Environmental Monitoring of the Manchester Naval Fuel Pier Replacement, Puget Sound, Washington, 1991-1994

CZES

Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by Philip Roni and
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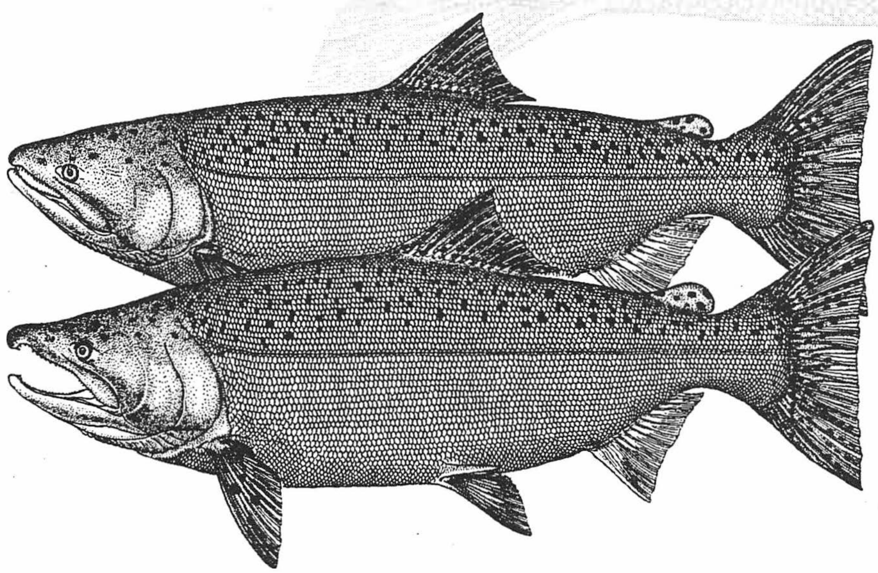
January 1996



ENVIRONMENTAL MONITORING OF THE MANCHESTER NAVAL FUEL PIER REPLACEMENT, PUGET SOUND, WASHINGTON, 1991-1994

by

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and
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Project Completion Report

Funded by
Department of Navy
Naval Facilities Engineering Command
Western Division
(Contract N62474-91-MP-00758)

and

Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
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January 1996

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EXECUTIVE SUMMARY

In February 1991, the Habitat Investigations Program of the Coastal Zone and Estuarine Studies Division, National Marine Fisheries Service, in cooperation with the U.S. Navy, began a monitoring program to assess environmental conditions before, during, and after the replacement of the Manchester Naval Fuel Department (MNFD) pier near Manchester, Washington. The environmental monitoring program was designed to assess the following: 1) pre-construction environmental quality; 2) potential habitat impacts caused by active pier replacement; and 3) subsequent environmental quality, once construction and demolition activities were complete and the new pier was in operation. Water quality, eelgrass (*Zostera marina*) distribution and density, juvenile salmonid migration patterns, and fish abundance were monitored from 1991 to 1994. This final report provides a summary of the fourth year of monitoring (1994), along with a summary and comparison of results from the previous 3 years of monitoring.

Water Quality

Water-quality measurements, including those taken during final dredging, pile driving, and pier demolition, were unexceptional in range and magnitude and indicated no long-term effects of pier replacement activities on dissolved oxygen, salinity, water temperature, or turbidity. The warmer water temperatures observed in 1992, thought to result from the 1992 El Niño-Southern Oscillation (ENSO) event, were not encountered in 1993 or 1994.

Eelgrass

Scuba surveys indicated that the total area covered by eelgrass near the MNFD fuel pier expanded in 1993 and 1994 following removal and replacement of the pier, although the true cause of the expansion of eelgrass cannot be discerned. While the eelgrass bed east of the pier expanded in both 1993 and 1994, reproductive shoot densities for the same period were extremely low compared to 1991 and 1992. Low reproductive shoot densities were also observed elsewhere in Puget Sound during this period. However, eelgrass vegetative shoot densities near the MNFD pier appeared normal and the observed decrease in reproductive shoots is thought to result either from regional changes in environmental conditions or a change in eelgrass reproductive strategy.

Juvenile Salmonid Migrations and Fish Abundance

A variable-mesh beach seine and a shallow-water purse seine were used to monitor juvenile salmonid migration and fish abundance during the expected juvenile salmon outmigration from mid-March to mid-June 1991 to 1993. Spring and summer beach- and purse-seine sampling on both sides and at the seaward end of the fuel pier indicated the presence of migratory juvenile chum, coho, and chinook salmon. Fish size, numbers, and presumed direction of travel suggested fish were successfully migrating underneath the pier, with few fish traveling around the pier. Differential sizes of chum salmon in the beach- and purse-seine catches suggested that larger chum salmon moved offshore, a behavior observed elsewhere for chum salmon.

Compared to catches in 1991 and 1992 before and during pier replacement, beach-seine catches in 1993 after project completion were remarkably similar with respect to average density, species richness, and juvenile salmon density. The largest differences among years resulted from the timing and magnitude of peak fish densities and species numbers. The earlier timing of events in 1992 was thought to result from environmental conditions, such as the warmer water associated with the 1992 ENSO event. The high magnitude of fish density and species richness observed in 1993 compared to 1991 and 1992 may have resulted from both natural and anthropogenic factors. These high densities may partially reflect improved environmental conditions since project completion and the presence of a pier with a more environmentally sensitive design.

The results of 4 years of monitoring suggest that the removal and replacement of the MNFD pier has had little effect on water quality, fish abundance, and fish migration within the project vicinity. However, additional monitoring is required to differentiate between natural variation and anthropogenic changes in both eelgrass and fish populations.

INTRODUCTION

The Manchester Naval Fuel Department (MNFD) has been receiving, storing, and supplying various types of petroleum products to military fleet units and for shore activities in the Pacific Northwest since World War II. Because of the generally poor condition and outmoded design of the MNFD fuel pier, it was replaced in 1993 with a new pier of comparable length. The pier replacement project involved dredging approximately 60,000 cubic meters of material from the site of the new pier, construction of a 390-m fuel pier, and demolition of the old pier. Pier replacement was completed by March 1993; the new fuel pier has been installed and is fully operational, and the old pier has been removed.

In February 1991, the Habitat Investigations Program of the Coastal Zone and Estuarine Studies (CZES) Division, National Marine Fisheries Service (NMFS), in cooperation with the U.S. Navy, began a monitoring program to assess environmental conditions before, during, and after fuel pier replacement. The MNFD fuel pier replacement environmental monitoring program was designed to assess the following: 1) pre-construction environmental quality; 2) potential habitat impacts caused by active pier replacement; and 3) subsequent environmental quality, once construction and demolition activities were complete and the new pier was in operation. Water quality, eelgrass (*Zostera marina*) distribution and density, juvenile salmonid migration patterns, and fish abundance were monitored from 1991 to 1994. In addition, purse seining was conducted in 1993 to monitor movements of juvenile chum salmon with respect to the fuel pier. Results of the first 3 years of monitoring were reported by Dey (1991), Weitkamp and Dey (1993) and Weitkamp (1994). This final report provides a summary of the fourth year of monitoring (1994), along with a summary and comparison of results from the previous 3 years of monitoring.

METHODS

Study Site

The MNFD is located on 95 hectares (234 acres) of land at Orchard Point in southern Kitsap County, 11 km (7 miles) west of Seattle and 18 km (11 miles) east of Bremerton, Washington (Fig. 1). The site is bounded by rural lands to the west, by Puget Sound and Rich Passage to the east and north, respectively, and by residential property and the town of Manchester to the south. The MNFD is the largest U.S. military underground fuel-storage facility in the continental United States, with 50 concrete or steel tanks (34 underground and 16 above) and a storage capacity of 281,000 m^3 (74.3 million gallons). Barges, tankers, combat support ships, and other vessels dock and unload or take on fuel at the completed pier.

Water Quality

Water temperature (°C), dissolved oxygen (DO) (mg L^{-1}), salinity (ppt), and turbidity in Nephelometric Turbidity Units (NTU) were monitored at six stations along two transects parallel to each side of the old and new piers (Dey 1991) (Fig. 2). An additional station, located 1.6 km south of the project site, was also sampled as a control to determine background (ambient) conditions. At each station, each water-quality parameter was measured at the surface, mid-depth, and bottom. Water temperature, DO, and salinity were measured in situ using either a Martek Mark XV Water Quality Data Logging System[1], or a

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

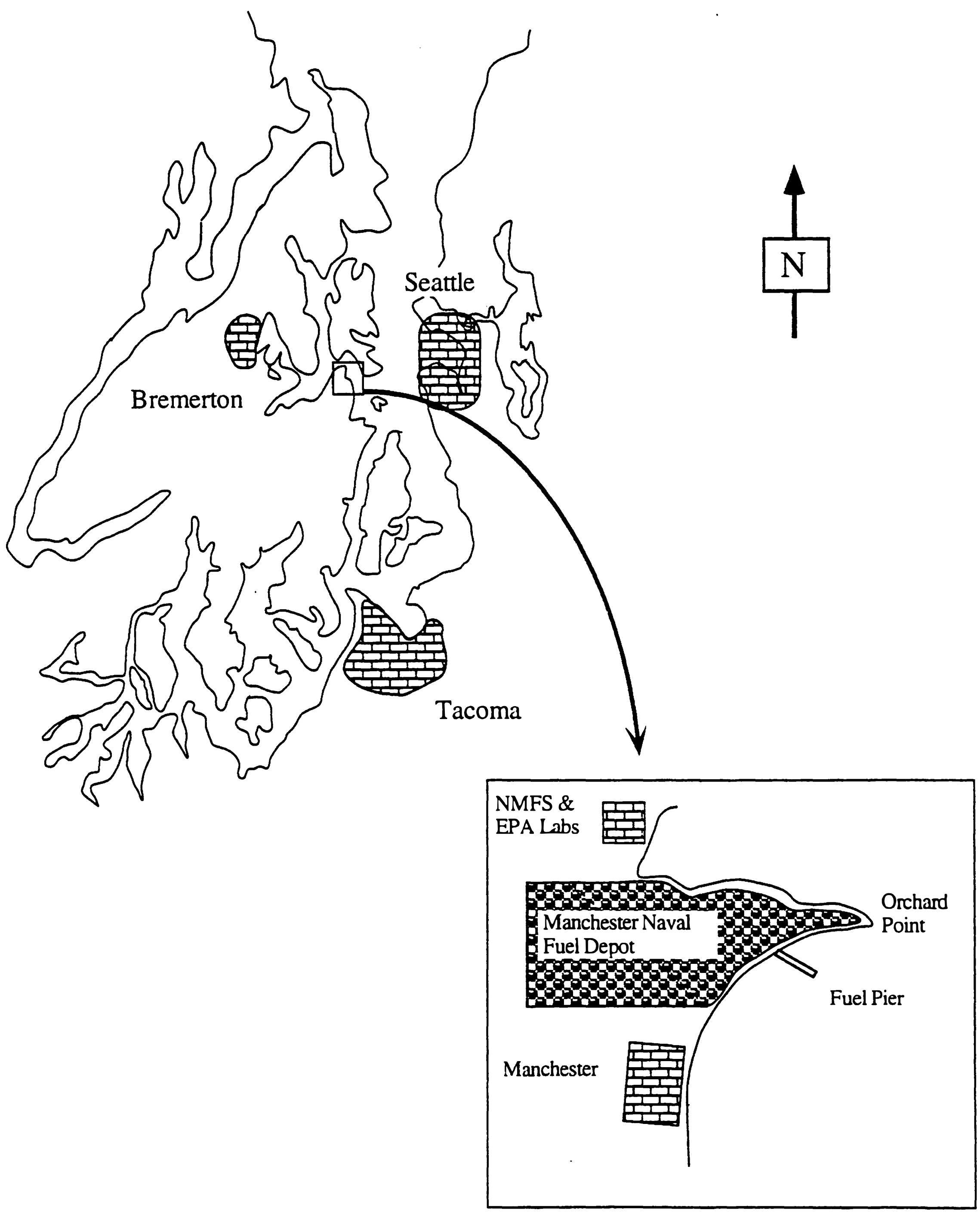

Figure 1. Location of the Manchester Naval Fuel Department fuel pier on Puget Sound.

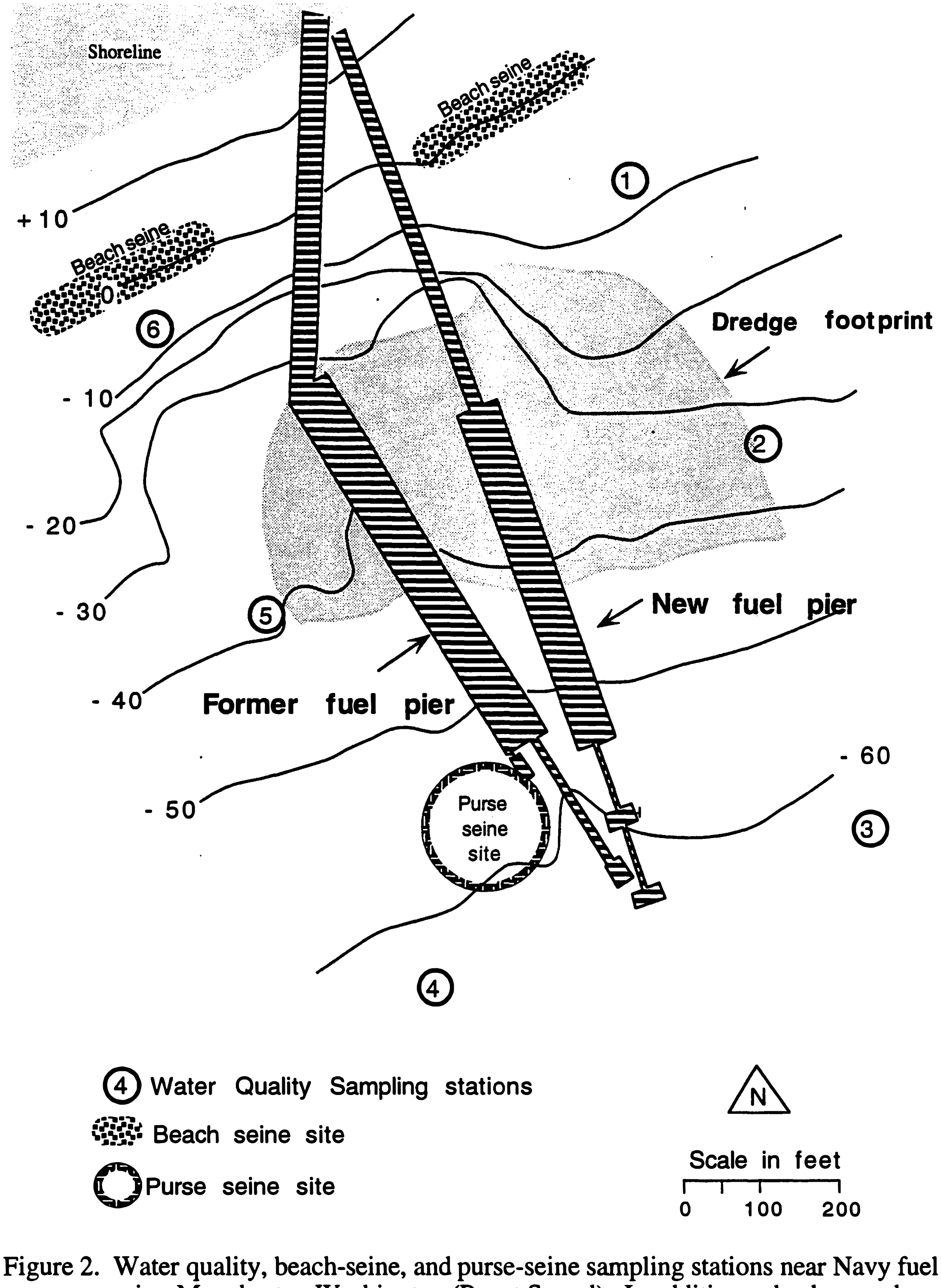

Figure 2. Water quality, beach-seine, and purse-seine sampling stations near Navy fuel pier, Manchester, Washington (Puget Sound). In addition, a background station (Station 7) for water quality and purse seining was established about 1.6 km south of the fuel pier. The position of the former fuel pier is included for clarity. Contour lines are in feet above (+) or below (-) mean lower low water.

YSI SCT salinity meter. Niskin bottles were used to collect water samples at each depth, and turbidity measurements were made with an HF Instruments, Model DRT-15 turbidity meter. During dredging and pile-driving operations, water-quality parameters were measured weekly at all seven designated stations. These stations included sites within and outside the authorized dilution zone, which encompasses the area 45.5 m (150 ft) radially and 91 m (300 ft) downcurrent from the point of dredging. Water quality was monitored monthly from February 1991 through August 1994, except during periods of dredging and pile driving, when water quality was monitored on a weekly basis. Additional water-quality measurements were made in conjunction with spring beach-seine and purse-seine sampling (1991-1993 only).

Eelgrass

Scuba divers surveyed eelgrass beds in the vicinity of the fuel piers in February and July 1991-1993, and July 1994. This allowed comparison of eelgrass distributions during the period of inactivity and minimum standing stock (February) with the period of maximum standing stock (July) (Harding and Butler 1979). At both times, divers moved along the perimeter of a contiguous eelgrass bed while an observer in a small boat recorded their position. Flagged buoys positioned at key reference points and a hand-held Global Positioning System (used in July only) aided the determination of diver locations.

July eelgrass density measurements were made during periods of extremely low tides (0.7 m below mean lower low water). Eelgrass densities were measured only on a single large eelgrass bed, which was observed east of the old fuel pier. This large eelgrass bed was bisected by the new fuel pier. The large eelgrass bed was divided into two sampling sections, based on shoot density. The lower-density portion of the eelgrass bed, designated Area 1, was located immediately west of the new fuel pier (Fig. 3). The high-density area, designated Area 2, extended east of the new fuel pier (Fig. 3). Areas 1 and 2 were divided into uniform sections with each section assigned a unique number. Section numbers were selected randomly for sampling and a 1-m^2 quadrat frame was used to determine reproductive eelgrass-shoot density within each selected section. The densities at 30 quadrats from each of the two areas were used to calculate mean reproductive shoot density.

Juvenile Salmonid Migrations and Fish Abundance

Migration and abundance studies were conducted from 15 March to 15 June 1991, 15 March to 17 June in 1992, and 16 March to 29 July 1993, during the expected juvenile salmon outmigration. No sampling of fish abundance was conducted in 1994. Two types of nets were used to sample fishes: a 50-m variable-mesh beach seine (19.0, 12.7, and knotless 9.5 mm bunt) (Sims and Johnsen 1974), and a shallow-water purse seine (17-mm mesh body and 13-mm mesh bunt, both knotless). The purse seine was used only in 1993, while beach seining was conducted during all 3 years.

The beach-seine samples were used to determine species composition of the fish assemblage and to estimate juvenile salmonid abundance in the nearshore area of the fuel pier. The purse-seine samples were used to supplement beach-seine results by determining the abundance of juvenile chum salmon and other fishes in the deep water near the seaward end of the fuel pier and in comparably deep water at the control site. The intent was to determine the influence of the pier on fish densities. This comparison was also used to determine whether juvenile chum salmon were migrating around the seaward end of the pier

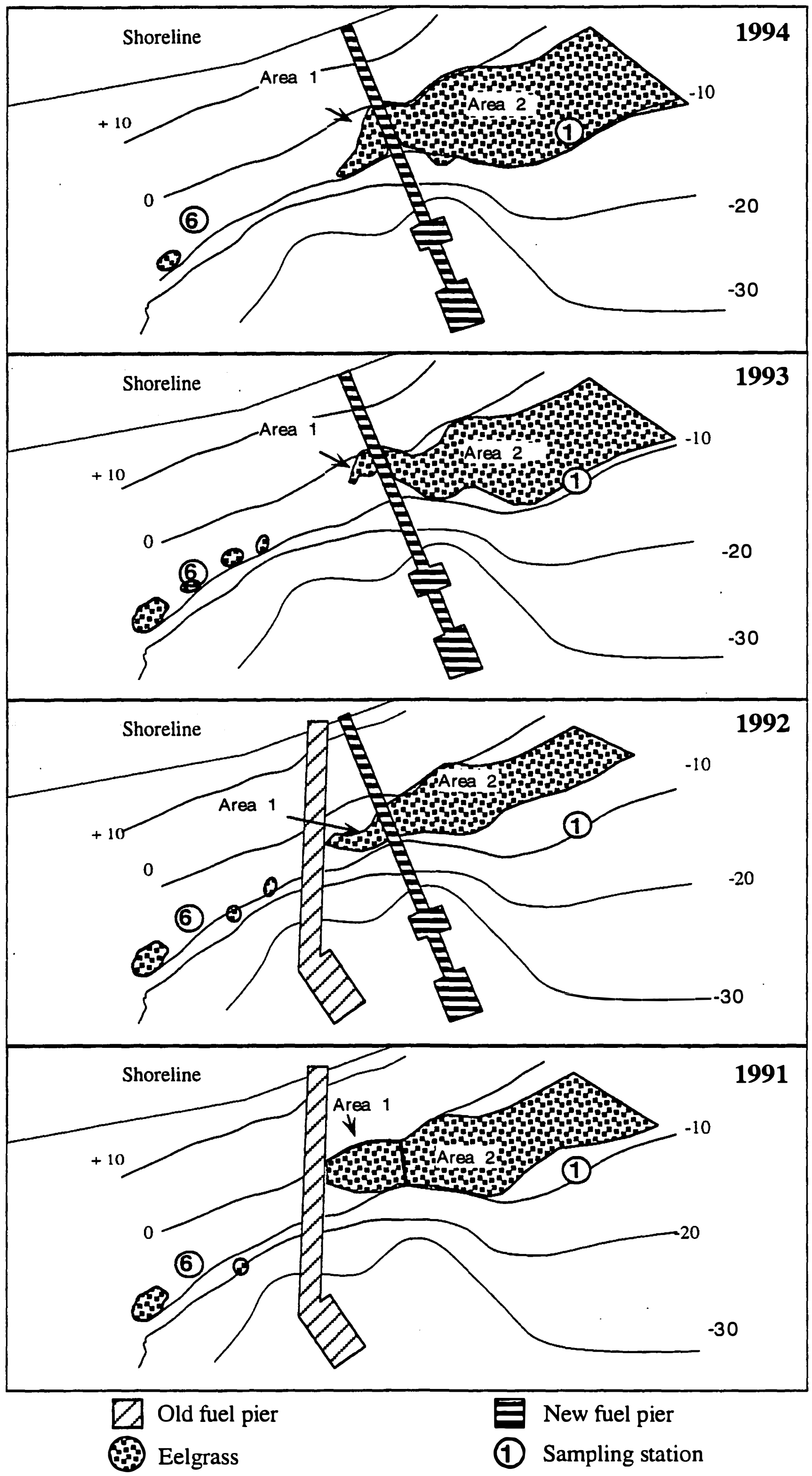

Figure 3. Approximate distribution of eelgrass near Navy fuel piers, Manchester, Washington (Puget Sound) 1991 through 1994. The presence of the old and new fuel pier during each survey is indicated. Sampling areas 1 and 2 are indicated. Contour lines are in feet above (+) or below (-) mean lower low water.

(densities higher near the pier than away from the pier), swimming underneath the pier, or following other migratory patterns (densities similar near and away from the pier).

Beach seining in 1993 was conducted biweekly from 16 March through 3 May and from 29 June through 29 July, and weekly from 3 May through June 29. This sampling period was longer than that in 1991 and 1992 because of the later juvenile chum salmon migration and the continued occurrence of chum salmon in the beach-seine catches.

On each sampling date, beach-seine sets were made on each side of the fuel pier near Stations 1 and 6 (Fig. 2). One end of the seine was anchored on the beach, and the net was extended by a small boat in a straight line directly offshore next to and approximately parallel to the pier. The free end of the net was then pulled in a wide arc away from the pier and back toward the shore and onto the beach. Beginning in mid-May 1993, beach-seine sets were shortened because of the large number of fish caught and the increased mortality that occurred while processing the large numbers of fish. Shortened sets were identical to the normal sets described above, except that the arc described by the net intersected the beach approximately 35 m (short set) or 20 m (extra short set) from the anchor, as opposed to intersecting the beach approximately 50 m from the anchor for a regular set.

The purse seine was fished approximately biweekly from 16 March to 14 June 1993, always within a day of beach seining. On each purse-seine sampling day, the net was fished as near as possible to the southwest corner of the fuel pier between Stations 4 and 5 (designated Station 4/5) (Fig. 2), and at the background station (Station 7). At both purse-seining locations, water depth was approximately 20 m. The purse seine was deployed using a round-haul technique wherein the net was initially stacked on the stern of an 8-m boat while a 5-m skiff pulled it off into the water. Both boats traveled in a wide arc in opposite directions, until the net was fully extended. The net was then closed (pursed) and fishes were forced into the bunt and collected from the bunt before pulling the net back onto the 8-m boat.

All fish collected by both net types were identified and counted: a subsample (n = 30, when possible) was anesthetized in benzocaine (ethyl-*p*-aminobenzoate) or tricaine methanesulfonate (MS-222) and measured for total length (mm), fork length (mm) (salmonids only), and weight (g). All juvenile salmonids were examined for fin clips or other distinguishing marks.

Using the estimated effective sampling area of the beach seine (1,270 m^2 for the regular set and 1,045 m^2 for the short set or 849 m^2 for the extra short set) and purse seine (795 m^2), densities were calculated and expressed as number of fish per hectare (ha = 10,000 m^2). In addition, two community structure indices were calculated for each sampling effort. The Shannon-Wiener Index (H) contains two components of diversity: number of species and evenness of individuals among species (Krebs 1978), and was calculated using the expression:

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

where P_i is the proportion of the *i*th species (i.e., n_i/N where n_i is the number of individuals of the *i*th species and N is the total number of individuals in the sample), and *s* is the number of species. A greater number of species, or a more even or equitable distribution of individuals among species, increases species diversity as measured by this function.

The second community structure index, Species Evenness (J), measures the proportional abundances among the various species in a sample (Pielou 1966). The value for

J has a range of 0.0 to 1.0, with 1.0 indicating that all species in the sample are numerically equal, and was calculated using the following expression:

$$J = \frac{H}{\log_2(s)}$$

where H is the Shannon-Wiener Index and s is the number of species.

RESULTS

Part 1 - 1994 Results

Water Quality

Sampling in 1994 occurred monthly from January to May and in August. Since the MNFD was completed in March 1993, the following water quality data represent post-construction conditions. Date, time, location, and depth for each routine measurement of dissolved oxygen (DO), salinity, water temperature, and turbidity for 1994 are presented in Appendix tables A1-A6.

Dissolved Oxygen

Dissolved oxygen measured at all depths (0 to 20 m) and sites, ranged from 7.2 to 9.2 mg L^{-1} (Appendix tables A1-A6) for 3 months in 1994 for which data were available. Meter malfunctions prevented measurements in April, May, and August 1994. Variation in DO among sites and depths in February and March was less than 0.2 mg L^{-1}, but greater than 1.0 mg L^{-1} on 10 January 1994. The DO concentrations at the surface were also higher than subsurface samples on this date. This may have resulted from slightly lower surface salinity.

Salinity

Salinity ranged from 29.4 to 33.5 ppt at all stations and was relatively constant at all sites and depths on a given date (Appendix tables A1-A6). A difference in surface and subsurface salinity of 2-3 ppt was observed at two sites on 10 January 1994. Rainfall during sampling may have resulted in lower surface salinity on this date.

Water Temperature

Water temperature displayed the expected seasonal trend, with the lowest average temperature in February (8.3 °C) and the highest in August (14.0 °C). Water temperature differences among samples were less than 0.5 °C from January through May and exhibited little variation in temperature by sample depth. August water temperature decreased slightly (< 1.8 °C) by depth, primarily at the deepest stations (Station 3 and 4). Unfortunately, the lack of data from 1 June through 30 July inhibited the detection of a clear seasonal trend in 1994 water temperatures.

Turbidity

Turbidity ranged from an average of 0.24 NTU (April) to 1.32 NTU (January) in 1994. No turbidity measurements were obtained in August. Variation in turbidity among stations on a given date was less than 0.8 NTU.

Eelgrass

Results of the July 1994 scuba surveys for eelgrass indicated that the large eelgrass bed (Area 2) east of the new pier continued to expand (Fig. 3). Both Area 1 (eelgrass bed west of new pier) and Area 2 expanded seaward. Area 1 expanded from approximately

150 m^2 in 1993 to approximately 420 m^2 in 1994, and Area 2 from approximately 7,600 m^2 in 1993 to 7,900 m^2 1994. Only one small patch approximately 24 m^2 was observed further east of the pier, compared to four similar patches in 1993.

July measurements of eelgrass reproductive shoot densities west of the new pier (Area 1) averaged 3.0 shoots m^{-2}, and ranged from 0 to 11 shoots m^{-2}. In Area 2, the high-density section east of the fuel pier, reproductive shoot density averaged 2.1 shoots m^{-2}, and ranged from 0 to 10 shoots m^{-2}.

Part 2 - Interannual Comparison (1991-1994)

Dredging, pile driving, and construction at the MNFD occurred from mid-February 1991 until March 1993. Water quality samples were taken only once before dredging (15 February 1991), and final dredging and pile driving was completed before the 24 February 1993 sampling effort. Washington State Department of Fish and Wildlife regulations did not allow dredging, pile driving and in-water construction from 15 February through 15 June. The following sections compare the results of water quality and fisheries data collected over the 4-year period. Water quality and fisheries field data collected on each date, station, and depth for 1991-1993 are provided Dey (1991), Weitkamp and Dey (1993), and Weitkamp (1994), while 1994 water quality data are provided in Appendix tables A1-A6.

Water Quality

Dissolved Oxygen

Throughout 4 years of sampling, dissolved oxygen, measured at all depths (0 to 20 m), ranged from 7 to 12 mg L^{-1}. Little variation in DO existed among sites on a given date.

Dissolved oxygen was not measured during in-water construction activity in 1993, or after March 1994 because of meter malfunctions. During dredging, DO concentrations within the dilution zone (area within 45.5 m radially and 91 m downcurrent of dredge point) were not detectably different from concentrations outside the dilution zone or at the background station (Station 7, 1 mile south of the pier). Highest average DO concentrations often occurred from January to March (Fig. 4). However, the absence of DO measurements for some months and the considerable interannual variation inhibited the detection of a seasonal trend.

Salinity

Salinity ranged from 24 to 33.5 ppt at all stations from 1991 to 1994. Salinity measurements from 1991 to 1993 were less than 30 ppt, while 1994 measurements were often in excess of 30 ppt (Appendix tables A1-A6). On all sampling days during construction and dredging activities (1991-1993), average salinity at the construction site was within 0.5 ppt of the salinity at Station 7, the control station.

Water Temperature

Water temperature displayed the expected seasonal trend, with the lowest temperatures in February and highest temperatures in August (Fig. 5). Water temperature differences at construction and control stations were generally less than 0.5 °C throughout the study, with the largest variation resulting from sampling depth.

Turbidity

During in-water construction, including dredging and pile driving from February 1991 to January 1993, turbidity at all depths (0 to 20 m) nearest the construction activity was

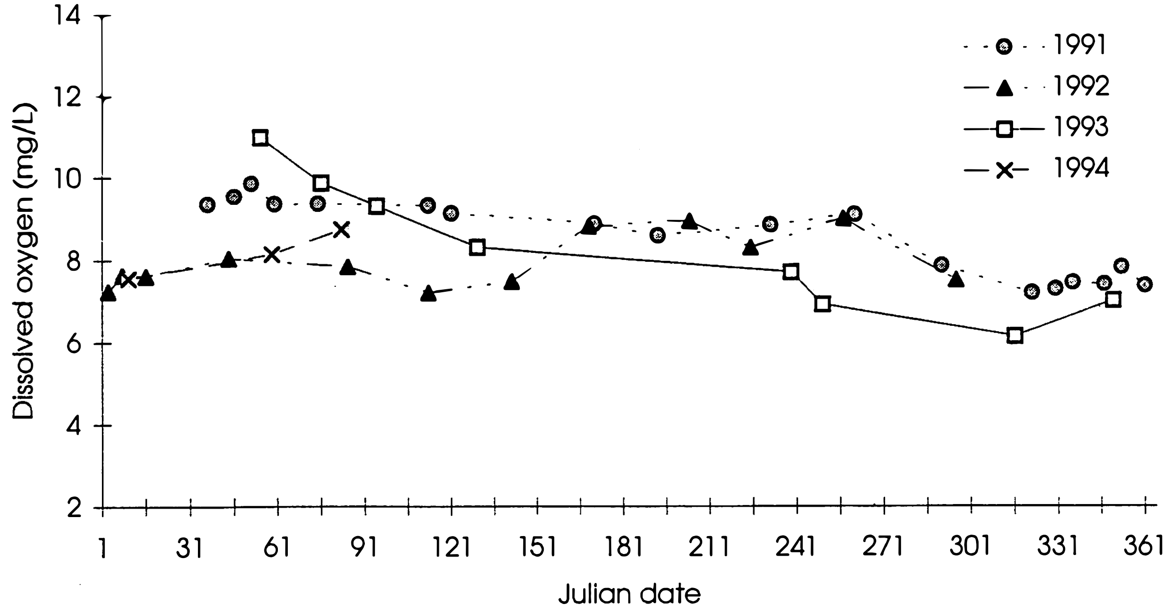

Figure 4. Dissolved oxygen concentration at Manchester, Washington (Puget Sound)all stations combined 1991-1994.

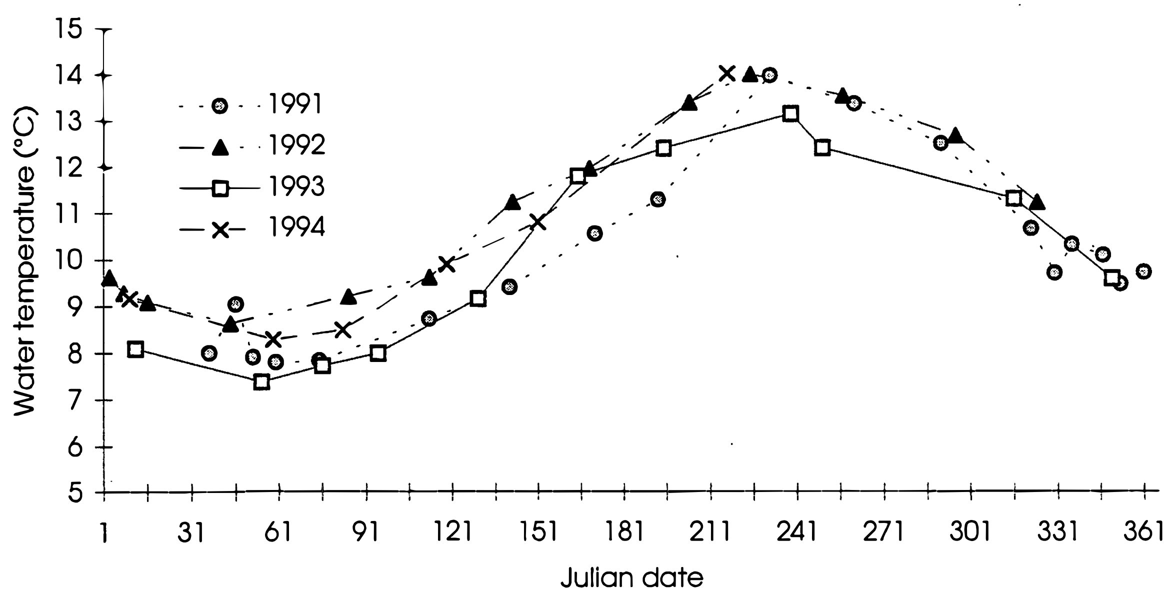

Figure 5. Mean water temperature (°C) 1991-1994 at Manchester, Washington (Puget Sound) all stations combined.

typically between 0.2 and 1.5 NTU, less than 1 NTU higher than at all other stations. However, turbidity occasionally exceeded the level of the background station (Station 7) during dredging in 1991. On two occasions, turbidity at a single station and depth exceeded the level at the background station by 2-3 NTU in 1991. On two different occasions (both in 1991), turbidity at 20 m depth at one station exceeded levels at the background station by 17-25 NTU. Based on measurements from Station 7, background turbidity was generally between 0.2 and 2.0 NTU from 1991 to 1994.

Eelgrass

Results of the scuba surveys for eelgrass indicate that the eelgrass bed declined in size during initial dredging and construction activities in 1991 and 1992, but expanded in 1993 and 1994 (Fig. 3, Table 1). The total approximate area covered by eelgrass increased from 5,800 m^2 in 1992 to 7,900 m^2 in 1994. The low-density area of eelgrass west of the new pier (Area 1) has continued to recover following completion of the pier and removal of the old pier. Area 1 encompassed approximately 420 m^2 in 1994, compared to 550, 330, and 150 m^2 for 1991, 1992 and 1993, respectively.

July measurements of eelgrass reproductive shoot densities were highly variable over the 4 year period, ranging from an average of 2.1 m^{-2} to 14.9 m^{-2} for Area 2 and 0.1 m^{-2} to 4.4 m^{-2} for Area 1. Reproductive shoot densities declined from 1991 to 1993, but recovered slightly or stayed the same in 1994 (Table 1). Vegetative shoot densities increased from 124.4 shoots m^{-2} in 1993 to 524 shoots m^{-2} in 1994, but were not recorded in 1991 or 1992.

Table 1. Estimated total area, reproductive shoot densities, and vegetative shoot densities of eelgrass beds within 150 m of Navy fuel pier 1991 -1994.

Year	Estimated Area (m^2)	Reproductive Shoots m^{-2} Area 1	Reproductive Shoots m^{-2} Area 2	Vegetative Shoots m^{-2} Area 2 only
1991	7,700	4.4	14.9	NA
1992	5,800	2.9	12.3	NA
1993	7,600	0.1	2.1	124.4
1994	7,900	3.0	2.1	524.0

Juvenile Salmonid Migrations and Fish Abundance

Differences in sampling intensity and frequency made statistical comparison of fish density and abundance data among years difficult. The data were, however, examined for annual and interannual trends in fish abundance and diversity.

Forty-two different fish species were collected from mid-March to late July 1991, 1992 and 1993. Of these 42 species, 40 were observed in 1993 while only 27 different species were collected in 1991 and 1992 (Table 2). Ten fish species collected in 1993 were not observed in either 1991 or 1992; however, 24 surveys were conducted in 1993 (15 beach seine and 9 purse seine) compared to 7 and 8 surveys in 1992 and 1991, respectively. The differences in sampling frequency and intensity among years may explain the differences in the number of species.

Most fish collected throughout the study were typical of Puget Sound intertidal beaches (Miller et al. 1975, Wingert and Miller 1979, Borton 1982). Five species of salmonids were collected including juvenile chum (*Oncorhynchus keta*), coho (*O. kisutch*), and chinook (*O. tshawytscha*) salmon and juvenile cutthroat trout (*O. clarki*) and steelhead (*O. mykiss*). In 1993, steelhead were captured only with the purse seine. The families Embiotocidae (surfperches), Pholidae (gunnels), and Pleuronectidae (righteye flounders) were each represented by three or more species, while the family Cottidae (sculpins) were represented by between four and nine species each year.

Juvenile chum salmon were the most frequently captured fish species for all 3 years and both gear types. Pacific staghorn sculpin (*Leptocottus armatus*), shiner perch (*Cymatogaster aggregata*), English sole (*Parophrys vetulus*), and juvenile chinook salmon

Table 2. Fish species caught by beach seine near Navy fuel pier, Manchester, Washington (Puget Sound), 1991-1993.[1]

Family Scientific name	Common name	Total number captured 1991	 1992	 1993
Rajidae				
Raja binoculata	big skate	0	0	2
Clupeidae				
Clupea pallasi	Pacific herring	1	0	12
Salmonidae				
Oncorhynchus clarki	cutthroat trout	12	10	12
Oncorhynchus keta	chum salmon	1,108	1,300	1,394
Oncorhynchus kisutch	coho salmon	254	28	11
Oncorhynchus mykiss	steelhead trout	2	3	0
Oncorhynchus tshawytscha	chinook salmon	351	784	124
Osmeridae				
Hypomesus pretiosus	surf smelt	0	10	315
Gadidae				
Meluccius productus	Pacific hake	5	1	0
Microgadus proximus	Pacific tomcod	0	0	152
Gasterosteidae				
Aulorhynchus flavidus	tube-snout	2	0	27
Gasterosteus aculeatus	threespine stickleback	1	4	3
Syngnathidae				
Syngnathus griseolineatus	bay pipefish	4	1	48
Hexagrammidae				
Hexagrammos decagrammus	kelp greenling	36	6	72
Cottidae				
Artedius fenestralis	padded sculpin	2	0	2
Clinocottus acuticeps	sharpnose sculpin	6	1	0

Table 2. Continued.

Family *Scientific name*	Common name	Total number captured 1991	1992	1993
Enophrys bison	buffalo sculpin	9	2	9
Hemilepidotus hemilepidotus	red Irish lord	0	0	11
Leptocottus armatus	Pacific staghorn sculpin	283	147	789
Myoxocephalus polyacanthocephalus	great sculpin	0	0	1
Nautichthys oculofasciatus	sailfin sculpin	0	1	4
Oligocottus maculosus	tidepool sculpin	0	0	3
Rhamphocottus richardsoni	grunt sculpin	0	0	1
Ruscarius meanyi	Puget Sound sculpin	0	0	1
Agonidae				
Agonus acipenserinus	sturgeon poacher	1	2	4
Cyclopteridae				
Liparis florae	tidepool snailfish	0	0	1
Embiotocidae				
Cymatogaster aggregata	shiner perch	386	176	773
Embiotoca lateralis	striped seaperch	19	7	103
Rhacochilus vacca	pile perch	11	11	39
Stichaeidae				
Lumpenus sagitta	snake prickleback	2	2	8
Xiphister atropurpureus	black prickleback	1	0	0
Pholidae				
Apodichthys flavidus	penpoint gunnel	3	66	53
Pholis laeta	crescent gunnel	0	2	10
Pholis ornata	saddleback gunnel	19	189	51
Ammodytidae				
Ammodytes hexapterus	Pacific sand lance	7	3	10,049

Table 2. Continued.

Family *Scientific name*	Common name	Total number captured 1991	 1992	 1993
Bothidae				
Citharichthys stigmaeus	speckled sanddab	0	0	644
Pleuronectidae				
Lepidopsetta bilineata	rock sole	10	103	63
Parophrys vetulus	English sole	169	43	287
Platichthys stellatus	starry flounder	19	9	24
Pleuronectes isolepis	butter sole	0	0	5
Pleuronichthys coenosus	C-O sole	0	1	10
Psettichthys melanostictus	sand sole	0	0	18

[1] Additional fish caught by purse seine in 1993 included 4 kelp greenling, 373 chum salmon, 36 coho salmon, 3 steelhead trout, 4 chinook salmon, 2 surf smelt, 3 threespine stickleback, and 7 kelp greenling.

were also captured in large numbers. On June 29, 1993, an unusually large number of Pacific sand lance (*Ammodytes hexapterus*) was captured (approximately 10,000). Only small numbers of Pacific sand lance were capture on all other dates. Fish densities at Station 6 (Fig. 2, west of fuel pier) generally exceeded those at Station 1 (Fig. 2, east of fuel pier) in 1991 and 1992, but not in 1993 (Table 3). The total number of species collected was generally higher at Station 1 in 1993, higher at Station 6 in 1992, and about equal at both stations in 1991. Both the density and the total number of species collected increased at both sites from March to July in all 3 years. The total density of fish captured by purse seine was higher at Station 4/5 than at Station 7 (Table 3).

Beach seining conducted from mid-March to late July 1991, 1992, and 1993 generally showed similar trends of increasing fish density and species richness over time, although the specific timing and magnitude of increases varied among years (Figs. 6 and 7). Mean density (average of Stations 1 and 6) peaked earliest in 1992 (27 March), with the next earliest peak in 1993 (8 June) and the latest in 1991 (13 June). The highest mean density was recorded in 1993 with 6,448 fish ha^{-1}, followed by 2,580 fish ha^{-1} in 1991 and 2,544 fish ha^{-1} in 1992 (Fig. 6, Table 4). This excluded a mean density of 50,608 recorded on 29 June 1993, which resulted from the capture of a large (> 10,000 fish) school of sandlance in one seine sample. An increase in the total number of species collected at the two beach-seine stations combined occurred earliest in 1992, followed by 1991 and 1993 (Fig. 7). However, the greatest number of species identified per sampling day between 16 March and 15 June occurred in 1993 (30 species), followed by 1991 and 1992 (27 species each; Table 4).

Despite differences in the timing and magnitude of peaks of abundance, mean values of various parameters were similar among years (Table 4). For example, mean fish

Table 3. Estimated fish density (fish/hectare) for beach and purse seine samples, at Manchester, Washington, 1991-1993.

Approx.	1991		1992		1993		1993 purse seine[2]	
Date[1]	Stat. 1	Stat. 6	Stat. 1	Stat. 6	Stat. 1	Stat. 6	Stat. 4/5	Stat. 7
16 Mar					601	15	0	0
27 Mar	112	32	2,608	2,480	31	8	0	0
5 Apr	814	420	176	1,352	31	154	0	0
24 Apr	1,179	72	592	1,440	15	300	0	13
8 May	294	3,366	1,024	3,016	92	23	13	13
10 May					716	576	13	0
21 May	950	3,076	192	2,048	327	1,539		
25 May	342	1,662			5,067	564	88	315
5 Jun	872	2,662	976	3,496	2,763	1,013		
8 Jun					1,424	11,472	2,709	1,814
15 Jun	236	4,924	936	2,080	6,300	2,008	290	176
22 Jun					2,581	1,166		
29 Jun					4,449	96,766		
14 Jul					1,606	562		
29 Jul					5,259	3,134		

[1] Dates are approximate, sampling dates varied from year to year by 1-5 days.

[2] Purse seining was conducted only in 1993, all other samples were made with a beach seine.

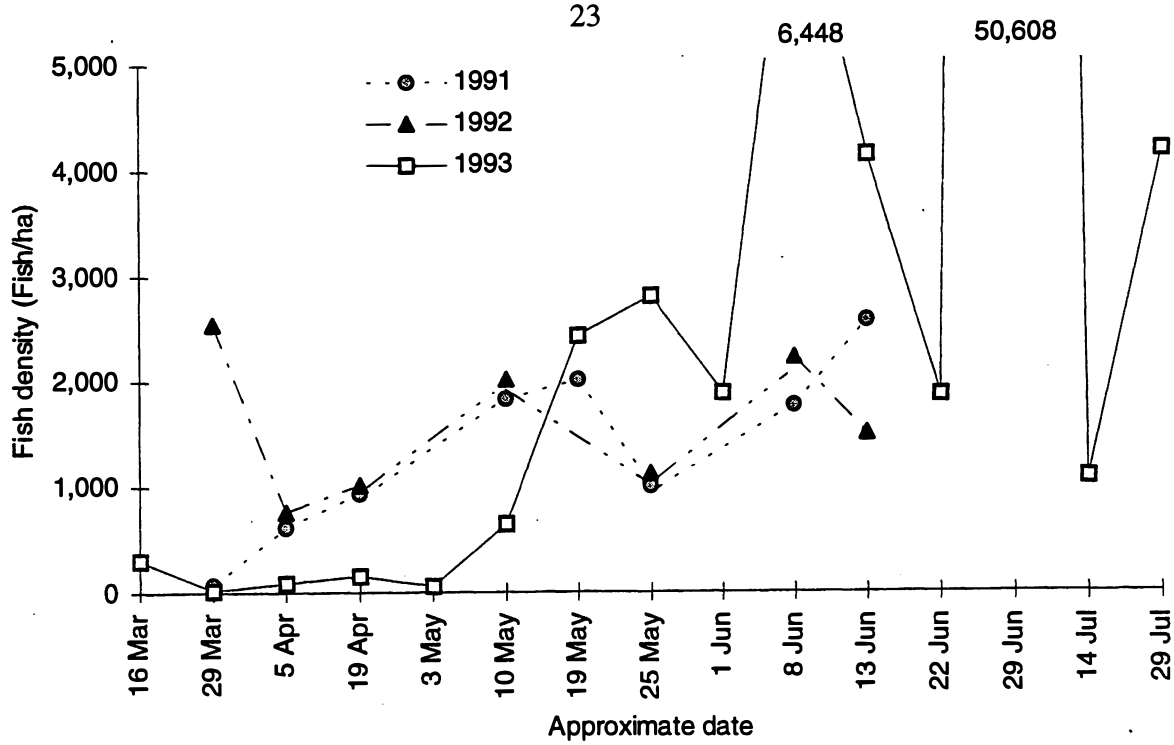

Figure 6. Mean fish density (average of Stations 1 and 6) calculated from beach seine catches, 16 March-29 July in 1991, 1992, and 1993, Manchester, Washington (Puget Sound).

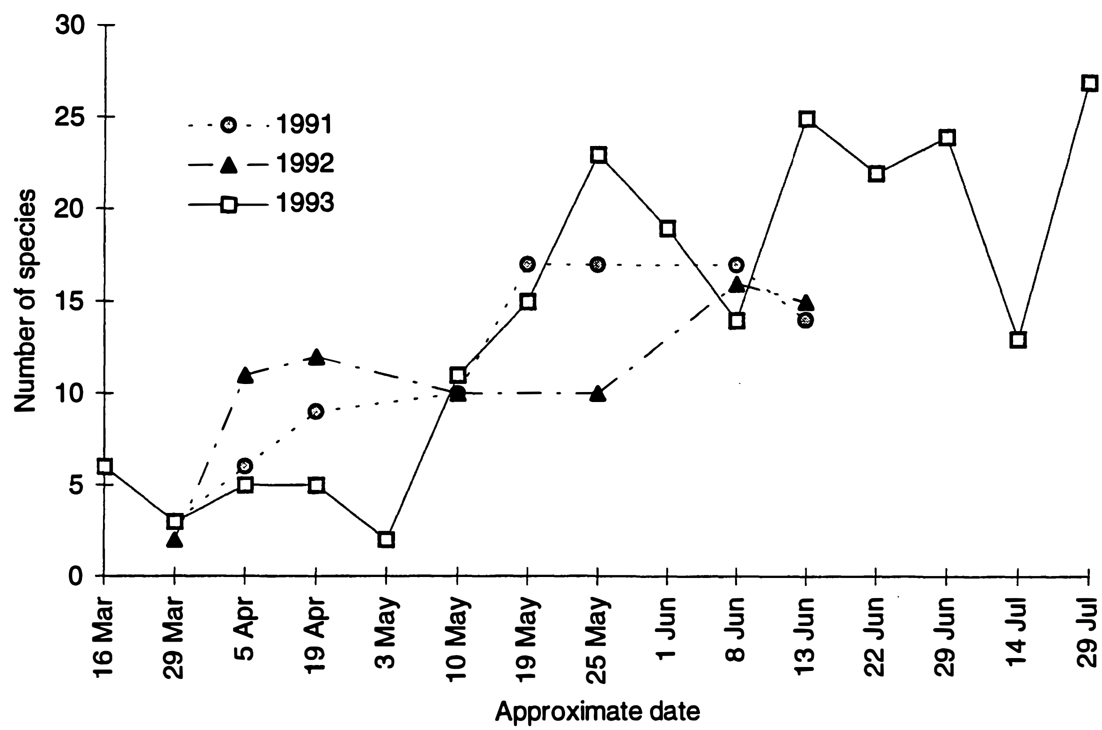

Figure 7. Number of fish species identified (Stations 1 and 6 combined) in beach seine catches 16 March - 29 July in 1991, 1992, and 1993, Manchester, Washington.

Table 4. A comparison of fish results among years, for catches between 16 March and 13 June. Mean values are the average of Station 1 and 6 values.

	1991	1992	1993
Mean fish density (fish ha^{-1}) averaged over 16 March-13 June	1,352	1,601	1,790
Peak fish density (fish ha^{-1})[a]	2,580 (13 June)	2,544 (27 March)	6,448 (8 June)
Total number of species	27	27	30
Mean number of species averaged over 16 March-13 June	11.6	10.9	11.6
Mean chum salmon density (fish ha^{-1}) averaged over 16 March-13 June	547	743	587
Peak chum salmon density (fish ha^{-1})[a]	1,643 (9 May)	2,540 (27 March)	4,723 (8 June)
Mean Shannon-Wiener Index of Species Diversity (H) averaged over 16 March-13 June	1.54	1.35	1.34
Mean Species Evenness (J) averaged over 16 March-13 June	0.58	0.42	0.47

[a] average of stations 1 and 6 for each date

densities (average of Stations 1 and 6) between 16 March and 13 June averaged 1,352, 1,601, and 1,790 fish ha^{-1} in 1991, 1992, and 1993, respectively. The average number of species and the average Shannon-Wiener and Species Evenness Indices for the period were also similar among years (Table 4). In general, the Shannon-Wiener Index (H'), which is a relative measure of both species diversity and equitable distribution of species, increased from March through June in all 3 years (Fig. 8). The Species Evenness Index (J'), which measures the proportional abundance of various species in the sample, varied considerably over the sampling period and showed no distinct trend (Fig. 9).

Differences in density among years were more pronounced for chum salmon than for all species combined (Figs. 6 and 10). This was primarily due to a distinct peak in chum salmon density along with considerable interannual variation in the timing and magnitude of chum salmon catches. Chum salmon density (average of Stations 1 and 6) peaked early in 1992, on 27 March (2,540 fish ha^{-1}), but did not peak until 9 May in 1991 (1,643 fish ha^{-1}) and 8 June in 1993 (4,723 fish ha^{-1})(Table 4). The average chum salmon density for the entire 1992 sampling period was higher (743 fish ha^{-1}) than for either the 1991 (547 fish ha^{-1}) or 1993 periods (587 fish ha^{-1})(Table 4). The mean length of juvenile chum salmon generally increased from March to July during all 3 years sampled (Fig. 11). Differences in mean length between stations occasionally exceeded 10 mm, however, this variation may have resulted from large differences (>tenfold) in sample size. Moreover, chum salmon length did not always increase over time, but this observation may be a product of infrequent sampling or of smaller, later-emerging fish moving into the area sampled. Finally, chum salmon

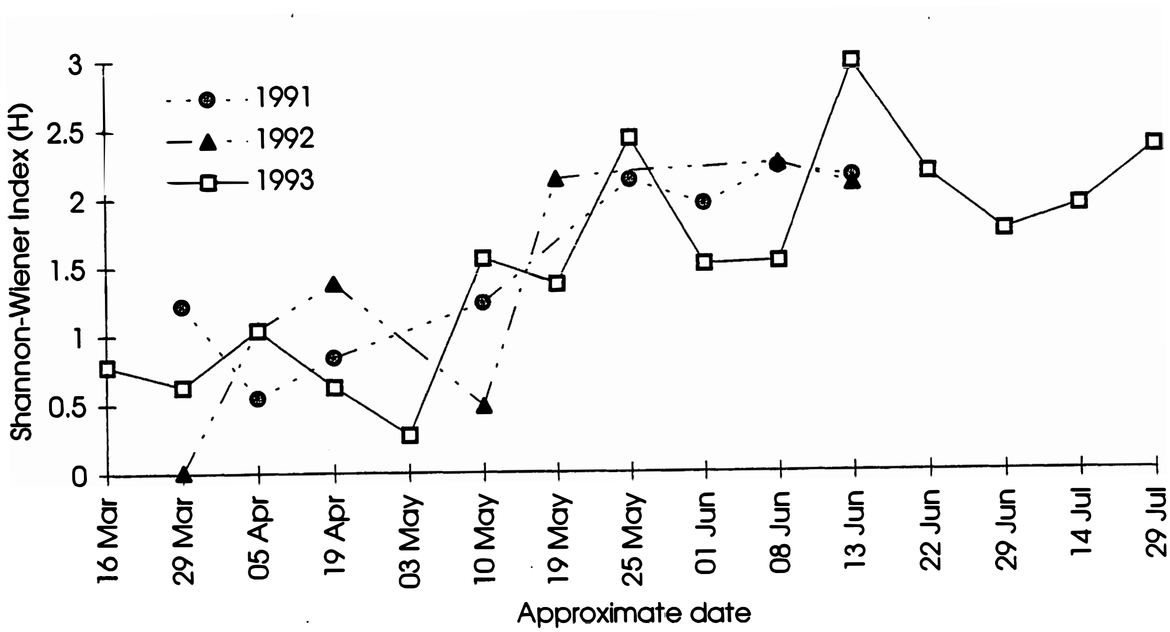

Figure 8. Shannon-Wiener Index (H) for fish captured by beach seine 1991-1993 at Manchester, Washington (Stations 1 and 6 combined).

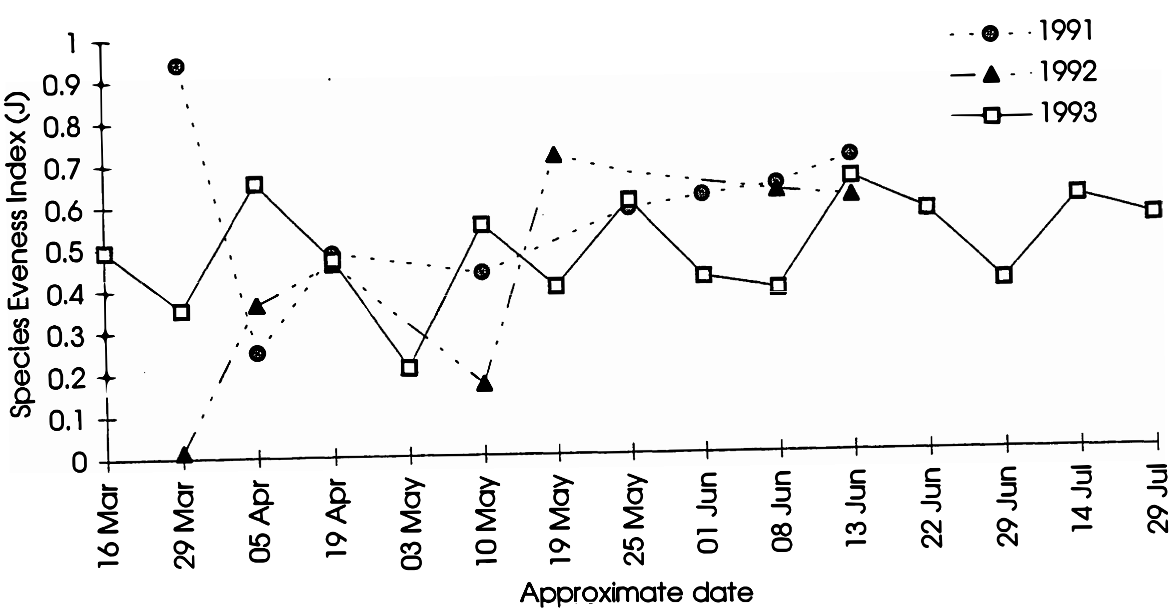

Figure 9. Species Evenness Index (J') for fish captured by beach seine 1991-1993 at Manchester, Washington (Stations 1 and 6 combined).

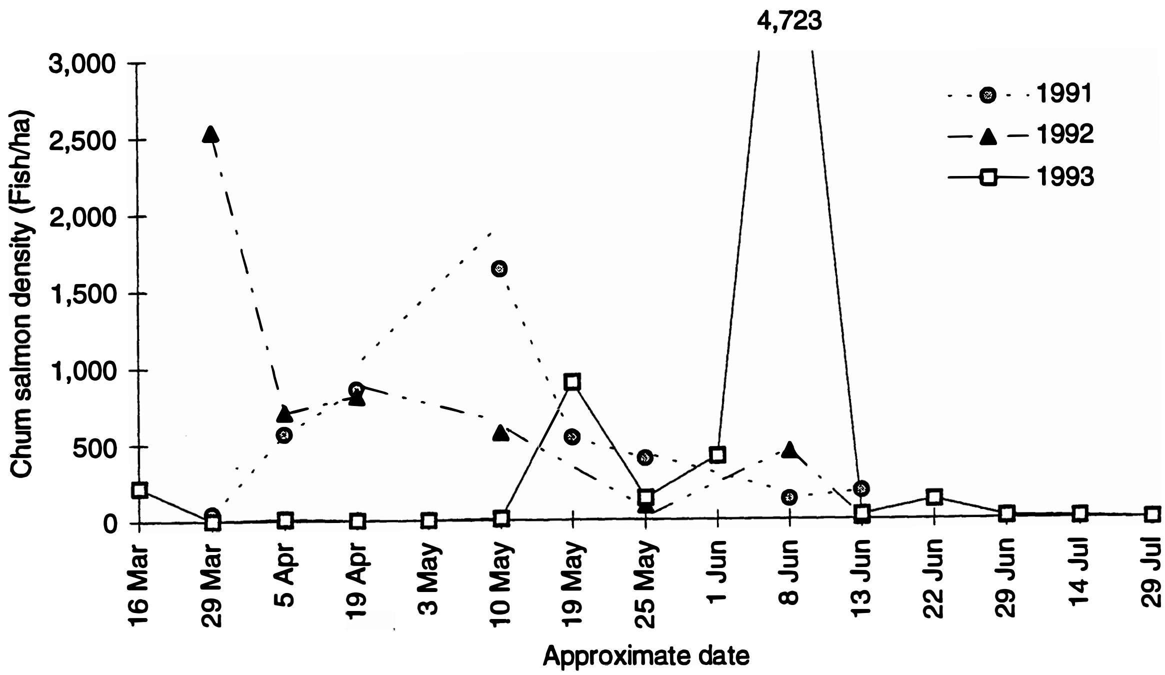

Figure 10. Mean density of juvenile chum salmon (average of Stations 1 and 6) calculated from beach seine samples, 16 March-29 July 1991, 1992, and 1993, Manchester, Washington (Puget Sound).

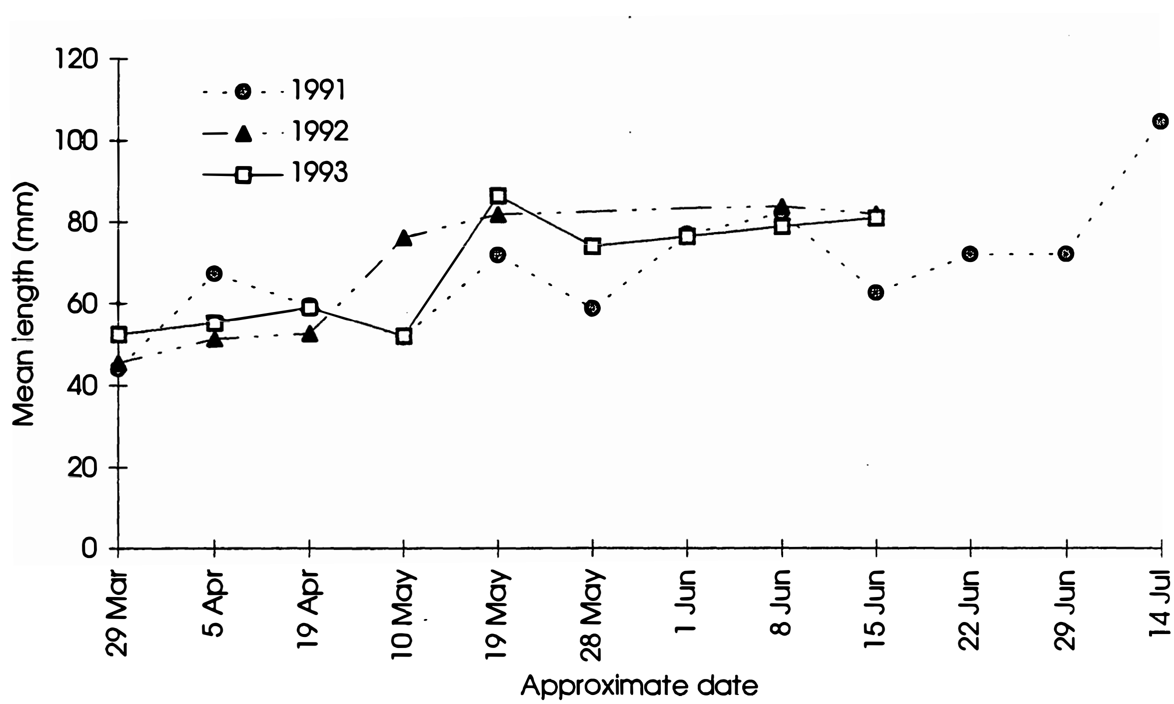

Figure 11. Mean total length (mm) of juvenile chum salmon caught by beach seine (Station 1 and 6 combined) 1991-1993.

captured with the purse seine were consistently larger than fish caught in the beach seine with the exception of one date (11 May 1993) (Fig. 12).

Purse seining in 1993 indicated very little difference between fish catches near or away from the fuel pier. Fish densities peaked simultaneously at the two purse seine stations and were preceded and followed by similarly low fish densities (Table 3). The pattern of species richness was also similar at both stations, with the most species collected in late May and early June. The peak density was slightly higher at Station 4/5 than at Station 7, possibly due in part to the attraction of fish to structures in water, such as piles and piers (Feist 1991). However, the average number of species identified was actually higher at Station 7 (1.1 species per set) than at Station 4/5 (0.9 species per set). No obvious predators of juvenile chum salmon were caught with the purse seine in deep water.

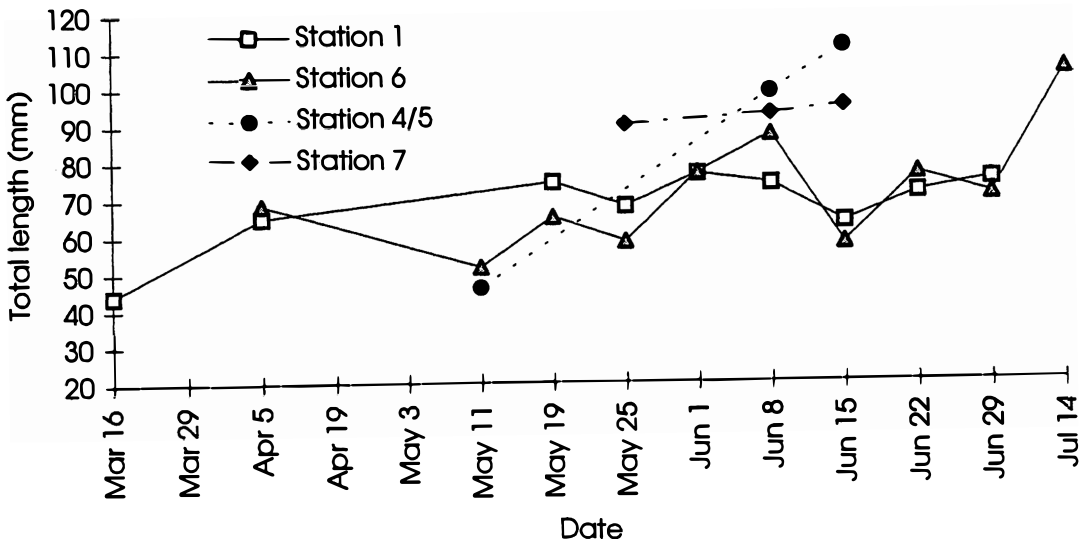

Figure 12. Mean total length (mm) of juvenile chum salmon caught by beach seine (Station 1 and 6) and purse seine (Station 4/5 and 7), 16 March-29 July 1993.

DISCUSSION

The MNFD fuel pier replacement environmental monitoring program was designed to assess the following: 1) pre-construction environmental quality; 2) potential habitat impacts caused by active pier replacement; and 3) subsequent environmental quality, once construction and demolition activities were complete and the new pier was in operation. It was anticipated that environmental quality would be most compromised during active construction because this created the greatest environmental disturbance. Once pier replacement was complete, however, environmental quality was expected to improve because of the termination of construction activity and disturbances related to removal of the old pier. In addition, the new pier has a narrower approach trestle crossing the intertidal area and fewer pilings than the old pier. It was also designed to be much less prone to accidental fuel spillage, thus further enhancing and protecting environmental quality upon project completion.

Environmental monitoring in 1991 occurred prior to in-water construction, but after initial dredging. During monitoring in 1992, both old and new piers were present, and considerable in-water and above-water construction was underway. In 1993 construction activities were completed by March and all sampling after this time represents post-project conditions. Consequently, comparisons of environmental quality among the 4 years should indicate whether observed post-construction conditions were different from conditions prior to or during construction.

Water Quality and Eelgrass

There are two important reasons for collecting data on water quality and eelgrass during and after fuel pier replacement: 1) to evaluate the direct effects of dredging, construction, and demolition on local water quality, and 2) to assess the possible influences of changes in physical factors (natural or otherwise) on interannual changes in eelgrass distribution and density, juvenile salmonid migrations, and resident fishes.

Dissolved oxygen, salinity, turbidity, and water temperature were unexceptional in 1994 and fell within the range of values recorded in 1991-1993 (Dey 1991, Weitkamp and Dey 1993, Weitkamp 1994) and within the expected values for this part of Puget Sound (Collias et al. 1974). Interannual comparisons indicated that dredging had little or no effect on DO, water temperature, or salinity. The elevated water temperatures recorded from winter through summer 1992, thought to be associated with the 1992 El Niño-Southern Oscillation (ENSO), were not observed in 1993 or 1994. Localized, slight increases in turbidity were observed during dredging only in 1991 (Weitkamp and Dey 1993).

Although the perimeter of the large eelgrass bed east of the fuel pier decreased during construction in 1992 (Weitkamp and Dey 1993), it appears that the eelgrass has expanded since placement of the new fuel pier. The southern edge of the large bed has moved farther seaward and the total area of eelgrass reached a high of approximately 7,900 m^2 in 1994. Therefore, although the total area occupied by eelgrass decreased in 1992, the area measured in 1994 exceeded that calculated for 1991, prior to pier construction. This indicates that any impact of fuel pier replacement on eelgrass at the MNFD was short-lived, with total area of eelgrass recovering approximately 18 months after project completion. However, eelgrass beds naturally display considerable interannual variation in perimeter shape, position, and total area (Spratt 1989). Consequently, the variation in eelgrass bed shape and size observed during our monitoring may have resulted from natural variation, and the size and position of the eelgrass bed may continue to change. Several years of monitoring would be required to determine the average post-replacement position of the eelgrass bed.

Reproductive shoot densities recorded in the large eelgrass bed in 1993 and 1994 were much lower than those measured in either 1991 or 1992 (Table 1). This decrease in reproductive shoot density most likely reflects changes in regional conditions rather than activities associated with pier replacement. The production of reproductive shoots is dependent on numerous environmental conditions, including ambient light level and water temperature (Phillips et al. 1983, Keddy 1987, van Dijk et al. 1992), both of which are affected by weather. Weitkamp (1994) suggested that a regional decrease in ambient light due to rain and cloud cover in 1993 may have been responsible for lower reproductive shoot densities in 1993 than in 1991 and 1992. In 1994, however, reproductive shoot densities remained low in Area 2 (2.1 shoots/m^2) and recovered slightly in the smaller less-dense Area 1 (3.0 shoots/m^2; Table 1), but weather conditions recorded at SeaTac International Airport between 1 March and 30 June 1994 were near normal (206 mm of precipitation, 49 rainy days, 18 sunny days; Seattle Times 1994).

To determine whether the incidence of low reproductive shoot densities was restricted to eelgrass near the fuel pier or whether this reflected a regional phenomenon, Weitkamp (1994) examined reproductive shoot densities at two other eelgrass beds in central Puget Sound in 1993: one in front of the NMFS Manchester Marine Experimental Station, approximately 2,700 m (9,000 feet) by water from the fuel pier on the north side of Orchard Point, and a second eelgrass bed at Seahurst County Park, approximately 21 km (12 miles) southeast of the fuel pier on the east shore of Puget Sound. Reproductive shoot densities averaged 1.0 shoot m^{-2} both in front of the Manchester Station and at Seahurst (n = 30 at each location). However, these values were much lower than reproductive shoot densities previously reported for Puget Sound in general (6-66 shoots m^{-2}) (Phillips 1984) or reported from the Manchester area in 1977 (4.8-8.8 shoots m^{-2}) (Phillips et al. 1983). Low densities recorded from these two eelgrass beds suggest that low reproductive shoot densities were regional in scope, and that densities were influenced by the rainy weather rather than a site-specific environmental disturbance such as pier replacement. Unfortunately, additional eelgrass surveys were not conducted at these sites in 1994 to compare with densities observed at the MNFD in 1994.

Eelgrass may also reproduce and expand through production of vegetative shoots (Phillips 1984). The vegetative shoot densities reported at the MNFD in 1993 and 1994 (124.4 and 524.4 shoots m^{-2}, respectively) are within the normal range of vegetative shoot densities reported for Puget Sound (Phillips 1984) and Manchester (Phillips et al. 1983). Therefore, the eelgrass beds at the MNFD may be reproducing and expanding primarily through vegetative shoots rather than reproductive (flowering) shoots. This would explain the apparent paradox of expanding eelgrass beds under low reproductive shoot densities.

In conclusion, the eelgrass at MNFD appears to have withstood and recovered from pier replacement. The perimeter of the eelgrass bed has continued to expand following completion of the MNFD. Low reproductive shoot densities in 1993 were most likely due to regional environmental factors or a change in eelgrass reproductive strategy rather than to site-specific factors associated with pier replacement. The high density and species diversity reported in beach-seine samples in 1993 indicate that eelgrass beds near the MNFD are providing good fish habitat.

Fishes

The two primary objectives of beach seining were to determine juvenile salmonid and marine fish abundance and movement in the vicinity of the MNFD fuel pier, and to assess changes in fish abundance among years, specifically between conditions prior to, during, and after pier-replacement disturbance.

Comparisons of fish catches in 1991, 1992, and 1993 indicated that the greatest differences among years were found in the timing and magnitude of peak densities and species richness. In contrast, average values for fish densities, species richness, species diversity, and species evenness in each year were fairly similar. Fish are temperature-sensitive, and differences in their timing between years are more likely to result from changes in water temperature and weather rather than from anthropogenic factors associated with pier replacement. However, the magnitude of peak densities and species richness may result from either anthropogenic or natural factors or both. For example, chum salmon have been observed avoiding pier construction sites (Bax et al. 1980) or in-water construction (Feist 1991). Tide stage also strongly affects beach-seine catches and was not controlled for in our study (Borton 1982, Bax 1983). In addition, water temperature may have affected larval fish mortality, thereby impacting densities of juvenile fishes.

Exceptionally warm water temperatures observed in 1992 associated with the 1992 ENSO event may explain earlier timing of peak abundance and species richness in 1992 compared to either 1991 or 1993. In contrast, the exceptionally high fish densities and species richness observed in 1993 may partially reflect the differences in sampling frequency and duration, improved fish habitat conditions following pier removal and replacement, or natural variation in fish production. Additional monitoring is required to determine whether increases in fish densities and species richness are the result of natural variation or improvement in fish habitat following pier replacement.

Pier Replacement and Juvenile Salmon Outmigration

It was anticipated that chum salmon migrating along-shore in shallow water would swim around the seaward end of the MNFD fuel pier rather than swim underneath it. This caused concern because chum salmon predators were thought to inhabit the deeper water, thus subjecting the juvenile migrants to higher predation pressure. To address this concern, purse seining was included in the 1993 monitoring program, with one purse-seining station (Station 4/5) at the southwest corner of the fuel pier (Fig. 2) and the other station (Station 7, the control site) approximately 1.6 km south of the fuel pier. This allowed us to compare densities of juvenile chum salmon and their predators in deep water next to and away from the fuel pier.

Results of purse seining indicated very little difference between fish catches next to and away from the fuel pier. Chum salmon densities were slightly higher at Station 4/5 than at Station 7, possibly due to the attraction of fish to piles and piers (Fiest 1991). No known predators of juvenile chum salmon were captured in deep water with the purse seine. Moreover, there has been considerable discussion over the degree to which other fishes prey on juvenile chum salmon (Simenstad et al. 1980, Bax 1983).

Purse-seine results did not indicate exceptionally high densities of chum salmon in deep water off the end of the fuel pier compared to other deep-water areas. This observation suggests that when encountering the pier during their along-shore migration, large numbers of chum salmon are not swimming around the end of the pier, but are either swimming underneath the pier or offshore.

Several other sources also indicate that the pier is not impeding along-shore juvenile salmon migration. Dey (1991) and Weitkamp and Dey (1993) suggested that consistently larger catches of chum salmon west of the fuel pier (Station 6) than east of the fuel pier (Station 1) were due to the unwillingness of chum salmon to swim under or around either the old or new fuel piers. However, these differences in fish densities at the two beach-seining stations, which were again observed during the 1993 monitoring, may reflect habitat preferences rather than the pier interfering with juvenile salmon migrations. Station 6 has a gravel-sand substrate with small patchy eelgrass beds, while Station 1 has a finer sandy-mud substrate with relatively dense eelgrass. The fish catches at the two stations were quite different with respect to both composition and number, indicating similar habitat selection by fishes other than chum salmon. In addition, catches of juvenile salmon at the two stations were not always different. For example, on the day of maximum chum salmon catches in 1992, equal numbers of chum salmon were caught on both sides of the pier, and average densities of chinook salmon were very similar on both sides of the pier in 1993 as well. These data suggest that the piers did not limit along-shore movement of juvenile chum salmon.

Furthermore, it is uncertain whether juvenile salmon are swimming directly seaward (west to east at MNFD), or may possibly swim farther into Puget Sound (south) before heading for the open ocean. A school of juvenile chum salmon was observed swimming south approximately 5 km south of the fuel pier, and marked juvenile chinook salmon from the Washington Department of Fish and Wildlife Soos Creek Hatchery (formerly Green River Hatchery) were caught near the MNFD pier in 1992 and 1993, south of their point of entry into Puget Sound (Weitkamp 1994). In addition, the new fuel pier has a narrower approach expected to be a barrier to along-shore migrations. Additional beach seining at beaches away from the fuel pier may help resolve some of these questions.

The purse-seine results, when combined with the beach-seine results, indicated chum salmon behavior typical of that observed in Hood Canal and in British Columbia. Juvenile chum salmon remain in shallow, nearshore areas with cover and feed on epibenthic organisms upon first entry into salt water. As these fish grow larger, they move offshore and become primarily neritic feeders (Miller et al. 1976, Fraser et al. 1979, Simenstad et al. 1980, Bax 1983). As a result of this transition, juvenile chum salmon caught offshore are generally larger than fish caught near shore (Bax 1983). Chum salmon length data indicated that a similar nearshore/offshore size segregation is occurring in the vicinity of the Manchester fuel pier (Fig. 11). With the exception of the 11 May catch at Station 4/5, chum salmon caught in deep water (Stations 4/5 and 7) with the purse seine were consistently larger than fish caught in the nearshore area with the beach seine (Stations 1 and 6) during 1993.

In conclusion, it appears that the new fuel pier may not have a substantial impact on juvenile salmon migrations. The fish do not appear to be migrating around the end of the fuel pier to avoid swimming underneath it. Instead, fish caught in deep water off the end of the pier are displaying behavior typical of chum salmon by moving offshore once they reach a critical size. Although nearshore densities of juvenile chum salmon were consistently higher on the west side of the pier than the east side, we suspect this to be a result of habitat preference rather than a reluctance of fish to swim underneath or around the fuel pier.

ACKNOWLEDGMENTS

This project benefitted considerably from the expertise and assistance of F. William Waknitz, Robert L. Emmett, George T. McCabe, Jr., Earl M. Dawley, Susan Hinton, Stephen J. Grabowski and Douglas B. Dey, all of the CZES Division. Considerable field assistance was provided by Ted Parker, JoAnne Butzerin, and Kathleen Neely, also from the CZES Division.

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APPENDIX A

Water quality measurements made at stations adjacent to the Navy fuel pier, Manchester, Washington (Puget Sound), 1994. See Figure 2 for station locations.

Appendix Table A-1

Water Quality
Manchester, WA
10 January 1994

Station	Time (PST)	Sample depth (m)	Dissolved oxygen (mg L^{-1})	Salinity ($^{o}/_{oo}$)	Temperature (^{o}C)	Turbidity (NTU)
1	1043	0	7.48	33.3	9.07	1.5
		2	7.44	33.4	9.07	1.2
2	1048	0	7.87	29.4	9.18	1.7
		5	7.30	33.5	9.2	1.3
		10	7.19	33.5	9.23	1.8
3	1053	0	8.05	33.5	9.20	1.5
		10	7.24	33.5	9.22	1.2
		20	7.18	33.5	9.22	1.6
4	1059	0	7.95	33.5	9.19	1.4
		10	7.39	33.5	9.23	1.5
		20	7.15	33.5	9.22	1.2
5	1104	0	7.81	29.8	9.15	1.3
		5	7.35	33.5	9.20	1.2
		10	7.22	33.5	9.22	0.8
6	1108	0	7.85	30.9	9.00	1.3
		2	7.51	33.4	8.99	1.2
7[a]	1117	0	9.18		9.22	1.1
		5	7.33	33.5	9.22	1.0
		10	7.23	33.5	9.20	1.3

[a] Background station, located 1.6 km south of fuel pier.

Appendix Table A-2

Water Quality
Manchester, WA
28 February 1994

Station	Time (PST)	Sample depth (m)	Dissolved oxygen (mg L^{-1})	Salinity ($^o/_{oo}$)	Temperature (°C)	Turbidity (NTU)
1	1005	0	8.25	32.7	8.32	1.6
		2	8.17	32.7	8.30	2.2
2	1011	0	8.29	32.8	8.32	1.6
		5	8.10	32.9	8.25	1.8
		10	8.05	32.9	8.27	1.7
3	1017	0	8.27	32.8	8.30	1.5
		10	8.06	32.9	8.25	1.5
		20	8.05	32.9	8.25	1.6
4	1024	0	8.28	32.8	8.32	1.8
		10	8.07	32.9	8.25	1.9
		20	8.01	32.9	8.25	2.0
5	1030	0	8.28	32.7	8.35	1.6
		5	8.07	33.0	8.26	1.4
		10	8.03	33.0	8.26	1.3
6	1035	0	8.30	32.3	8.39	1.7
		2	8.17	32.7	8.27	1.7
7[a]	1043	0	8.31	32.7	8.35	1.4
		5	8.08	32.9	8.26	1.3
		10	8.03	33.0	8.26	2.0

[a] Background station, located 1.6 km south of fuel pier.

Appendix Table A-3

Water Quality
Manchester, WA
24 March 1994

Station	Time (PST)	Sample depth (m)	Dissolved oxygen (mg L^{-1})	Salinity (‰)	Temperature (°C)	Turbidity (NTU)
1	1442	0	8.78	32.2	8.55	1.1
		2	8.77	32.2	8.48	1.4
2	1448	0	8.80	32.2	8.60	1.1
		5	8.74	32.2	8.45	1.2
		10	8.70	32.2	8.46	1.0
3	1456	0	8.78	32.2	8.48	1.0
		10	8.71	32.2	8.45	1.3
		20	8.64	32.3	8.42	1.2
4	1506	0	8.87	30.8	8.50	0.9
		10	8.69	32.2	8.43	1.2
		20	8.63	32.2	8.43	1.4
5	1517	0	8.78	32.2	8.58	0.9
		5	8.74	32.2	8.46	1.3
		10	8.70	32.2	8.45	1.0
6	1527	0	8.84	32.2	8.60	0.9
		2	8.80	32.2	8.58	1.2
7[a]	1533	0	8.80	32.3	8.51	1.0
		5	8.74	32.2	8.50	1.2
		10	8.68	32.2	8.46	1.1

[a] Background station, located 1.6 km south of fuel pier.

Appendix Table A-4

Water Quality
Manchester, WA
29 April 1994

Station	Time (PST)	Sample depth (m)	Dissolved oxygen (mg L^{-1})	Salinity (‰)	Temperature (°C)	Turbidity (NTU)
1	1440	0	--[a]	31.0	10.0	0.8
		2	--	32.0	9.8	0.2
2	1452	0	--	32.0	10.0	0.2
		5	--	32.0	10.0	0.1
		10	--	32.0	9.9	0.3
3	1459	0	--	33.0	9.9	0.3
		10	--	32.0	9.9	0.4
		20	--	32.0	9.9	0.3
4	1506	0	--	32.0	9.8	0.2
		10	--	32.0	9.9	0.2
		20	--	32.0	9.9	0.4
5	1516	0	--	31.0	9.9	0.2
		5	--	32.0	10.0	0.5
		10	--	32.0	10.0	0.3
6	1523	0	--	32.0	9.9	0.2
		2	--	32.0	9.8	0.1
7	1539	0	--	32.0	10.0	0.1
		5	--	31.0	9.8	0.2
		10	--	33.0	9.9	0.5

[a] Not measured due to meter malfunction.

Appendix Table A-5

Water Quality
Manchester, WA
31 May 1994

Station	Time (PST)	Sample depth (m)	Dissolved oxygen (mg L^{-1})	Salinity ($^o/_{oo}$)	Temperature (°C)	Turbidity (NTU)
1	1237	0	--[a]	30.0	11.5	0.2
		2	--	30.0	11.2	0.5
2	1229	0	--	30.0	10.8	0.1
		5	--	30.0	10.8	0.3
		10	--	30.0	10.8	0.7
3	1219	0	--	30.0	10.8	0.2
		10	--	30.0	10.8	0.2
		20	--	31.0	10.8	0.2
4	1154	0	--	30.0	10.5	0.3
		10	--	30.0	10.7	0.2
		20	--	30.0	10.7	0.9
5	1203	0	--	30.0	10.7	0.4
		5	--	30.0	10.8	0.5
		10	--	31.0	10.8	0.3
6	1212	0	--	31.0	10.8	0.9
		2	--	30.0	10.8	0.2
7[b]	1143	0	--	30.5	10.7	0.2
		5	--	30.5	10.7	0.2
		10	--	31.5	10.8	0.5

[a] Not measured due to meter malfunction.
[b] Background station, located 1.6 km south of fuel pier.

Appendix Table A-6

Water Quality
Manchester, WA
5 August 1994

Station	Time (PST)	Sample depth (m)	Dissolved oxygen (mg L^{-1})	Salinity (‰)	Temperature (°C)	Turbidity (NTU)
1	1140	0	--	31.5	15.0	--
		2	--	31.0	14.8	--
2	1147	0	--	32.0	14.5	--
		5	--	32.0	14.3	--
		10	--	31.5	13.5	--
3	1151	0	--	31.0	14.5	--
		10	--	31.0	13.4	--
		20	--	31.5	12.8	--
4	1157	0	--	31.5	14.5	--
		10	--	32.0	14.2	--
		20	--	32.0	13.0	--
5	1206	0	--	31.0	14.3	--
		5	--	31.0	14.0	--
		10	--	31.5	13.7	--
6	[b]	0	--	--	--	--
		2	--	--	--	--
7[c]	[b]	0	--	--	--	--
		5	--	--	--	--
		10	--	--	--	--

[a] Not measured due to meter malfunction.
[b] Boat mechanical problems prevented completion of survey, no samples.
[c] Background station, located 1.6 km south of fuel pier.