George T. McCabe, Jr., Susan A. Hinton, and **Robert L. Emmett**
Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service,
National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, Washington 98112-2097

Benthic Invertebrates and Sediment Characteristics in a Shallow Navigation Channel of the Lower Columbia River, Before and After Dredging

Abstract

Little is known about the impact of dredging on benthic invertebrates in navigation channels of the lower Columbia River. To help fill this informational void, we conducted benthic invertebrate and sediment studies in a shallow navigation channel in the river before and after dredging. 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, Washington (River Kilometer 70), and at an upstream reference area in 1993-1995. No significant effects ($P > 0.05$) of the ferry channel dredging project on *Corbicula fluminea*, Ceratopogonidae larvae, *Corophium* spp., or total benthic invertebrate densities were detected in the statistical analysis, although benthic invertebrate densities were significantly different ($P < 0.05$) between surveys and areas for some organisms. 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 reference area. Two measures of community structure, Diversity (H) and Equitability (E), were calculated for each area for each survey. No significant effects ($P > 0.05$) of the ferry channel dredging project on the benthic invertebrate community structure, as measured by H and E, were detected. No significant effects ($P > 0.05$) of the ferry channel dredging project on sediment median grain size or percent volatile solids were detected. Results from this study will provide information to aquatic resource agencies that assess the potential environmental effects of dredging in similar habitats of the lower Columbia River.

Introduction

The lower Columbia River from the mouth to Portland, Oregon, is an important navigation channel that is maintained to a depth of 12.2 m by dredging. In addition, various shallower, secondary navigation channels in the lower river are maintained through dredging. Little is known about the impact of dredging on benthic invertebrates in the lower Columbia River. To help fill this informational void, we conducted benthic invertebrate and sediment studies in the Wahkiakum County Ferry Channel, Washington (River Kilometer (RKm) 70), 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 our 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 of the ferry channel from 24 January to 17 February 1994. About 14,258 m^3 of sediments were removed from the channel and disposed of at an in-water disposal site about 4 km downstream from the ferry channel. Although the ferry channel is about 579 m long, only about 244 m had to be dredged, as the remainder of the channel is naturally deep. The dredged portion of the ferry channel is 61 m wide and authorized to a depth of 2.7 m.

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 by benthic invertebrates in the dredged portion of the ferry channel. We collected samples in a reference area located about 3.2 km 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 reference area. Results from this study will provide information to aquatic resource agencies that 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 reference area in October 1993; January, February, April, July, and October 1994; and January and April 1995 (Figure 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. Mean water depths, by survey, in the ferry channel and reference area ranged from 2.0 to 3.8 m and 2.3 to 4.7 m (mean lower low water), respectively. Sampling stations were located using a radar range-finder and the Global Positioning System (GPS).

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 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, refrigerated, and analyzed for grain size, percent silt/clay, and percent volatile solids by the U.S. Army Corps of Engineers, North Pacific Division Materials Laboratory, Troutdale, Oregon.

Data Analyses

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 ith 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 reference area) and surveys using two-way analysis of variance (ANOVA) (Cruze and Hartzell 1991). Results from the two-way ANOVAs were used to determine significant ($P \leq 0.05$) impacts of the dredging project on benthic invertebrate densities, H, and E. Because sampling was conducted in the ferry channel and reference area prior to and after dredging, we were able to determine any significant impacts of the dredging by using the interaction term (survey x area) in the ANOVA. A significant interaction indicated a statistically significant effect of the dredging. 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). Mean densities of invertebrates from individual sampling stations provided the data for statistical tests.

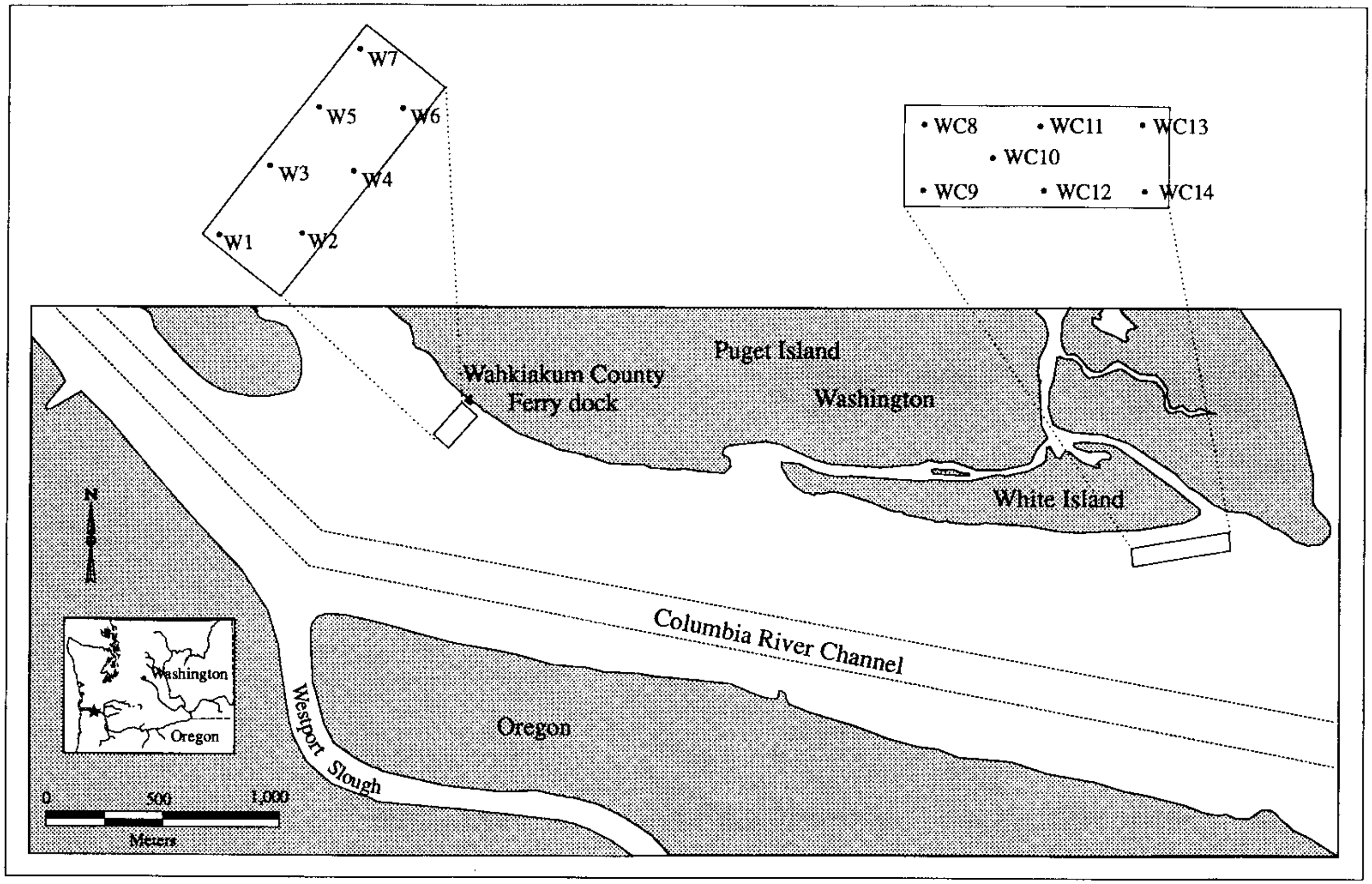

Figure 1. Locations of the Wahkiakum County Ferry Channel, Washington, and the upstream reference area. Locations of benthic invertebrate and sediment sampling stations in the dredged portion of the ferry channel and reference area are shown in the insets.

Median grain size and percent volatile solids of the sediment samples were each compared between areas (i.e., the ferry channel and reference area) and surveys using two-way ANOVA (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 nonnormal distribution of the data and the lack of an adequate data transformation.

Results

Benthic Invertebrates

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 reference area (Table 1). In both areas, these three taxa represented 90% or more of the total benthic invertebrate densities during all surveys, except the July 1994 survey in the reference area. In both areas, *Corophium* spp. were generally the most abundant benthic invertebrates (Figure 2). We estimated that about 98% of the *Corophium* spp. were *C. salmonis* and the remainder *C. spinicorne*. The proportional abundances of *Corophium* spp. in the ferry channel ranged from 59% in July 1994 to 93% in January 1995; in the reference area, the proportional abundances ranged from 24% in July 1994 to 85% in January 1994.

The total numbers of taxa/categories collected in the ferry channel and reference area (data combined for both areas) ranged from 11 in April 1994 to 27 in October 1994. Mean numbers of taxa/categories (by survey) in the ferry channel and reference area were similar, ranging from 6 to 11 (Table 2).

The differences between areas for *Corbicula fluminea*, Ceratopogonidae larvae, *Corophium* spp., and total benthic invertebrate densities and H and E did not change over the surveys, indicating that the dredging did not have a statistically significant ($P \leq 0.05$) effect on these parameters (Table 3). All interaction terms (survey x area) in the analyses were nonsignificant ($P > 0.05$), indicating no effect of the dredging. Although we could not detect statistically significant effects of the dredging on benthic invertebrate densities, there appeared to be a potential dampening effect on invertebrates immediately after the dredging (Table 1). The dredging in the ferry channel did not appear to have any obvious impact on less common taxa found in the channel.

Corbicula fluminea, Ceratopogonidae larvae, and total benthic invertebrate densities were significantly different between surveys and areas (ANOVA, $P < 0.05$), with densities being significantly higher ($P < 0.05$) in the reference area than in the ferry channel (Tables 1 and 3). In the reference area, mean total benthic invertebrate densities (by survey) ranged from 2,291 organisms/m^2 in July 1994 to 25,266 organisms/m^2 in April 1994 (Table 1). Mean total benthic invertebrate densities (by survey) in the ferry channel ranged from 2,004 organisms/m^2 in February 1994 to 23,794 organisms/m^2 in January 1995. Mean *Corbicula fluminea* densities in the reference area ranged from 631 organisms/m^2 in April 1995 to 2,765 organisms/m^2 in April 1994 (Table 1), and mean densities in the ferry channel ranged from 194 organisms/m^2 in February 1994 to 1,360 organisms/m^2 in October 1994. In the reference area, mean densities of Ceratopogonidae larvae ranged from 521 organisms/m^2 in July 1994 to 2,159 organisms/m^2 in October 1994 (Table 1). Mean densities of Ceratopogonidae larvae in the ferry channel ranged from 396 organisms/m^2 in February 1994 to 1,116 organisms/m^2 in January 1994.

Corophium spp. densities, H, and E were significantly different between surveys (ANOVA, $P < 0.05$), but not between areas (ANOVA, $P > 0.05$) (Table 3). In the reference area, mean densities of *Corophium* spp. (by survey) ranged from 542 organisms/m^2 in July 1994 to 19,888 organisms/m^2 in April 1994 (Table 1). Mean densities in the ferry channel ranged from 1,364 organisms/m^2 in February 1994 to 22,157 organisms/m^2 in January 1995. Mean H values (by survey) in the reference area ranged from 1.02 in January 1994 to 2.22 in July 1994 (Table 2). In the ferry channel, mean H values (by survey) ranged from 0.84 in April 1995 to 1.85 in July 1994. Mean E values (by survey) in the reference area ranged from 0.34 in October 1994 to 0.70 in July 1994 (Table 2). In the ferry channel, mean E values (by survey) ranged from 0.30 in October 1994 to 0.61 in July 1994.

TABLE 1. Mean densities (number/m²) of benthic invertebrates collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a reference area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Taxon/category	October 1993	January 1994	February 1994	April 1994	July 1994	October 1994	January 1995	April 1995
FERRY CHANNEL								
Nemertea	2	0	0	0	14	106	55	170
Nematomorpha	0	0	0	0	0	0	0	0
Turbellaria	4	0	15	0	2	12	3	<1
Polychaeta								
Neanthes limnicola	0	0	0	0	1	1	0	1
Oligochaeta	27	94	16	121	29	1,074	68	220
Gastropoda	0	0	0	0	0	0	0	0
Lymnaeidae (unident. limpet)	0	0	0	0	0	1	0	0
Fluminicola virens	27	3	2	2	81	344	299	120
Juga plicifera	0	0	0	0	0	1	1	0
Bivalvia	0	0	0	0	0	1	0	0
Corbicula fluminea	510	392	194	445	289	1,360	642	398
Anodonta spp.	0	0	0	0	0	2	<1	0
Ostracoda	0	0	<1	3	4	22	2	18
Amphipoda								
Corophium spp.	3,342	8,565	1,364	3,836	1,427	16,509	22,157	12,171
Ramellogammarus spp.	0	0	0	0	0	0	0	0
Ramellogammarus oregonensis	2	1	0	11	0	2	4	23
Hyalella azteca	0	<1	0	0	0	1	1	0
Pontoporeia hoyi	0	0	0	0	0	1	0	0
Isopoda								
Gnorimosphaeroma oregonensis	0	0	0	0	1	0	0	0
Porcellio scaber	0	0	0	0	0	<1	0	0
Copepoda								
Harpacticoida	0	0	0	0	0	<1	0	0
Hydracarina	0	0	0	0	0	3	5	0
Insecta								
Collembola adult	<1	0	0	0	1	0	0	0
Plecoptera nymph	0	0	0	0	0	0	0	0
Ephemeroptera nymph	0	0	0	0	0	34	2	0
Odonata nymph	<1	0	0	0	0	11	<1	0
Hemiptera	0	0	0	0	0	0	0	0
Trichoptera larvae	0	0	0	0	0	<1	1	0
Coleoptera larvae	0	0	0	0	0	0	1	0
Miscellaneous Diptera								
Chironomidae larvae	20	14	16	57	71	158	21	17
Chironomidae pupae	1	0	0	0	34	2	<1	<1
Ceratopogonidae larvae	1,076	1,116	396	969	460	744	532	683
Total number/m²	5,012	10,185	2,004	5,444	2,414	20,390	23,794	13,821

Continued, next page

TABLE 1. Continued

Taxon/category	October 1993	January 1994	February 1994	April 1994	July 1994	October 1994	January 1995	April 1995
			REFERENCE AREA					
Nemertea	4	0	9	<1	66	11	29	123
Nematomorpha	0	0	<1	0	0	0	0	0
Turbellaria	3	0	19	0	2	1	0	0
Polychaeta								
Neanthes limnicola	0	0	0	0	6	2	1	0
Oligochaeta	119	171	87	536	195	259	197	212
Gastropoda	7	0	0	0	0	0	0	0
Lymnaeidae (unident. limpet)	0	0	0	0	0	1	0	0
Fluminicola virens	78	114	84	78	243	348	131	43
Juga plicifera	0	<1	<1	0	0	<1	1	<1
Bivalvia	0	0	0	0	0	0	0	0
Corbicula fluminea	1,160	1,897	2,459	2,765	673	1,568	1,783	631
Anodonta spp.	0	0	0	0	0	0	0	0
Ostracoda	0	<1	0	<1	<1	0	0	0
Amphipoda								
Corophium spp.	2,448	19,822	14,869	19,888	542	17,127	17,084	9,277
Ramellogammarus spp.	2	0	0	0	0	0	0	0
Ramellogammarus oregonensis	0	19	56	13	1	3	4	4
Hyalella azteca	0	0	0	0	0	0	0	0
Pontoporeia hoyi	0	0	0	0	0	0	0	0
Isopoda								
Gnorimosphaeroma oregonensis	0	0	0	0	0	0	0	0
Porcellio scaber	0	0	0	0	0	0	0	0
Copepoda								
Harpacticoida	0	0	0	0	0	0	0	0
Hydracarina	0	0	0	0	0	0	0	0
Insecta								
Collembola adult	<1	0	0	0	<1	1	<1	0
Plecoptera nymph	0	0	<1	0	0	0	0	0
Ephemeroptera nymph	0	<1	<1	0	<1	0	3	0
Odonata nymph	0	0	0	0	0	0	0	0
Hemiptera	0	<1	1	0	0	0	0	0
Trichoptera larvae	0	0	0	0	0	0	0	0
Coleoptera larvae	0	0	0	0	0	0	<1	0
Miscellaneous Diptera								
Chironomidae larvae	31	93	80	329	20	26	17	16
Chironomidae pupae	2	0	<1	0	21	1	0	<1
Ceratopogonidae larvae	1,489	1,311	1,431	1,656	521	2,159	1,122	980
Total number/m^2	5,343	23,428	19,097	25,266	2,291	21,508	20,372	11,286

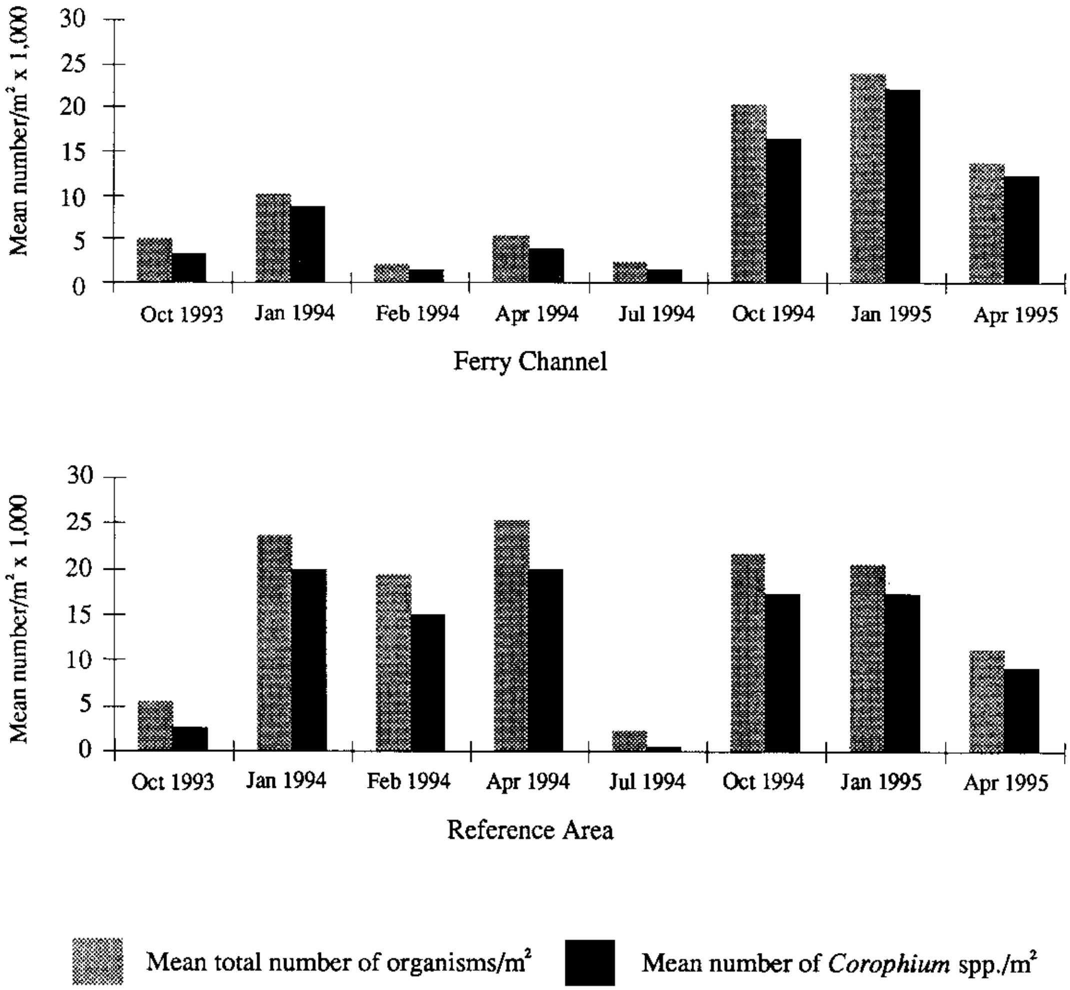

Figure 2. Mean densities of benthic invertebrates (total) and *Corophium* spp. in Wahkiakum County Ferry Channel, Washington, and a reference area. 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

Sediments

Although median grain size was significantly smaller in the ferry channel than in the reference 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 reference area were 0.29 and 0.37 mm, respectively (Table 4). Median grain sizes were 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 reference area, mean median grain sizes ranged from 0.33 mm in January 1995 to 0.40 mm in October 1993 (Table 4).

The overall means for percents silt/clay in the ferry channel and reference area were 2.8 and 1.1%, respectively (Table 4). In the ferry channel, mean percents silt/clay ranged from 0.1% in January 1994 to 8.6% in July 1994. Mean percents silt/clay in the reference area ranged from 0.4% in October 1993 and January 1994 to 2.1% in April 1995.

TABLE 2. Mean numbers of benthic invertebrate taxa/categories identified and mean diversities (H) and mean equitabilities (E) calculated for benthic invertebrate samples collected during eight surveys in Wahkiakum County Ferry Channel, Washington, and a reference area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

	October 1993	January 1994	February 1994	April 1994	July 1994	October 1994	January 1995	April 1995
				FERRY CHANNEL				
No. of taxa	7	6	6	6	8	11	9	7
H	1.34	1.07	1.25	1.26	1.85	1.03	1.03	0.84
E	0.49	0.43	0.47	0.50	0.61	0.30	0.38	0.32
				REFERENCE AREA				
No. of taxa	7	7	8	7	9	9	8	7
H	1.58	1.02	1.03	1.26	2.22	1.07	1.13	1.18
E	0.57	0.38	0.37	0.47	0.70	0.34	0.38	0.44

TABLE 3. Results of two-way analysis of variance for selected benthic invertebrate parameters measured in Wahkiakum County Ferry Channel, Washington, and a reference 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	Survey	7	5.40	0.000*
density ($\log_{10}$),	Area	1	6.23	0.014*
total	Survey x area	7	1.90	0.078
	Total (deg. freedom)	111		
Corbicula fluminea	Survey	7	2.39	0.027*
density ($\log_{10}$)	Area	1	13.07	0.000*
	Survey x area	7	1.03	0.415
	Total (deg. freedom)	111		
Corophium spp. density	Survey	7	5.07	0.000*
($\log_{10}$)	Area	1	0.25	0.615
	Survey x area	7	1.53	0.166
	Total (deg. freedom)	111		
Ceratopogonidae larvae	Survey	7	3.39	0.003*
density	Area	1	22.12	0.000*
	Survey x area	7	1.65	0.129
	Total (deg. freedom)	111		
Diversity (H)	Survey	7	11.76	0.000*
	Area	1	2.04	0.156
	Survey x area	7	1.00	0.438
	Total (deg. freedom)	111		
Equitability (E)	Survey	7	6.24	0.000*
	Area	1	0.35	0.554
	Survey x area	7	0.81	0.579
	Total (deg. freedom)	111		

No effect of the ferry channel dredging project on percent volatile solids was detected, as indicated by the nonsignificant interaction ($P = 0.56$) between survey and area in the ANOVA. Percents volatile solids were not significantly different between areas (ANOVA, $P = 0.45$) and, overall, averaged 0.6% in each area (Table 4). Percents volatile solids were significantly different between surveys (ANOVA, $P = 0.01$). In the ferry channel, mean percents volatile solids ranged from 0.5% in January 1994 to 0.8% in April 1994 (Table 4). In the reference area, mean percents

TABLE 4. Mean median grain sizes (mm), percents silt/clay, and percents total volatile solids of sediments sampled in Wahkiakum County Ferry Channel, Washington, and a reference area, 1993-1995. The ferry channel was dredged after the January 1994 survey and prior to the February 1994 survey.

	October 1993	January 1994	February 1994	April 1994	July 1994	October 1994	January 1995	April 1995
			FERRY CHANNEL					
Grain size (mm)	0.31	0.32	0.31	0.29	0.24	0.29	0.27	0.30
Silt/clay (%)	0.3	0.1	1.3	1.7	8.6	2.7	5.0	2.6
Vol. solids (%)	0.6	0.5	0.6	0.8	0.7	0.6	0.7	0.7
			REFERENCE AREA					
Grain size (mm)	0.40	0.37	0.39	0.38	0.39	0.36	0.33	0.35
Silt/clay (%)	0.4	0.4	1.7	1.0	0.9	0.5	1.6	2.1
Vol. solids (%)	0.6	0.6	0.6	0.8	0.6	0.5	0.5	0.7

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, U.S. Army Corps of Engineers, Portland District, P.O. Box 2946, Portland, OR 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 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 *C. 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.

Our study clearly demonstrates the need for at least one reference area in environmental assessments of dredging projects. Also, it is important to conduct sampling prior to dredging in both the impacted and reference areas. Underwood (1992) goes one step farther and states the need for multiple reference areas in environmental assessments, with sampling before and after in both the impact and reference areas. It is not practical or economically feasible to establish multiple reference areas in most benthic invertebrate studies. Without the data from the reference 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 reference 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 (RKm 37), 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 (RKm 40-42). 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 effects ($P > 0.05$) of the ferry channel dredging project on benthic invertebrate densities or community structure from the statistical analyses of the data; however, there appeared to be a potential dampening effect on invertebrates in the ferry channel immediately after the dredging. In addition, we detected no significant effects ($P > 0.05$) of the dredging project on sediment median grain size or percent volatile solids.

Acknowledgements

We thank Lawrence Davis, Roy Pettit, Dennis Umphfres, Donald Gruber, and Nathan Cook for their assistance in collecting benthic samples during this study. Benjamin Sandford provided advice on the statistical analysis of the data. We thank Robert Hoffman for reviewing the manuscript. We appreciate the cooperation of the operators of the Wahkiakum County Ferry during our sampling efforts. The U.S. Army Corps of Engineers provided most of the funding for this study.

Literature Cited

Cruze, E., and B. Hartzell. 1991. Minitab reference manual, PC version, release 8. Quickset Inc., Rosemont, Pennsylvania.

Davis, J. S. 1978. Diel activity of benthic crustaceans in the Columbia River estuary. M.S. Thesis, Oregon State Univ., Corvallis. 170 pp.

Hinton, S. A., G. T. McCabe, Jr., and R. L. Emmett. 1995. In-water restoration between Miller Sands and Pillar Rock Island, Columbia River: environmental surveys, 1992-93. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-23. 47 pp.

Holton, R. L., D. L. Higley, M. A. Brzezinski, K. K. Jones, and S. L. Wilson. 1984. Benthic infauna of the Columbia River estuary. Final report on the benthic infauna work unit of the Columbia River Estuary Data Development Program. Oregon State Univ., Corvallis. 179 pp. plus appendices.

Hughes, R. G. 1988. Dispersal by benthic invertebrates: the *in situ* swimming behaviour of the amphipod *Corophium volutator*. J. Mar. Biol. Assoc. United Kingdom 68:565-579.

Kirn, R. A., R. D. Ledgerwood, and A. L. Jensen. 1986. Diet of subyearling chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River estuary and changes effected by the 1980 eruption of Mount St. Helens. Northw. Sci. 60(3):191-196.

Krebs, C. J. 1978. Ecology: the experimental analysis of distribution and abundance. Harper and Row, New York. 678 pp.

McCabe, G. T., Jr., R. L. Emmett, W. D. Muir, and T. H. Blahm. 1986. Utilization of the Columbia River estuary by subyearling chinook salmon. Northw. Sci. 60(2):113-124.

McCabe, G. T., Jr., and S. A. Hinton. 1993. Benthic invertebrates and sediments in vegetated and nonvegetated habitats at three intertidal areas of the Columbia River estuary, 1992. Final Rep. to U.S. Army Corps of Eng. by U.S. Natl. Mar. Fish. Serv., Seattle, Washington. 37 pp.

McCabe, G. T., Jr., W. D. Muir, R. L. Emmett, and J. T. Durkin. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary. Fish. Bull., U.S. 81(4):815-826.

Morton, J. W. 1977. Ecological effects of dredging and dredge spoil disposal: a literature review. U.S. Fish Wildl. Serv. Tech. Pap. 94. 33 pp.

Muir, W. D. 1990. Macroinvertebrate drift abundance below Bonneville Dam and its relation to juvenile salmonid food habits. M.S. Thesis, Portland State Univ., Portland, Oregon. 40 pp.

Muir, W. D., and R. L. Emmett. 1988. Food habits of migrating salmonid smolts passing Bonneville Dam in the Columbia River, 1984. Regul. Rivers: Res. and Manage. 2:1-10.

Muir, W. D., R. L. Emmett, and R. J. McConnell. 1988. Diet of juvenile and subadult white sturgeon in the lower Columbia River and its estuary. Calif. Fish and Game 74(1):49-54.

Received 28 October 1997
Accepted for publication 2 March 1998

Underwood, A. J. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. J. Exp. Mar. Biol. Ecol. 161:145-178.

U.S. Army Corps of Engineers. 1992. Westport, Oregon-Puget Island, Washington, Wahkiakum County Ferry Channel draft detailed project report, Section 107 study. U.S. Army Corps of Engineers, Portland District, P.O. Box 2946, Portland, Oregon. 33 pp. plus appendices.

Van Dolah, R. F., D. R. Calder, and D. M. Knott. 1984. Effects of dredging and open-water disposal on benthic macroinvertebrates in a South Carolina estuary. Estuaries 7(1):28-37.