182
WC12	519	1,355	4,007	2,600	877	2,637	954	1,062
WC13	1,229	1,309	815	636	417	889	1,454	204
WC14	2,618	1,769	1,062	1,315	318	2,671	2,103	1,118
Mean	1,499	1,320	1,440	1,667	525	2,174	1,130	986

nonsignificant interaction (P = 0.44 for H; P = 0.60 for E) between survey and area in the ANOVA (Table 2). Both H and E were significantly different between surveys (ANOVA, P = 0.00), but not between areas (P = 0.16 for H; P = 0.55 for E). Mean H values (by survey) in the control area ranged from 1.02 in January 1994 to 2.22 in July 1994. In the ferry channel, mean H values (by survey) ranged from 0.84 in April 1995 to 1.85 in July 1994 (Table 7). Mean E values (by survey) in the control area ranged from 0.34 in October 1994 to 0.70 in July 1994. In the ferry channel, mean E values (by survey) ranged from 0.30 in October 1994 to 0.61 in July 1994 (Table 8).

Sediments

Although median grain size was significantly smaller in the ferry channel than in the control area (ANOVA, P = 0.00), no effect of the ferry channel dredging project on median grain size was detected in the statistical analysis, as indicated by the nonsignificant interaction (P = 0.88) between survey and area in the ANOVA. The overall means for median grain sizes in the ferry channel and control area were 0.29 and 0.37 mm, respectively (Table 9). Median grain size was not significantly different between surveys (ANOVA, P = 0.18). Mean median grain sizes in the ferry channel ranged from 0.24 mm in July 1994 to 0.32 mm in January 1994, whereas in the control area, mean median grain sizes ranged from 0.33 mm in January 1995 to 0.40 mm in October 1993 (Table 9).

The overall means for percent silt/clay in the ferry channel and control area were 2.8 and 1.1%, respectively (Table 10). In the ferry channel, mean percent silt/clay ranged from 0.1% in January 1994 to 8.6% in July 1994. Mean percent silt/clay in the control area ranged from 0.4% in October 1993 and January 1994 to 2.1% in April 1995.

Table 7. Diversities (H) of benthic invertebrates collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	1.71	1.24	1.56	1.01	2.07	0.72	1.82	0.62
W2	1.59	1.18	1.34	1.39	2.00	1.43	1.30	1.00
W3	1.30	1.46	1.32	1.48	1.88	0.86	0.41	1.15
W4	1.33	0.60	1.38	1.38	2.04	0.55	1.67	0.93
W5	1.33	0.90	1.51	1.34	1.91	0.58	1.27	0.83
W6	1.15	0.39	0.87	0.95	1.94	1.14	0.29	0.78
W7	0.97	1.72	0.80	1.25	1.14	1.92	0.43	0.56
	----	----	----	----	----	----	----	----
Mean	1.34	1.07	1.25	1.26	1.85	1.03	1.03	0.84
CONTROL AREA								
WC8	1.32	0.54	1.13	0.87	2.23	1.27	0.37	1.54
WC9	1.60	1.19	1.67	0.95	1.97	0.71	2.02	0.89
WC10	1.75	0.87	0.89	1.84	2.11	0.98	1.09	1.39
WC11	1.82	1.10	0.93	1.03	2.39	1.09	0.77	1.02
WC12	1.48	1.57	1.17	1.68	2.10	0.86	0.94	1.52
WC13	1.74	0.75	0.42	0.77	2.52	1.20	1.12	0.36
WC14	1.34	1.12	1.02	1.65	2.24	1.41	1.59	1.52
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Mean	1.58	1.02	1.03	1.26	2.22	1.07	1.13	1.18

Table 8. Equitabilities (E) of benthic invertebrates collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	0.61	0.53	0.60	0.39	0.69	0.21	0.70	0.24
W2	0.62	0.46	0.48	0.54	0.63	0.51	0.50	0.32
W3	0.46	0.63	0.47	0.74	0.67	0.29	0.13	0.41
W4	0.48	0.22	0.60	0.59	0.64	0.17	0.53	0.40
W5	0.47	0.39	0.54	0.48	0.64	0.16	0.64	0.42
W6	0.50	0.14	0.34	0.34	0.65	0.29	0.07	0.30
W7	0.31	0.66	0.28	0.42	0.34	0.48	0.11	0.16
	----	----	----	----	----	----	----	----
Mean	0.49	0.43	0.47	0.50	0.61	0.30	0.38	0.32
CONTROL AREA								
WC8	0.40	0.18	0.38	0.31	0.67	0.34	0.12	0.51
WC9	0.62	0.40	0.72	0.37	0.62	0.22	0.78	0.34
WC10	0.68	0.31	0.27	0.71	0.67	0.33	0.39	0.54
WC11	0.65	0.37	0.27	0.34	0.75	0.36	0.27	0.34
WC12	0.57	0.68	0.50	0.56	0.66	0.31	0.28	0.65
WC13	0.55	0.25	0.12	0.27	0.76	0.35	0.37	0.11
WC14	0.52	0.48	0.36	0.71	0.75	0.47	0.48	0.59
	----	----	----	----	----	----	----	----
Mean	0.57	0.38	0.37	0.47	0.70	0.34	0.38	0.44

Table 9. Median grain sizes (mm) of sediments sampled in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	0.32	0.32	0.29	0.28	0.32	0.29	0.33	0.31
W2	0.31	0.30	0.32	0.32	0.28	0.29	0.31	0.30
W3	0.31	0.31	0.31	0.29	0.03	0.27	0.24	0.31
W4	0.32	0.31	0.34	0.32	0.28	0.29	0.32	0.34
W5	0.29	0.32	0.32	0.30	0.25	0.31	0.33	0.33
W6	0.30	0.36	0.35	0.28	0.31	0.21	0.16	0.29
W7	0.30	0.29	0.24	0.26	0.22	0.37	0.20	0.25
	----	----	----	----	----	----	----	----
Mean	0.31	0.32	0.31	0.29	0.24	0.29	0.27	0.30
CONTROL AREA								
WC8	0.50	0.39	0.51	0.38	0.66	0.38	0.31	0.39
WC9	0.37	0.42	0.34	0.37	0.32	0.31	0.34	0.39
WC10	0.37	0.36	0.39	0.30	0.30	0.29	0.35	0.28
WC11	0.47	0.36	0.45	0.48	0.40	0.49	0.35	0.45
WC12	0.30	0.33	0.37	0.43	0.36	0.37	0.26	0.35
WC13	0.45	0.40	0.31	0.33	0.34	0.30	0.43	0.21
WC14	0.34	0.35	0.35	0.35	0.33	0.35	0.30	0.36
	----	----	----	----	----	----	----	----
Mean	0.40	0.37	0.39	0.38	0.39	0.36	0.33	0.35

Table 10. Percents silt/clay of sediments sampled in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	0.2	0.1	0.7	0.6	0.1	0.6	0.2	0.3
W2	0.1	0.1	0.4	0.1	0.2	1.7	1.0	0.3
W3	0.2	0.1	0.5	0.3	52.9	1.5	1.1	0.1
W4	0.1	0.0	0.6	0.2	0.3	1.3	0.2	0.3
W5	0.3	0.1	1.0	1.5	0.7	1.9	0.2	0.5
W6	0.4	0.4	0.7	2.2	0.1	10.6	19.8	0.8
W7	0.5	0.2	5.1	6.8	6.1	1.2	12.5	15.6
	----	----	----	----	----	----	----	----
Mean	0.3	0.1	1.3	1.7	8.6	2.7	5.0	2.6
CONTROL AREA								
WC8	0.2	1.0	0.6	1.1	0.3	0.5	6.9	5.2
WC9	0.2	0.1	6.1	0.5	0.0	0.7	0.2	0.5
WC10	0.4	0.1	1.1	0.8	4.8	1.0	1.1	0.2
WC11	0.7	0.3	1.4	1.3	0.3	0.8	1.0	0.7
WC12	0.5	0.1	0.7	0.3	0.3	0.2	0.6	0.2
WC13	0.1	1.1	0.8	2.6	0.4	0.4	0.5	7.8
WC14	0.7	0.2	1.0	0.2	0.4	0.2	1.1	0.3
	----	----	----	----	----	----	----	----
Mean	0.4	0.4	1.7	1.0	0.9	0.5	1.6	2.1

No effect of the ferry channel dredging project on percent volatile solids was detected in the statistical analysis, as indicated by the nonsignificant interaction (P = 0.56) between survey and area in the ANOVA. Percent volatile solids were not significantly different between areas (ANOVA, P = 0.45), and overall, averaged 0.6% in each area (Table 11). Percent volatile solids were significantly different between surveys (ANOVA, P = 0.01). In the ferry channel, mean percent volatile solids ranged from 0.5% in January 1994 to 0.8% in April 1994 (Table 11). In the control area, mean percent volatile solids ranged from 0.5% in October 1994 and January 1995 to 0.8% in April 1994. Sediments from the ferry channel were tested for contaminants prior to the dredging project and were found to be uncontaminated (Jon Gornick, COE, Portland District, P.O. Box 2946, Portland, Oregon 97208. Pers. commun. 26 February 1996).

DISCUSSION

The effects of dredging on benthic invertebrate communities vary widely. Morton (1977), who conducted a literature review of the ecological effects of dredging and dredge spoil disposal, noted that initial effects can range from negligible to severe and impacts range from short to long-term. Based on his literature review, Morton (1977) concluded that short-term, small-scale dredging and dredge spoil disposal projects impacted benthic communities less than long-term, large-scale projects.

We were unable to detect any significant effect of the clamshell dredging project on the standing crops of benthic invertebrates in Wahkiakum County Ferry Channel. Apparently, benthic invertebrates in the dredged area were able to recolonize the area quite rapidly after dredging. In a study of the effects of dredging on benthic macroinvertebrates in a South

Table 11. Percents total volatile solids of sediments sampled in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Station	Oct 93	Jan 94	Feb 94	Apr 94	Jul 94	Oct 94	Jan 95	Apr 95
FERRY CHANNEL								
W1	0.6	0.4	0.4	0.5	1.0	0.3	0.4	0.5
W2	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.6
W3	0.6	0.6	0.4	0.8	0.6	0.4	0.7	0.4
W4	0.7	0.5	0.5	1.0	0.6	0.6	0.5	0.8
W5	0.6	0.4	0.7	0.8	0.8	0.7	0.5	0.6
W6	0.5	0.4	0.5	0.7	0.7	0.9	1.6	0.7
W7	0.8	0.7	1.0	1.1	0.7	0.5	0.9	1.2
	---	---	---	---	---	---	---	---
Mean	0.6	0.5	0.6	0.8	0.7	0.6	0.7	0.7
CONTROL AREA								
WC8	0.8	0.8	0.5	0.8	0.8	0.4	0.6	0.7
WC9	0.8	0.5	0.4	0.6	0.5	0.4	0.5	0.5
WC10	0.8	0.6	0.6	0.7	0.6	0.6	0.6	0.8
WC11	0.9	0.6	0.6	1.0	0.6	0.5	0.5	0.6
WC12	0.3	0.4	0.7	0.6	0.5	0.6	0.3	0.5
WC13	0.4	0.5	1.1	1.1	0.6	0.6	0.4	0.8
WC14	0.5	0.7	0.4	0.7	0.6	0.4	0.5	0.9
	---	---	---	---	---	---	---	---
Mean	0.6	0.6	0.6	0.8	0.6	0.5	0.5	0.7

Carolina estuary, Van Dolah et al. (1984) noted short-term effects of a dredging project, with substantial recovery within 3 months. They attributed much of the rapid recolonization to immigration via sediments of the slumping channel walls, which were similar to the sediments removed during dredging. Benthic invertebrates living in the slumping channel walls adjacent to Wahkiakum County Ferry Channel could have contributed to the rapid recolonization of the dredged area by benthic invertebrates. Although the sediments outside of the ferry channel were not sampled, we assume that they were similar to those removed from the ferry channel. If the sediments in slumping channel walls had been considerably different than those removed from the channel, then the benthos in the ferry channel may not have recovered as rapidly.

Corophium salmonis may also have migrated into the dredged channel from areas more distant than the slumping channel walls. Davis (1978) observed that *C. salmonis* actively migrated into the water column in the Columbia River estuary. *Corophium volutator*, a related Atlantic species, has been found to swim above the bottom during part of its life (Hughes 1988). If *C. salmonis* populations in the reach of the Columbia River near the Wahkiakum County Ferry Channel exhibit similar behavior, they could have been carried into the ferry channel by river currents. Muir (1990) found that *Corophium salmonis* was one of the three most abundant organisms collected in the drift along the bottom of the river downstream from Bonneville Dam.

No significant changes occurred in the benthic invertebrate community structure, as measured by H and E, in Wahkiakum County Ferry Channel as a result of the dredging project. Ideally, all benthic organisms should have been identified to the same taxonomic level, preferably species, for the community structure assessments; however, this was not practical or feasible given the financial constraints of the study. Even though different taxonomic levels of identification were used in calculating both H and E, we believe our statistical comparisons are valid since similar taxonomic levels were used throughout the study. No attempt was made to compare our H and E values to those of other research studies.

Our study clearly demonstrates the need for at least one control area in environmental assessments of dredging projects. Also, it is important to conduct sampling prior to dredging in both the impacted and control areas. Underwood (1992) goes one step farther and states the need for multiple control areas in environmental assessments, with sampling before and after in both the impact and control areas. Unfortunately, it is not practical or economically feasible to establish multiple control areas in most benthic invertebrate studies. Without the data from the control area, we would not have been able to make accurate conclusions regarding the impact of the dredging project on the benthos in the ferry channel. Samples collected in the control area provided a means of assessing natural variation in the standing crops and community structure of benthic invertebrates in a specific reach of the lower Columbia River. Other researchers have noted that benthic invertebrate populations in other reaches of the lower Columbia River vary seasonally (Holton et al. 1984, McCabe and Hinton 1993, Hinton et al. 1995). In Grays Bay (RM 23), Holton et al. (1984) observed that *Corophium salmonis* densities ranged from 4,122 organisms/m^2 in July 1981 to 31,754 organisms/m^2 in February 1981. Hinton et al. (1995) noted significant ($P < 0.05$) temporal differences in standing crops of benthic invertebrates (total), including *Corophium* spp., in a study area between Miller Sands and Pillar Rock Island, Columbia River estuary (RM 26). In our study, densities of *Corophium* spp. fluctuated during the eight surveys, with the lowest overall density in July 1994.

In conclusion, we detected no significant effect ($P > 0.05$) of the ferry channel dredging project on benthic invertebrate densities or community structure from the statistical analyses of the data. In addition, we detected no significant effect ($P > 0.05$) of the dredging project on sediment median grain size or percent volatile solids.

This report does not constitute formal comments of the NMFS under the Fish and Wildlife Coordination Act or the National Environmental Policy Act.

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APPENDIX

Appendix Table 1. Geographic locations of benthic sampling stations in Wahkiakum County Ferry Channel, Washington, and control stations, 1993-1995. All stations beginning with "W" were in the ferry channel; stations beginning with "WC" were in the control area. The depth (mean lower low water) is a mean from eight surveys.

Station	Mean depth (m)	Latitude	Longitude
W1	4.4	46°09.103'N	123°22.723'W
W2	4.0	46°09.081'N	123°22.708'W
W3	3.2	46°09.134'N	123°22.684'W
W4	3.0	46°09.132'N	123°22.672'W
W5	2.7	46°09.154'N	123°22.667'W
W6	2.5	46°09.147'N	123°22.638'W
W7	3.0	46°09.170'N	123°22.654'W
WC8	1.3	46°08.825'N	123°20.311'W
WC9	4.0	46°08.800'N	123°20.265'W
WC10	2.6	46°08.807'N	123°20.110'W
WC11	1.9	46°08.833'N	123°20.000'W
WC12	4.0	46°08.820'N	123°19.999'W
WC13	2.1	46°08.830'N	123°19.964'W
WC14	5.0	46°08.789'N	123°19.977'W

Appendix Table 2. Invertebrate taxa/categories found in Wahkiakum County Ferry Channel, Washington, and a control area, 1993-1995; the data were combined for both areas for each survey.

Taxon/category	1993	1994					1995	
	Oct	Jan	Feb	Apr	Jul	Oct	Jan	Apr
Nemertea	x		x	x	x	x	x	x
Nematomorpha			x					
Turbellaria	x		x		x	x	x	x
Polychaeta								
Neanthes limnicola					x	x	x	x
Oligochaeta	x	x	x	x	x	x	x	x
Gastropoda	x							
Lymnaeidae (unid. limpet)						x		
Fluminicola virens	x	x	x	x	x	x	x	x
Juga plicifera		x	x			x	x	x
Bivalvia						x		
Corbicula fluminea	x	x	x	x	x	x	x	x
Anodonta spp.						x	x	
Ostracoda		x	x	x	x	x	x	x
Amphipoda								
Corophium spp.	x	x	x	x	x	x	x	x
Corophium salmonis	x	x	x	x	x	x	x	x
Corophium spinicorne	x	x	x	x	x	x	x	x
Ramellogammarus spp.	x							
Ramellogammarus oregonensis	x	x	x	x	x	x	x	x
Hyalella azteca		x				x	x	
Pontoporeia hoyi						x		
Isopoda								
Gnorimosphaeroma oregonensis					x			
Porcellio scaber						x		

Appendix Table 2. Continued.

Taxon/category	1993 Oct	1994 Jan	1994 Feb	1994 Apr	1994 Jul	1994 Oct	1995 Jan	1995 Apr
Copepoda								
Harpacticoida						x		
Hydracarina						x	x	
Miscellaneous Insecta								
Collembola adult	x				x	x	x	
Plecoptera nymph			x					
Ephemeroptera nymph		x	x		x	x	x	
Odonata nymph	x					x	x	
Hemiptera		x	x					
Trichoptera larvae						x	x	
Coleoptera larvae							x	
Miscellaneous Diptera								
Chironomidae larvae	x	x	x	x	x	x	x	x
Chironomidae pupae	x		x		x	x	x	x
Ceratopogonidae larvae	x	x	x	x	x	x	x	x
Total no. of taxa/categories	16	14	18	11	17	27	23	15