Environmental Studies at Proposed Ocean Dredged Material Disposal Sites off the Mouth of the Columbia River

Final Report

June 2003

Prepared for:

U.S Army Corp of Engineers
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1 Introduction

This report presents the results and analysis conducted for the Army Corps of Engineers (USACE), Portland District and EPA, Region 10 in support of Environmental Studies at Two Ocean Disposal Sites off the Mouth of the Columbia River (DACW57-02-R-0010). The studies were conducted by MEC Analytical Systems (MEC) located in Sequim, Washington, and Science Applications International Corporation (SAIC), located in Bothell, Washington. Data collection efforts took place over a four-month period between July and October of 2002.

1.1 Study Objectives

The environmental studies conducted for this program were designed to provide important information regarding the existing biological conditions at two ocean disposal sites located off the mouth of the Columbia River, the Deep Water Site (DWS) and the Shallow Water Site (SWS) (Figure 1.1) Information collected at the DWS represents predisposal conditions since the location has not received dredge material to date but is a proposed disposal area. Data collected from the SWS represents conditions which may have been influenced by the previous placement of dredged material.

The main study objectives were:

- Provide a physical characterization of the benthic habitat at the DWS,
- Characterize the benthic invertebrate community at the DWS,
- Characterize the demersal fish and invertebrate community (type and abundance) at the DWS and SWS,
- Assess the crab population (relative abundance) at the DWS and SWS (crab abundance is the primary objective at the SWS),
- Assess the uniqueness of the site(s) to the rest of the coastal area, and
- Provide a basis of comparison for any future monitoring efforts required by the Portland District Ocean Disposal Site Management plan.

2 Study Design and Data Collection Methods

This section provides an overview of the types of data collected during this study and a description of the methods utilized to meet the study objectives. Data collection efforts included sediment profile imaging photography (SPI), benthic and fish community analysis, Dungeness crab abundance, and sediment conventional parameters (Table 2.1). The data types collected are not the same at both sites, since the SWS have been used in the past for the disposal of dredged material. Therefore, the information collected at the SWS focused on abundance of Dungeness crab and demersal fish and invertebrates.

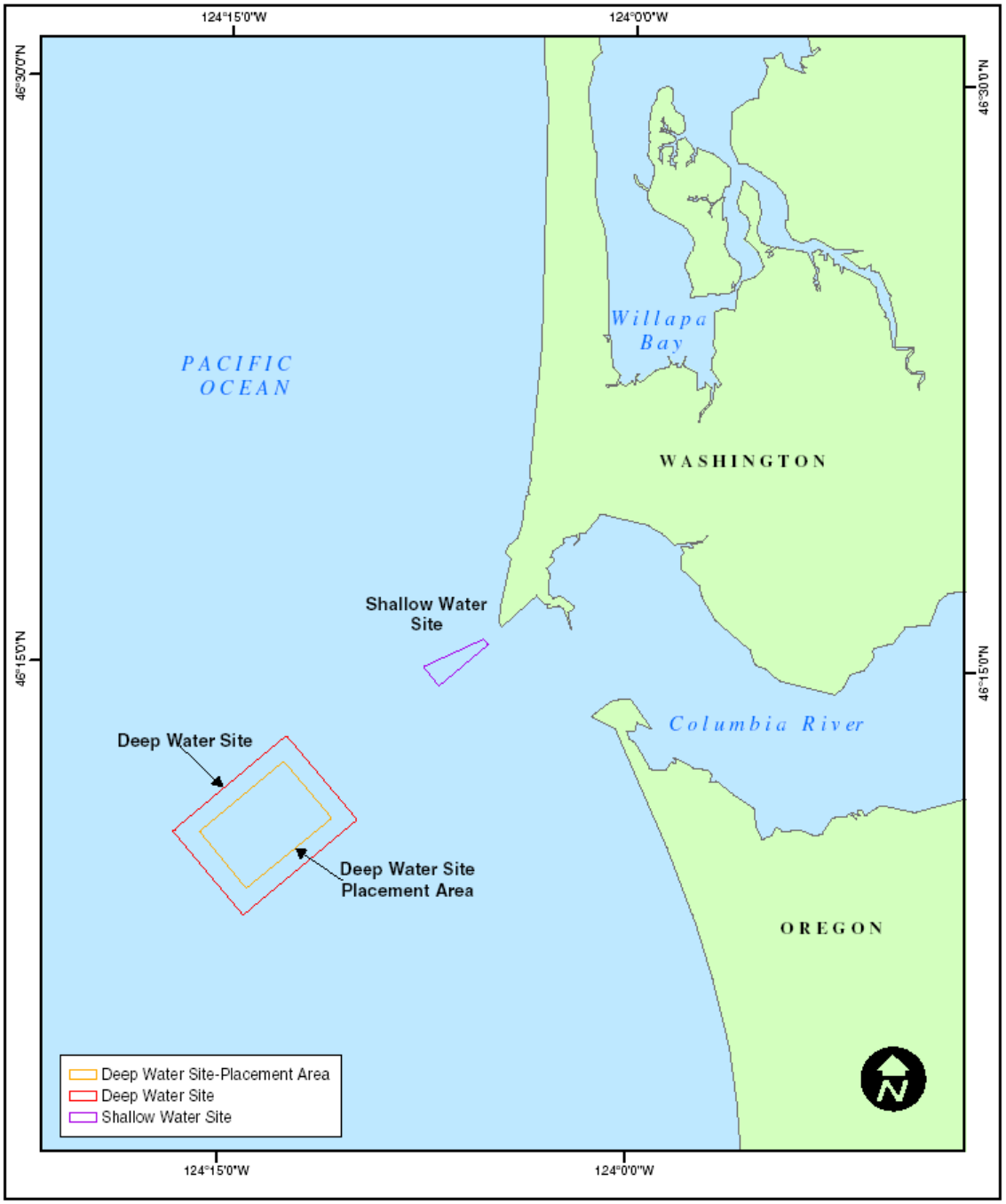


Figure 1.1. Location of Dredged Material Disposal Sites off the Mouth of the Columbia River.

Table 2.1. Data Collection Methods.

Date Type	SPI	Grab Samples	Bottom Trawl	Crab Pots	Literature Review[1]
Benthic Infauna	X	X			X
Epifauna		X	X		X
Dungeness Crab			X	X	X
Demersal Fish & Invert.			X		X
Benthic Habitat	X	X			X
Sediment Conventionals	X	X			X

[1]*Literature review consisted of comparing the results of this study to existing information on the respective biological communities.*

2.1 Data Types

The data types collected for this study included still photographs of the sediment-water interface (i.e. sediment profile images) and sediment surface (i.e. plan view images); grab samples for analysis of benthic community structure and conventional sediment parameters; crab pot sampling for Dungeness crab; and bottom trawls for demersal fish and epibenthic invertebrates. SPI is a remote photographic method that allows for the visualization of the sediment-water interface and provides a rapid determination of sediment grain size, anaerobic zones, and general biological characteristics. SPI can be deployed at a high sampling density, allowing a more targeted sampling of benthic infauna and conventional parameters. A more detailed description of data collection methods are presented in Sections 2.7

2.2 Sampling Locations

The differences in size, location, and study objectives at the two disposal sites dictate the use of distinct sampling strategies and levels of effort for each site. Each site was subdivided into equally spaced grid cells to ensure consistent spatial coverage of proposed sampling locations. The total number of grid cells for each site was determined in part by the relative size of the site, the level of effort required for each data collection method, and sufficient sample density to provide meaningful information. The most frequent sampling was done using the SPI (at the DWS only), which can be deployed quickly and efficiently over large regions. Subsequent sampling locations for benthic community analysis and sediment conventional measurements were based on the initial results of the SPI survey, and were collected only at the DWS. Bottom trawls were conducted at multiple locations within each disposal site. Crab pots were deployed for two 24-hour periods at multiple locations within each site. Table 2.2 presents the type and number of samples collected at each site.

Table 2.2. Type and Number of Sample Locations Collected At Each Site.

Data Type/Sampling Method	SWS			DWS		
	July	Sept.	Oct.	July	Sept.	Oct.
Sediment Profile Images (3 replicates each station)	0	0	0	48	36	12
Plan-View Images	0	0	0	0	48	0
Benthic Infauna (3 replicates each in spring and fall) Locations Outside of Disposal Site (1 sample /site)	0 0	0 0	0 0	5 4	5 4	0 0
Sediment Conventional Parameters (Grain size and TOC; 1 replicate each station)	0	0	0	5+4	5+4	0
Bottom Trawls (5000-ft transects; 2 replicates)	2	2	2	5	5	0
Crab Pots (Two 24-hr deployments)	12	12	0	24	24	0

2.2.1 Shallow Water Site (SWS)

The SWS was subdivided into a grid of 20 cells (partial cells excluded) of approximately 93,000-m^2 (305-m x 305-m) each. Cells were designated A through C along the western boundary and 1 through 10 along the southern boundary. Crab pots were deployed at 12 locations for two 24-hr periods within the SWS (Figure 2.1). These 12 locations were dispersed so that at least every other cell was sampled. Two replicate bottom trawls traversing east-west were also conducted in rows B and C (Figure 2.2). Row A was not chosen for a trawl due to its limited length. Each trawl occupied a distance of approximately 1520-m by 5.6 m for a total of ~8,570 m^2 each or 0.86 hectares.

2.2.2 Deepwater Site (DWS)

The DWS was subdivided into a grid of 48 cells of approximately 873,152-m^2 (934-m by 934-m) for each cell. Cells were designated A through F along the western boundary and 1 through 8 along the southern boundary. SPI survey station locations sampled each of the 48 grid cells, within both the placement (24 locations) and surrounding buffer areas (24 locations; Figure 2.3). Triplicate benthic infauna samples were collected at 8 locations co-located with selected SPI stations (Figure 2.4). Four additional benthic grabs were collected outside of the DWS, north, south, east, and west of the DWS. Grid cells selected for benthic infauna sampling were determined in the field based on the initial review of SPI images collected during the July survey. Crab pots were deployed at every other grid, 24 locations, for two 24-hr periods within the DWS (Figure 2.5). Five trawl lines, two replicates each, including four within the placement area and two in the buffer area, were conducted traversing from north to south for approximately 1520-m by 5.6 m for a total of ~8,570 m^2 each (0.86 ha) (Figure 2.6). Trawl lines were labeled using the southern boundary cell designations. Replicate trawls were conducted in columns 1, 3, 5, 7, and 8 and were labeled Trawl transects I, III, V, VII, and VIII. Replicates were denoted as replicate 1 or replicate 2.

2.2.3 Sampling Vessel

The Limit Stalker, a 65-ft commercial shrimp trawler stationed in Warrenton, Oregon, was used for all sampling activities at the two sites. This vessel was outfitted to accommodate both commercial otter trawl demersal fish and shrimp trawling, as well as scientific and engineering consulting services off the coasts of Washington and Oregon. The Limit Stalker is owned by Mr. Frank James. The vessel is operated by Captain Tom Jones, a skipper with more than 20 years of experience in Oregon and Washington coastal waters, including the Columbia River Bar and environs. The vessel is equipped with winches, davits, and an A-Frame to accommodate the various sampling instruments. The back deck provided extensive open area to accommodate the sampling gear and operations undertaken at these sites (Figure 2.7).

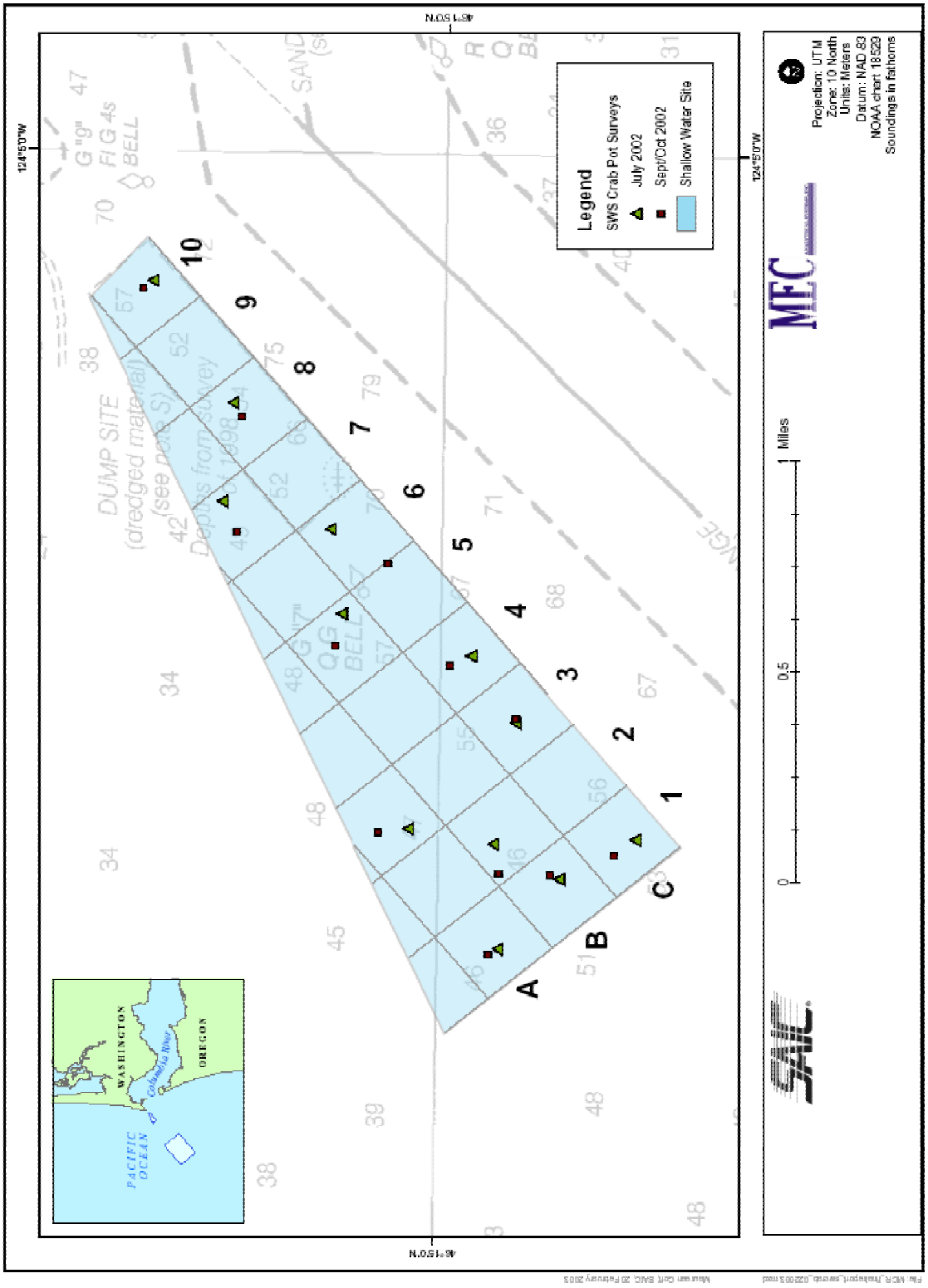


Figure 2.1. Crab Pot Sampling Locations at SWS in July and September 2002.

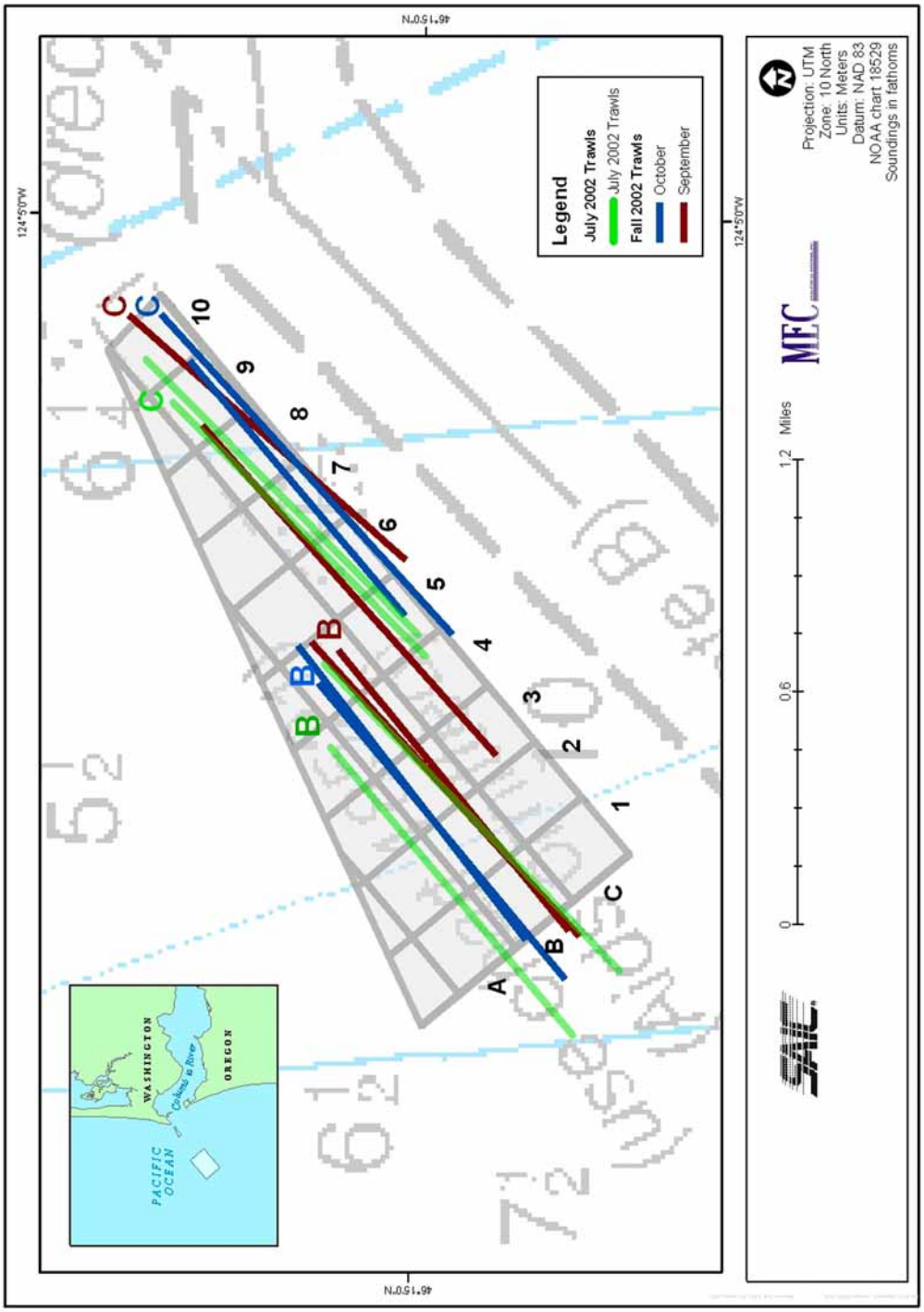


Figure 2.2. Bottom Trawl Locations at the SWS in July and September/October 2002.

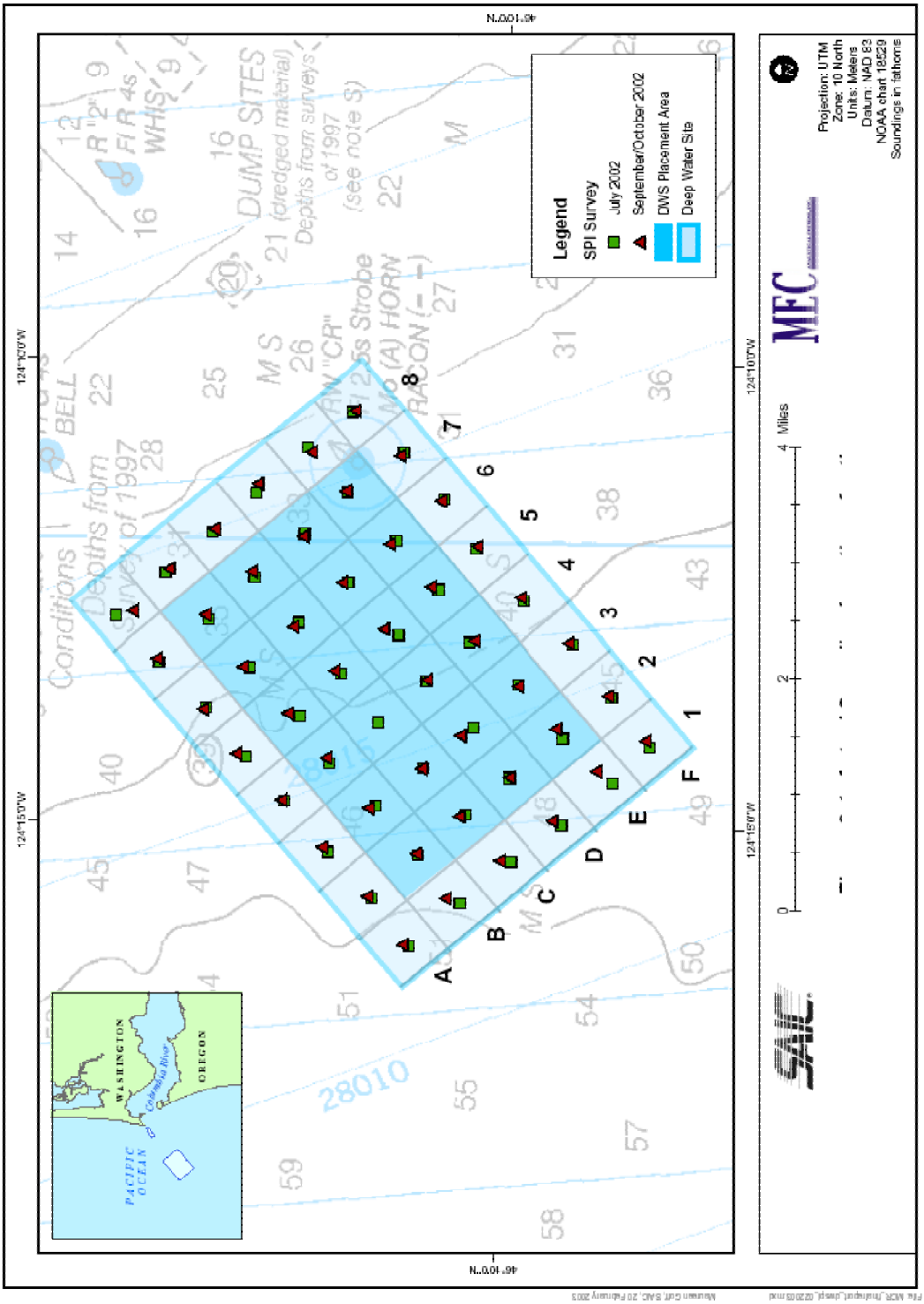


Figure 2.3. Actual DWS Sampling Locations for Sediment Profile Imaging; July and September/October 2002.

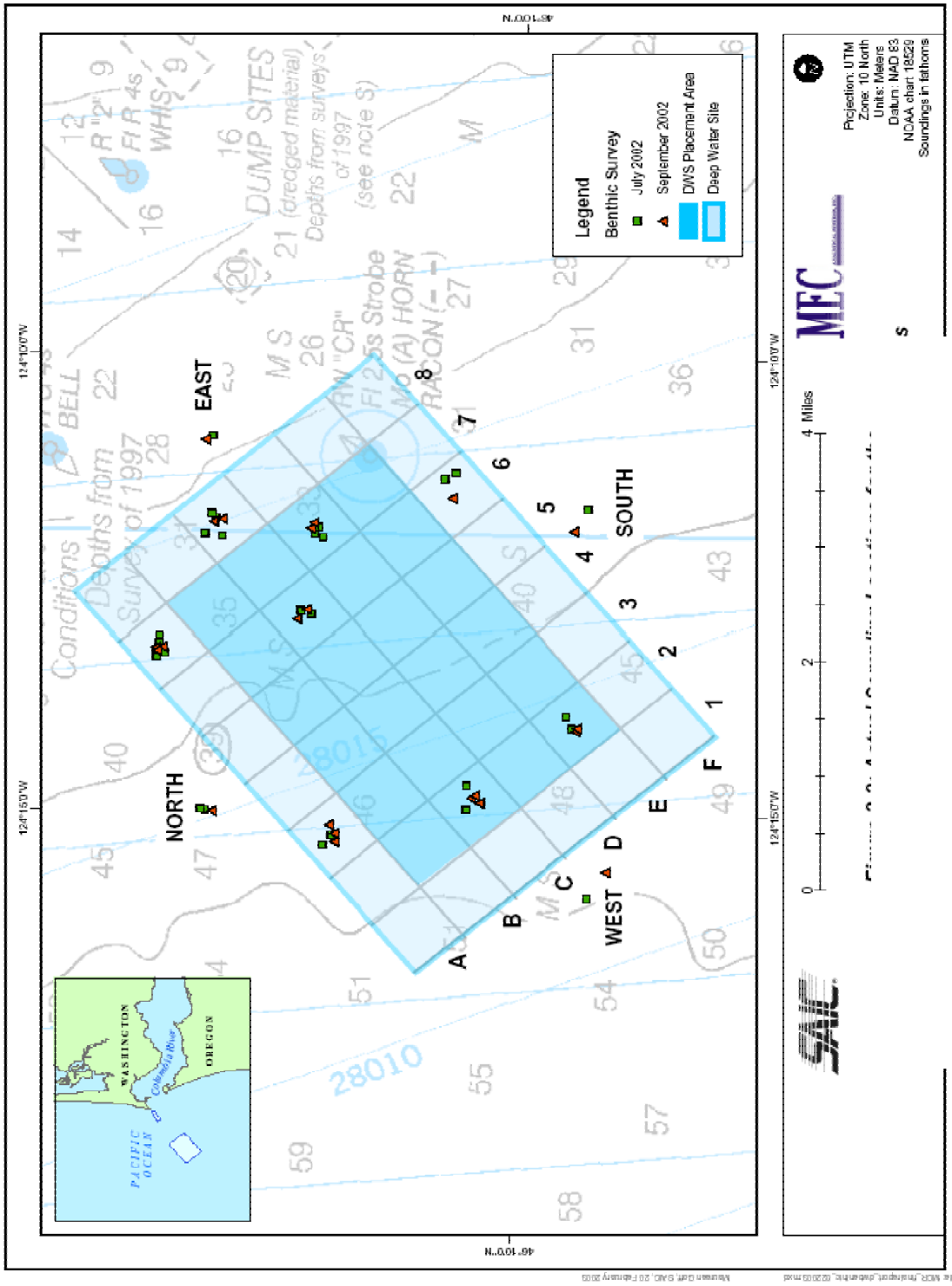


Figure 2.4. Actual Sampling Locations at DWS for Benthic Infauna and Sediment Conventionals, July/September 2002.

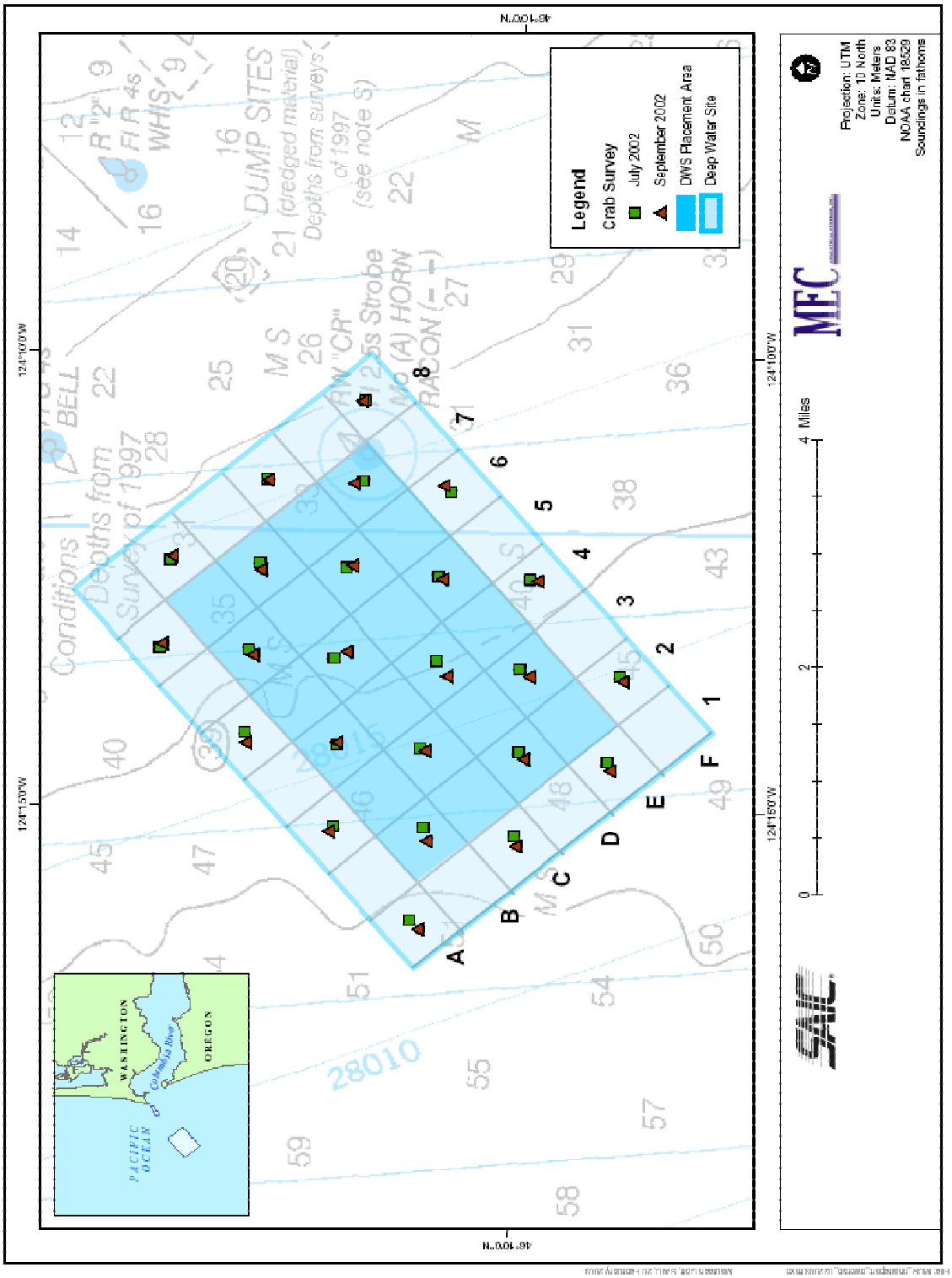


Figure 2.5. Sampling Locations for Crab Pot Deployment at DWS in July and September 2002.

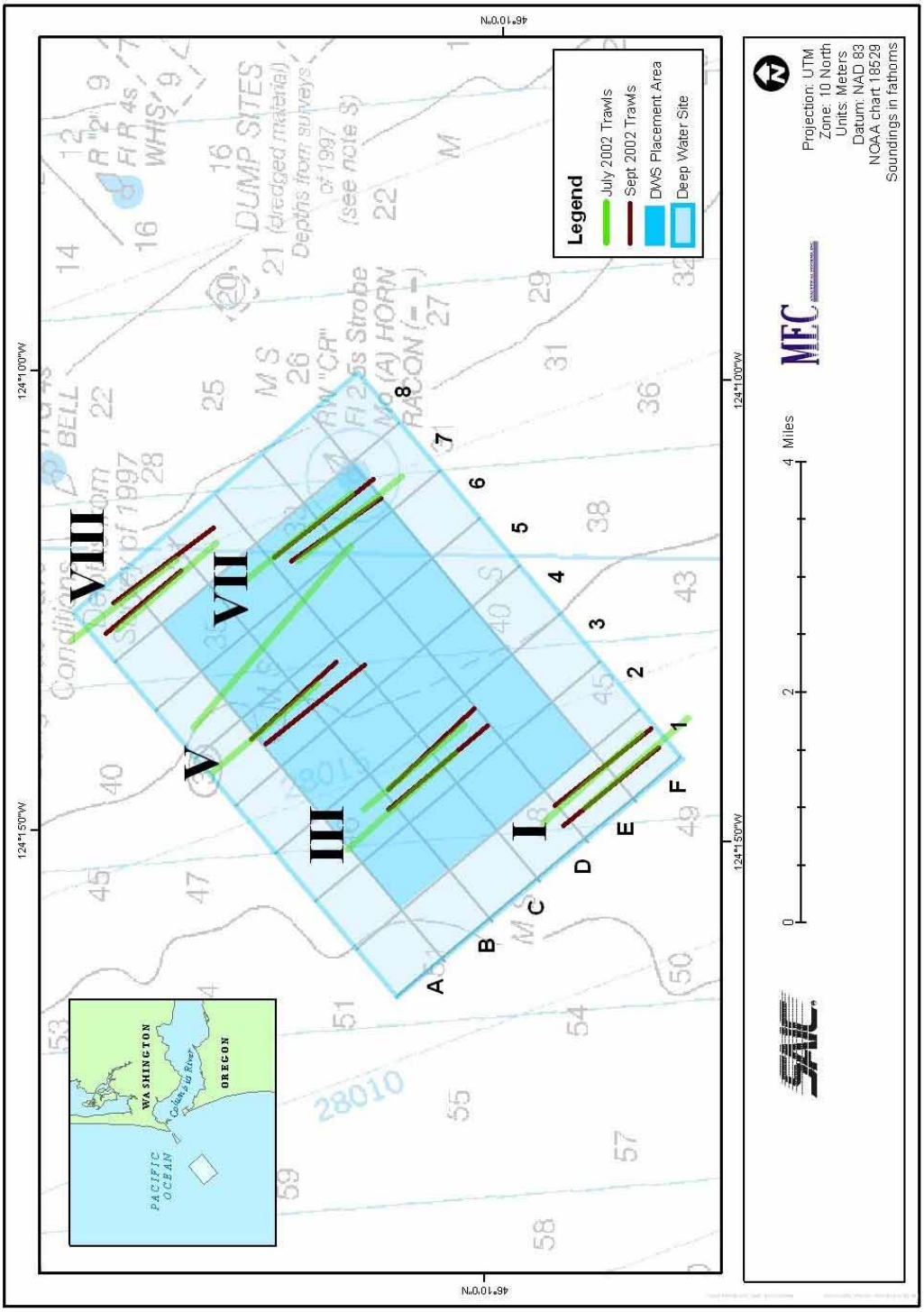


Figure 2.6. Location of Bottom Trawls at DWS in July and September 2002.

Figure 2.7. Photographs of Survey Vessel, the Limit Stalker; Crab Pot and Otter Trawl Deployment.

2.2.4 Navigation and Positioning

Navigation and positioning was accomplished using a differential global positioning system (DGPS) integrated with a computerized navigation system. The use of U.S. Coast Guard differential corrections and a 12-channel GPS receiver provided positional accuracy of ± 3 meters. Vessel coordinates were updated every two seconds and transmitted directly to the onboard system. The system provided a plan-view chart display to aid the helmsman and allowed the electronic recording of transect and sampling locations. All station coordinates were reported in latitude and longitudes using decimal minutes accurate to 1/1000 of a minute.

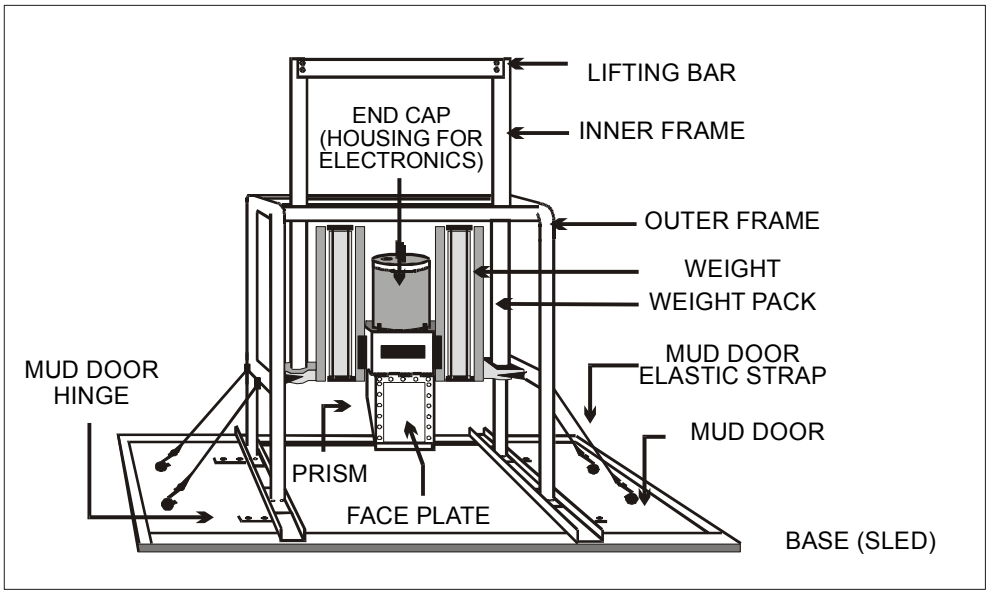
2.3 Sediment Profile Imaging

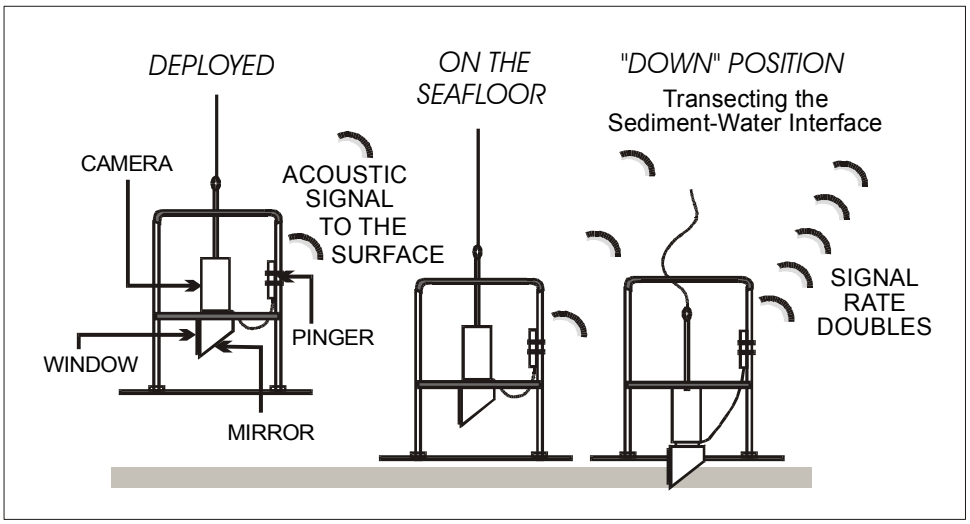
Sediment profile imaging (SPI) was conducted using a specially designed, high resolution, underwater camera that collects a vertical image of the upper 15-20 cm of the seafloor. A Benthos 3731 sediment profile imaging camera was used to survey the benthic habitat conditions of the DWS (Figure 2.8). The camera prism operates like an inverted periscope with a knife-sharp edge and controlled penetration, allowing for the collected of undisturbed profiles of the upper layers of sediment. The images were then evaluated for various biological and chemical parameters. The SPI camera provides a rapid and cost effective method for collecting information on seafloor conditions over large areas. A more detailed discussion of the SPI methodology used during this study is presented in Appendix A and the collected images are presented in Appendix D.

At the end each survey day, the film from the SPI camera was developed to verify successful data acquisition. Each SPI image was inspected and assessed for environmental conditions at the site.

The formal analysis of the SPI survey results was used to more thoroughly assess the condition of the benthic habitat and the physical characteristics of the surface sediment. Three replicate images were taken at each station. A single replicate image was selected for analysis from each location. Parameters assessed using the images include:

- Grain size mode and range
- Prism penetration depth
- Surface boundary roughness
- Depth of apparent redox potential discontinuity
- Benthic habitat classification
- Infaunal successional stage
- Calculation of the organism-sediment index





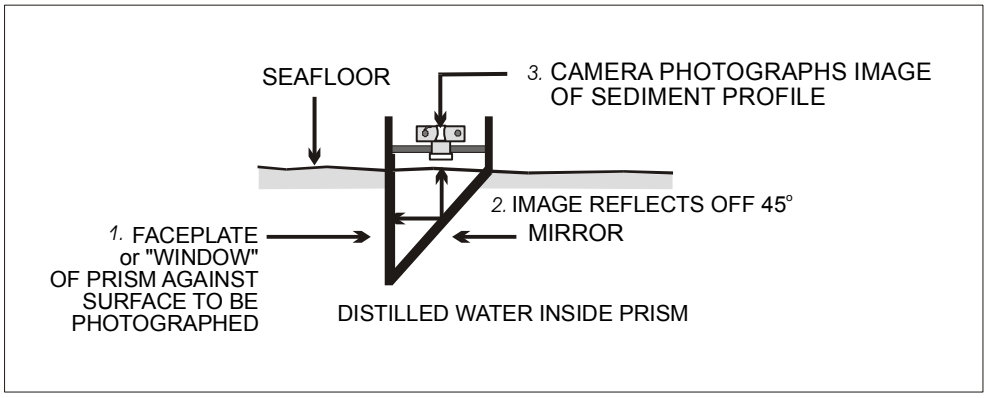


Figure 2.8. Sediment Profile Imaging Camera.

2.3.1 Plan View Images

Plan-view images were taken using a downward-looking PhotoSea underwater 35-mm camera and strobe that are mounted on the Benthos sediment profile camera. The plan-view camera photographs a 20-cm by 30-cm area near the front of the SPI camera faceplate and provides a high-resolution image of the sediment surface. Plan-view images were used in conjunction with SPI to provide information for identifying surficial physical and biological features (e.g., sand ripples, clam siphons). Operational difficulties with the PhotoSea camera limited the number of useable plan-view images collected for this survey.

2.4 Benthic Community

Benthic infauna samples were collected from selected sites for benthic community analysis and conventional parameters such as grain size and TOC. Sampling locations were determined based on an initial review of the SPI results collected at the beginning of the July survey. A qualitative categorization of the SPI images by habitat characteristics (e.g., relative grain size, sand wave presence or absence, depth to the redox discontinuity, organism type and presence) was used to characterize similar bottom topography and organism type. Stations for benthic infauna sampling were determined by placing one, two, or three stations into each of the basic environmental categories. Areas of similar habitat types that were larger had more stations located within them. Triplicate benthic community samples were collected at eight locations within the DWS and single samples at four locations outside of the DWS. Benthic infaunal and sediment conventional samples were co-located at the selected SPI stations, in part, to ground truth observations made from the images. To assess seasonal variation in benthic community diversity and abundance, the benthic community sampling locations for the September survey were co-located with the July sampling locations.

The benthic environment was sampled using a double, modified van Veen grab sampler with a combined surface area of 0.2 m^2. The grab sampler consists of two, side-by-side stainless steel 0.1 m^2 van Veen grabs. Each grab opens and closes independently, allowing the collection of two single grabs, reducing the chance for dual failure (debris caught in one sampler doesn't affect the other sampler). The double van Veen grab sampler was used to ensure that acceptable sediment samples of ample surface area were effectively and efficiently obtained. The dual grabs also allowed the collection of two benthic community replicates in a single attempt, thereby reducing the overall level of effort. A single replicate consisted of the entire contents of a van Veen grab (0.1-m^2); thus the double van Veen grab sampler provided two replicates for each successful deployment with each benthic replicate being processed separately. Therefore, only two successful deployments were required to meet the sampling requirements for a given location by providing three benthic replicates and one grab to be used for conventional sediment parameter sampling.

This sampler has been used throughout the West Coast in sediment types ranging from fine grain silts and clays to coarse grain sands in water depths of a few meters to depths in excess of 1000 meters. Acceptable grab samples were determined by meeting the following criteria (PSEP 1987):

- Sampler is not overfilled,
- Overlying water is present,
- No leakage of water during recovery,
- Sediment surface is relatively flat with no evidence of disturbance or winnowing, and

- A minimum penetration depth of 10-cm is achieved in sandy silt or silty sand environments and greater than 5 cm of penetration in medium to coarse sands.

Adequate penetration into sediments is based on the location of the typical benthic infauna within a column of sediment. Penetration of various sediment types ranging from 5-cm in coarse sands to 10-cm in finer grained silt and clay environments is based on the collection of >90% of the individuals and species that would typically be encountered within those sediment types when box cores are used to sample to sediment depths of >20-cm.

Once a sample was accepted, a description of the collected material was then recorded in logbooks including such information as penetration depth, color, texture, odor, and biological structures or any other notable features.

The sediment from each grab was processed in the field. After characterizing the sediment coarseness by visual and textural means, measuring the penetration depth that the sampler attained, observing the color and noticing the presence of odors or obvious organisms, the samples were sieved on board through a 1.0- mm screen. Water used to sieve the organisms was obtained from the surrounding seawater after filtration to remove water column organisms. Organisms and debris collected on the screen were placed in magnesium sulfate solution to relax the organisms and then preserved using seawater-buffered formalin solutions of at least 8-10%. The samples were placed in a container appropriate for the volume of the sample and tagged with internal and external labels. Sieved residue <100-mL in volume was placed in plastic whirl pack bags. Larger volumes of debris were placed in larger containers made of either glass or plastic. Field notes and chain-of-custody records were maintained to indicate the number and size of sample containers obtained from each grab sample. Samples were sent via courier to MEC's benthic laboratory for further analysis and archive.

2.5 Sediment Conventional Parameters

Grain size and total organic carbon (TOC) content are important sediment characteristics that influence benthic infaunal assemblages. Grain size distributions were characterized by the percent fractions of gravel, sand, silt, and clay comprising the substrate material. TOC is a measure of the total amount of nonvolatile, volatile, semi-volatile, and particulate organic compounds. TOC is related to the food source for deposit feeding infauna. Both of these parameters could be directly influenced by the nature of the dredged material disposed at the sites.

Sediment grain size and TOC were used to relate the physical and chemical characteristics of the benthic habitat to the invertebrate demersal fish and communities; this information was also used to ground truth the SPI images. The subsamples of sediment used for these analyses were collected from a single grab sample, separate from the samples collected for benthic analysis. The sediments were taken from the upper 2-cm of the sediment column to represent the predominant biogenic zone.

The sediment aliquot was removed from the upper 2-cm using a small cookie-cutter device that selectively removes this depth of material. The samples for grain size and TOC were kept cool at approximately 4°C during transport and storage. Sample descriptions were described and chain-of-custody procedures were used to document the number and location of the grab samples collected. These samples were stored and shipped for analysis to MEC, a Washington State certified laboratory.

2.6 Demersal Fish and Invertebrate Community Studies

Ecologically and commercially important demersal fish and invertebrate species are present at both the SWS and DWS disposal sites. Major recreational and commercial fisheries that may be present include flatfish, rockfish, salmon, shrimp and crab**.** For the purposes of this study, the fish and invertebrates that are typically captured using commercial otter trawls were sampled using a smaller research otter trawl net. The modified Willis trawl net is an otter trawl with 7.6 m opening kept open with otter boards. The lead line has ¼" chain tied to the bottom of the opening of the net. The chain is allowed to bow approximately 1" from the lead line. This lead line and chain move along the bottom disturbing fish and invertebrates so that they rise up from the bottom and are swept along within the net. The head rope has floats that maintain the vertical opening of the net. The mesh of the otter trawl is 2" stretch mesh and the net has a cod end line of ½"stretch mesh. The cod end liner is provided to retain smaller fish and invertebrates that are swept into the net but likely to escape when the net is retrieved. The net is deployed from the research vessel on a ½ inch steel cable connected to a ball bearing swivel with 75 ft bridles which extend to the otter boards. The net is trawled at a speed of ~2.5 knots overground for a period of 20 minutes and a distance of ~1520 meters. Two replicate trawls were conducted in parallel; separated by approximately 500 ft at each designated sampling location. For calculation of area sampled, the average door spread (5.62 m) was used as the width dimension of the trawl since the otter trawl doors have a herding effect. The resulting area trawled was 8,5721 m^2 or 0.86 hectares.

In the shallower waters, the scope for the trawl was approximately 4:1. In the deeper waters, where the mass of the cable provides a catenary in the wire a smaller scope length is required and the scope that was used was approximately 3/1 for the wire relative to the water depth. When sampling transects, the trawl net was deployed before reaching the location for trawl initiation so that the trawl would reach bottom at the desired on-bottom location. This was accomplished by deploying the trawl net while the sampling vessel maintained a constant forward speed. Individual trawl lines were conducted at similar depths, as feasible, from start to finish. Vessel position was tracked throughout the trawling transect, as well as time, depth, and vessel speed. Bridle and towlines were monitored and adjusted as needed to maintain effective spread, diving, and operability of the net. Bottom trawls were conducted during the day when demersal fish and invertebrates are more likely to stay close to the bottom, as opposed to feeding in the water column at night. Sampling was performed in July, September, and October (SWS only) to assess seasonal variation in demersal fish population diversity and abundance.

Upon completion of the on-bottom time, the vessel is kept in gear and the winch pulled the trawl towards the vessel where the otter doors collapse to the center of the vessel while closing the net. The net was then retrieved and the collected organisms were slaked to the end of the net where they were released into large plastic tubs. The fish and invertebrates were sorted into species, measured, weighed, and examined for external lesions. The demersal fish were identified and measured to the nearest centimeter, board-length size class, or to nearest millimeter if there are less than 10 of any individual species. Demersal invertebrates were identified to species, counted, measured where appropriate to indicate carapace length, and sex determined on appropriate species (crabs). The fish were then examined for any signs of external lesions or parasites (e.g., *Lironeca vulgaris* gill isopods, *Phryxocephalus cincinnatus*, eye parasites on sand dabs, or signs of fin erosion or epithelial papillomas).

Great care was taken to avoid excessive mortality by minimizing fish handling, processing each catch as quickly as possible, and carefully returning each specimen to the water. Individuals that

could not be readily identified or there was uncertainty in the identification were preserved in 10% formalin for later identification. Uncommon species were retained for archival purposes.

2.7 Dungeness Crab Survey

Dungeness crabs provide an important commercial fishery in waters off the mouth of the Columbia River. As noted in the draft environmental assessment for the disposal sites, Dungeness crab population numbers are subject to large cyclical fluctuations in abundance (USACE 2002). However, there are currently no established methods for determining true crab density in open coast systems (P. Dinnel, pers. comm. 2002). This is due to a complex life history, including periods of segregation by sex, molt stage, egg presence, and size (Diamond 1983; Diamond and Hankin 1985; Hankin et al. 1989; Smith and Jamieson 1990). Studies of snow crab have found the mean and modal size of the catch differed between small-meshed crab pots, large-meshed crab pots, and day and night bottom trawls resulting in varied crab age and abundance estimates (Dawe, pers. communication 2002). In shallow water systems a more comprehensive assessment of crab populations, including density, may be achieved by using divers to ground truth complementary methods, but the hazardous conditions at the SWS and the depth at the DWS preclude this method. While Dungeness crab catch records are generally believed to represent fluctuations in the actual population (Higgins et al. 1997), this data cannot be used for site-specific density estimates. As a result the most accurate determination of the crab population at the disposal site locations is to estimate relative abundance of crabs for each area.

Two separate sampling methods were used to determine the relative abundance of Dungeness crabs within the two disposal sites: 1) deployment of modified commercial crab pots, and 2) bottom trawls. The resulting data from crab pot deployment was then used to determine the catch per unit effort (CPUE) of Dungeness crabs. The bottom trawls provided an estimate of total number of crabs caught per hectare of seafloor trawled. This sampling technique does not result in a true density estimate but rather a relative abundance and minimum density estimate due to an unknown percentage of crabs that were able to avoid the tow, or were missed by the tow as a result of being buried below the sediment surface. The combination of these methods allowed for the determination of the relative abundance of crabs within the proposed disposal sites. The size distributions and physical descriptions of the crabs found in these locations were characterized from the crab pot and trawl sampling and are described below.

Commercial crab pots (0.91-m diameter by 0.36-m deep) were modified so that all portions of the pot, except the entry doors, were covered in ¾" diagonal, non-toxic, non-corrosive plastic mesh. The purpose of the mesh was to retain any smaller crabs that enter the traps but would otherwise be absent from the catch record due to the escape ports, or the standard large mesh of commercial pots. By using the smaller mesh the selectivity bias toward larger crabs was reduced. Crab pot sampling locations were pre-determined in order to provide an even distribution throughout the disposal sites. Twelve locations within the SWS and 24 locations at the DWS were sampled using crab pots. All pots were deployed and remained in place for two 24-hour periods at the SWS and the DWS. Each pot was retrieved after a 24-hour soak, emptied for identification and enumeration of all organisms. Crab pots were then re-baited and re-deployed for a second 24-hour period. A combination of hanging bait, consisting of salmon and rockfish (i.e., *Sebastes* spp.), and a commercial stainless steel baiter filled with squid were placed in each crab pot. The depth, GPS location, time of pot set, and time of pot pull was recorded for each sampling location.

Not all crab pots were recoverable, particularly for the SWS, which was subject to very strong ebb tides that, at times, would pull the buoys under, rendering them unrecoverable. In addition, both sites were subject to crab pot loss as a result of coming in contact with fishing and shipping traffic. This was evident in the recovery of one heavily damaged DWS pot that was recovered along the southern edge of the river channel near Hammond, 14 miles from the point of its deployment site. Although the data was no longer viable for use in our site analysis due to its damaged condition and considerable displacement, the pot demonstrated that the meshed pots effectively caught and retained smaller crabs, as there were numerous crabs ranging from 40-100 mm still inside the pot[1].

The number and species of all organisms was recorded for each 24 hr deployment period. The first 30 Dungeness crab in each pot were sexed, measured, examined for shell strength, and carefully returned to the water. In addition, all females were examined for eggs. If more than 30 crabs were present in a single pot, the remaining crabs were simply counted and returned to the water. Crab measurements consisted of carapace width (CW) taken immediately anterior to the tenth anterolateral spine, to the nearest millimeter using Vernier calipers. Appearance and feel of the smaller legs were used to determine shell condition and strength.

Bottom trawls were conducted using a 7.6- modified Willis otter trawl at two locations in the SWS and at six locations at the DWS as described in Section 2.5. Two replicate trawls, conducted in parallel, at approximately 1520-m were conducted during the sampling events (i.e. July and September). An additional set of trawls was conducted at the SWS in October during a supplemental field event necessary to complete the fall SPI survey. Dungeness crabs collected in bottom trawls were sexed, measured, counted, and shell strength examined in the same manner as described for crab pots.

3 Results

This section presents the results for both the July and September/October surveys at both the SWS and DWS organized by data type collected.

3.1 SPI Survey Results

A total of 96 useable images were collected and analyzed at 48 SPI stations in the DWS representing seasonal conditions immediately prior to July and following September, the typical time period that dredged material is placed at ocean disposal sites off of MCR[2]. Two types of analyses were performed on these data. First, the slides were subjectively reviewed on board the sampling vessel the day after collection. The slides were examined and visually categorized based on apparent grain size and color, relative abundance of infaunal organisms, the presence of clasts, feeding voids, sand waves, and depth of penetration into the sediment. These data were then grouped into sets of slides and stations that had similar characteristics. These groupings were numbered, plotted on station maps and contoured to portray areas of the bottom with similar

[1] *One missing crab pot was found in the estuary between Warrenton and Astoria while transiting back to port. The pot was badly damaged, but was found to contain juvenile Dungeness crab as small as 40 mm, much smaller than those collected from the study area. This observation provided anecdotal evidence that 1) the modified crab pots were capable of capturing and retaining small crabs; and 2) smaller Dungeness crabs present within the estuary were not found at either disposal site. It is believed a barge or freighter inadvertently dragged the displaced crab pot to the location in the estuary where it was recovered. It is not known how long the pot was "fishing" the estuary.*

[2] *No dredged material was disposed of at the DWS prior to or during the time of these 2002 surveys.*

sediment characteristics. Stations were then allocated into these contoured areas for benthic infaunal sampling (Section 3.3). Figure 3.1 represents this original estimate of the types of bottom areas identified at the DWS during July, based on information from SPI images (Figure 3.2).

Second, one representative image from each station was analyzed using the REMOTS® system to detect the presence of dredged material and determine several physical and biological parameters. A detailed description of the REMOTS® parameters for the 2002 surveys is provided in Appendix A, and summaries of the July and September image analysis results is presented in Tables 3.1 and 3.2, respectively.

3.1.1 Grain Size Distribution

The grain size distribution in SPI images as determined by REMOTS® analysis was reported as the major mode in phi size. The phi size range for sediments is from –1 phi (gravel), -1 to 4 phi (sand), 4 to 8 phi (silt), to greater than 8 phi (clay). The July survey indicated a grain size distribution that consisted predominately of fine sand (3 to 2 phi; 54%) to very fine sand (4 to 3 phi; 40%), with a few locations dominated by silt (>4 phi; 6%). The finer grained material (very fine sand and silt) were generally located in the deeper western portion of the DWS (Figure 3.3). The results from the September survey were very similar to the July survey with sediments consisting mostly of fine sand (58%) and very fine sand (36%), with a few locations dominated by silt (>4 phi; 6%). The September distribution pattern was also similar to the earlier survey with the very fine sand and silt located in the deeper and western-most portion of the DWS (Figure 3.4).

3.1.2 Prism Penetration Depth

The SPI prism penetration depths were similar during both sampling events ranging from 3.88 to 14.78 cm with a mean penetration depth of 8.5 cm. In general, penetration depths were greater (over 10 cm) in the deeper, western-most quarter of the site, and lower (less than 10 cm) in the eastern three-quarters of the site. Shallow prism penetrations (less than 5 cm) were limited to a few sporadic sites in the eastern half of the disposal sites. Since the camera weight was constant throughout each survey, the penetration depths indicate that the sediments in the deeper western portion of the site represent a less consolidated, ‘soft’ bottom, with a relatively lower bearing capacity and shear strength than the shallower, sandier sediments in the eastern portion of the site. Penetration depth contours are presented in Tables 3.1 and 3.2 for the July and September/October surveys, respectively.

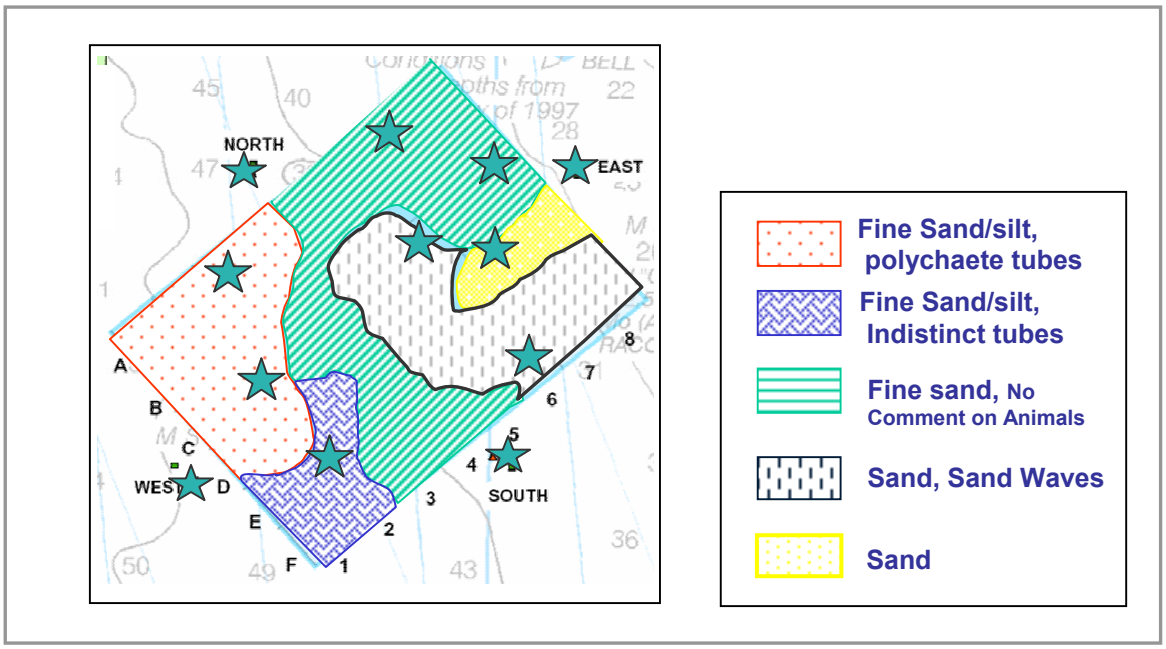


Figure 3.1. Benthic Habitat Types Using Sediment Profile Imaging.

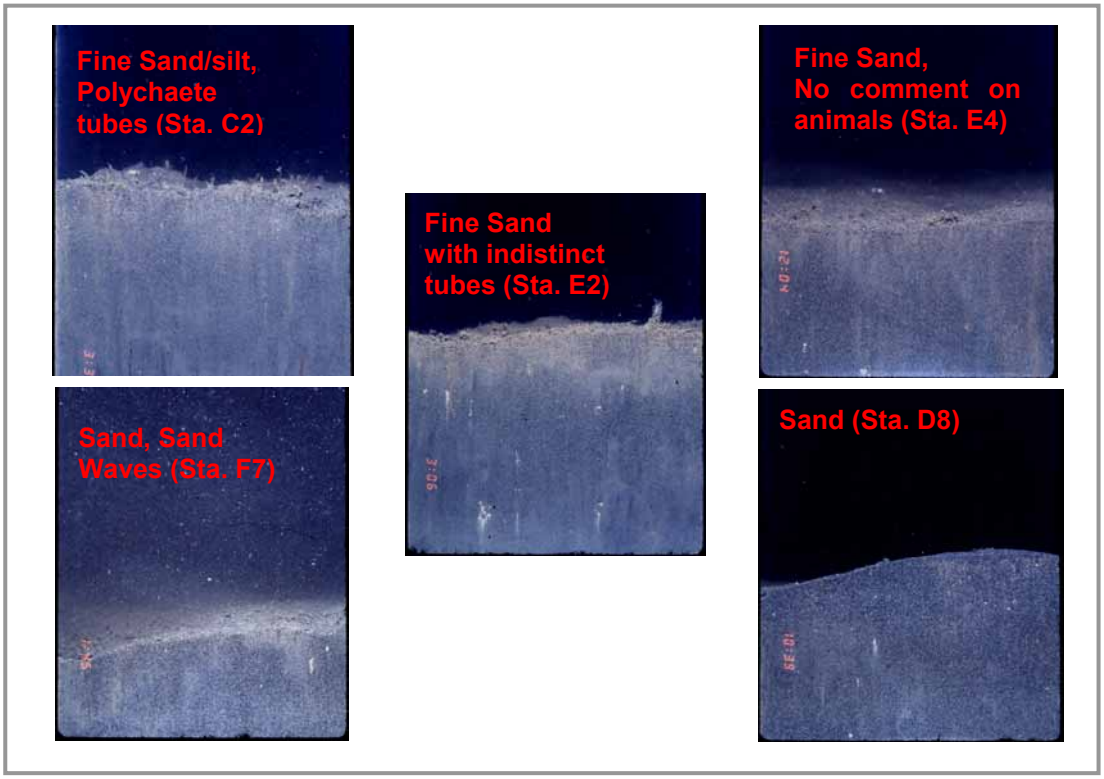


Figure 3.2. SPI Images of 5 Benthic Habitat Types.

Table 3.1. Summary of REMOTS® Sediment-Profile Imaging Results for the Columbia River DWS (July 2002)

Station	Grain Size Major	Camera	Dredged Material	Boundary Roughness	Benthic Habitat	Highest Stage	Successional Stages	RPD Mean(cm)	OSI Mean	OSI Median
	Mode (# Replicates)	Penetration Mean (cm)	Thickness Mean (cm)	Mean (cm)	(# Replicates)	Present	Present (# Replicates)			
DWA1	4 to 3 phi (1)	14.33	0.00	0.80	UN.SS (1)	ST I	ST I (1)	0.84	3.00	3.00
DWA2	4 to 3 phi (1)	12.90	0.00	0.79	UN.SS (1)	ST I on III	ST I on III (1)	1.82	8.00	8.00
DWA3	4 to 3 phi (1)	10.32	0.00	0.55	UN.SS (1)	ST I	ST I (1)	1.31	3.00	3.00
DWA4	4 to 3 phi (1)	7.34	0.00	1.00	SA.F (1)	ST I	ST I (1)	0.75	2.00	2.00
DWA5	3 to 2 phi (1), 4 to 3 phi (1)	7.22	0.00	0.69	SA.F (2)	ST I	ST I (2)	1.28	3.00	3.00
DWA6	3 to 2 phi (1)	9.52	0.00	1.32	SA.F (1)	ST I	ST I (1)	1.56	4.00	4.00
DWA7	3 to 2 phi (1)	8.05	0.00	1.32	SA.F (1)	ST I	ST I (1)	1.27	3.00	3.00
DWA8	3 to 2 phi (2)	7.77	0.00	1.68	SA.F (2)	ST I on III	ST I (1), ST I on III (1)	0.71	4.50	4.50
DWB1	> 4 phi (2)	14.06	0.00	1.34	UN.SS (2)	ST I on III	ST I (1), ST I on III (1)	2.53	6.50	6.50
DWB2	4 to 3 phi (1)	8.88	0.00	0.61	UN.SS (1)	ST I	ST I (1)	1.26	3.00	3.00
DWB3	4 to 3 phi (2)	10.29	0.00	0.50	SA.F (1), UN.SS (1)	ST I on III	ST I on III (2)	0.91	6.50	6.50
DWB4	4 to 3 phi (1)	8.85	0.00	0.70	SA.F (1)	ST I	ST I (1)	1.56	4.00	4.00
DWB5	3 to 2 phi (1)	5.88	0.00	0.48	SA.F (1)	ST I	ST I (1)	0.63	2.00	2.00
DWB6	3 to 2 phi (1)	8.07	0.00	1.00	SA.F (1)	ST I	ST I (1)	1.67	4.00	4.00
DWB7	3 to 2 phi (1), 4 to 3 phi (1)	5.38	0.00	0.50	SA.F (2)	ST I	ST I (2)	1.32	3.50	3.50
DWB8	4 to 3 phi (1)	9.91	0.00	1.59	SA.F (1)	ST I	ST I (1)	1.43	3.00	3.00
DWC1	> 4 phi (1)	13.16	0.00	1.14	UN.SS (1)	ST I on III	ST I on III (1)	1.82	8.00	8.00
DWC2	4 to 3 phi (1)	11.28	0.00	1.29	UN.SS (1)	ST I on III	ST I on III (1)	0.98	7.00	7.00
DWC3	3 to 2 phi (1), 4 to 3 phi (1)	8.16	0.00	1.08	SA.F (1), UN.SS (1)	ST I on III	ST I (1), ST I on III (1)	1.26	5.00	5.00
DWC4	4 to 3 phi (1)	6.01	0.00	0.88	SA.F (1)	ST I	ST I (1)	1.07	3.00	3.00
DWC5	3 to 2 phi (1)	9.11	0.00	0.55	SA.F (1)	ST I	ST I (1)	1.25	3.00	3.00
DWC6	3 to 2 phi (1)	10.58	0.00	0.84	SA.F (1)	ST I	ST I (1)	0.53	2.00	2.00
DWC7	3 to 2 phi (1)	4.51	0.00	0.84	SA.F (1)	ST I	ST I (1)	1.08	3.00	3.00
DWC8	3 to 2 phi (1)	8.49	0.00	2.26	SA.F (1)	ST I	ST I (1)	1.02	3.00	3.00
DWD1	4 to 3 phi (1)	11.77	0.00	0.73	UN.SS (1)	ST I on III	ST I on III (1)	1.45	7.00	7.00

Abbreviations defined in Appendix A.

Table 3.1. Summary of REMOTS® Sediment-Profile Imaging Results for the Columbia River DWS (July 2002). *Continued*

Station	Grain Size Major	Camera	Dredged Material	Boundary Roughness	Benthic Habitat	Highest Stage	Successional Stages	RPD Mean(cm)	OSI Mean	OSI Median
	Mode (# Replicates)	Penetration Mean (cm)	Thickness Mean (cm)	Mean (cm)	(# Replicates)	Present	Present (# Replicates)			
DWD2	4 to 3 phi (1)	12.74	0.00	0.76	UN.SS (1)	ST I	ST I (1)	1.28	3.00	3.00
DWD3	3 to 2 phi (1)	7.94	0.00	0.88	SA.F (1)	ST I	ST I (1)	1.95	4.00	4.00
DWD4	3 to 2 phi (1)	6.83	0.00	0.62	SA.F (1)	ST I	ST I (1)	1.00	3.00	3.00
DWD5	3 to 2 phi (1)	4.70	0.00	0.36	SA.F (1)	ST I	ST I (1)	1.23	3.00	3.00
DWD6	3 to 2 phi (1)	4.92	0.00	0.94	SA.F (1)	ST I	ST I (1)	1.12	3.00	3.00
DWD7	3 to 2 phi (1)	4.81	0.00	1.52	SA.F (1)	ST I	ST I (1)	0.94	3.00	3.00
DWD8	3 to 2 phi (1), 4 to 3 phi (1)	7.99	0.00	1.58	SA.F (2)	ST I	ST I (2)	0.72	0.50	0.50
DWE1	> 4 phi (1)	13.27	0.00	0.82	UN.SS (1)	ST I on III	ST I on III (1)	0.88	7.00	7.00
DWE2	4 to 3 phi (2)	10.15	0.00	0.79	UN.SS (2)	ST I to II	ST I (1), ST I to II (1)	1.14	3.50	3.50
DWE3	4 to 3 phi (1)	6.89	0.00	0.93	SA.F (1)	ST I	ST I (1)	1.57	4.00	4.00
DWE4	3 to 2 phi (1)	6.41	0.00	0.50	SA.F (1)	ST I	ST I (1)	0.99	3.00	3.00
DWE5	3 to 2 phi (2)	6.01	0.00	0.96	SA.F (2)	ST I	ST I (2)	0.57	2.00	2.00
DWE6	4 to 3 phi (1)	5.38	0.00	0.85	SA.F (1)	ST I	ST I (1)	0.91	3.00	3.00
DWE7	3 to 2 phi (1)	6.05	0.00	0.63	SA.F (1)	ST I	ST I (1)	0.51	2.00	2.00
DWE8	3 to 2 phi (1)	7.14	0.00	0.82	SA.F (1)	ST I	ST I (1)	0.36	2.00	2.00
DWF1	4 to 3 phi (1), > 4 phi (1)	12.03	0.00	0.73	UN.SS (2)	ST I on III	ST I (1), ST I on III (1)	1.49	5.50	5.50
DWF2	4 to 3 phi (1)	9.40	0.00	0.56	UN.SS (1)	ST I	ST I (1)	1.76	4.00	4.00
DWF3	4 to 3 phi (1)	6.47	0.00	1.05	UN.SS (1)	ST I	ST I (1)	0.86	3.00	3.00
DWF4	3 to 2 phi (1)	5.28	0.00	0.98	SA.F (1)	ST I	ST I (1)	0.63	2.00	2.00
DWF5	4 to 3 phi (1)	6.61	0.00	1.00	SA.F (1)	ST I	ST I (1)	1.44	3.00	3.00
DWF6	3 to 2 phi (1)	5.31	0.00	1.16	SA.F (1)	ST I	ST I (1)	1.65	4.00	4.00
DWF7	3 to 2 phi (1)	4.27	0.00	1.86	SA.F (1)	ST I	ST I (1)	0.76	3.00	3.00
DWF8	3 to 2 phi (1)	3.88	0.00	0.84	SA.F (1)	ST I	ST I (1)	0.86	3.00	3.00
AVG		8.26	0.00	0.95				1.17	3.70	3.70
MAX		14.33	0.00	2.26				2.53	8.00	8.00
MIN		3.88	0.00	0.36				0.36	0.50	0.50

Abbreviations defined in Appendix A.

Table 3.2. Summary of REMOTS® Sediment-Profile Imaging Results for the Columbia River DWS (September 2002).

Station	Grain Size Major	Camera	Dredged Material	Boundary Roughness	Benthic Habitat	Highest Stage	Successional Stages	RPD Mean (cm)	Methane	OSI Mean	OSI Median
	Mode (# replicates)	Penetration Mean (cm)	Thickness Mean (cm)	Mean (cm)	(# replicates)	Present	Present (# replicates)		Present		
DWA1	4 to 3 phi (1)	14.66	0.00	0.78	UN.SS (1)	ST I on III	ST I on III (1)	2.02	No	8.00	8.00
DWA2	4 to 3 phi (1)	12.75	0.00	1.60	UN.SS (1)	ST I on III	ST I on III (1)	2.60	No	9.00	9.00
DWA3	4 to 3 phi (1)	9.44	0.00	0.66	UN.SS (1)	ST I	ST I (1)	2.95	No	5.00	5.00
DWA4	4 to 3 phi (1)	9.02	0.00	1.04	UN.SS (1)	ST I on III	ST I on III (1)	2.25	No	8.00	8.00
DWA5	3 to 2 phi (1)	11.42	0.00	1.34	SA.F (1)	ST I	ST I (1)	1.02	No	3.00	3.00
DWA6	3 to 2 phi (1)	7.92	0.00	1.94	SA.F (1)	ST I	ST I (1)	2.53	No	5.00	5.00
DWA7	4 to 3 phi (1)	6.30	0.00	1.68	SA.F (1)	ST I	ST I (1)	0.83	No	3.00	3.00
DWA8	3 to 2 phi (1)	9.62	0.00	1.17	SA.F (1)	ST I	ST I (1)	2.32	No	5.00	5.00
DWB1	> 4 phi (1)	14.31	0.00	0.66	UN.SI (1)	ST I on III	ST I on III (1)	2.75	No	9.00	9.00
DWB2	4 to 3 phi (1)	12.09	0.00	0.58	UN.SS (1)	ST I on III	ST I on III (1)	1.64	No	8.00	8.00
DWB3	4 to 3 phi (1)	9.75	0.00	2.04	UN.SS (1)	ST I on III	ST I on III (1)	2.35	No	9.00	9.00
DWB4	3 to 2 phi (1)	9.58	0.00	1.52	SA.F (1)	ST I	ST I (1)	2.71	No	5.00	5.00
DWB5	3 to 2 phi (1)	6.92	0.00	1.70	SA.F (1)	ST I	ST I (1)	2.34	No	5.00	5.00
DWB6	3 to 2 phi (1)	5.44	0.00	0.61	SA.F (1)	ST I	ST I (1)	1.31	No	3.00	3.00
DWB7	3 to 2 phi (1)	6.97	0.00	3.70	SA.F (1)	ST I	ST I (1)	1.65	No	4.00	4.00
DWB8	3 to 2 phi (1)	4.93	0.00	1.36	SA.F (1)	ST I	ST I (1)	0.59	No	2.00	2.00
DWC1	4 to 3 phi (1)	13.80	0.00	0.77	UN.SS (1)	ST I on III	ST I on III (1)	2.37	No	9.00	9.00
DWC2	4 to 3 phi (1)	12.28	0.00	0.84	UN.SS (1)	ST I on III	ST I on III (1)	3.00	No	9.00	9.00
DWC3	4 to 3 phi (1)	10.08	0.00	0.94	UN.SS (1)	ST I on III	ST I on III (1)	2.52	No	9.00	9.00
DWC4	3 to 2 phi (1)	9.26	0.00	0.98	SA.F (1)	ST I	ST I (1)	1.87	No	4.00	4.00
DWC5	3 to 2 phi (1)	6.53	0.00	0.79	SA.F (1)	ST I	ST I (1)	1.29	No	3.00	3.00
DWC6	3 to 2 phi (1)	7.52	0.00	0.46	SA.F (1)	ST I	ST I (1)	2.11	No	4.00	4.00
DWC7	3 to 2 phi (1)	6.84	0.00	1.22	SA.F (1)	ST I	ST I (1)	1.63	No	4.00	4.00
DWC8	4 to 3 phi (1)	9.92	0.00	1.38	UN.SS (1)	ST I	ST I (1)	2.77	No	5.00	5.00
DWD1	4 to 3 phi (1)	14.78	0.00	0.57	UN.SS (1)	ST I on III	ST I on III (1)	2.46	No	9.00	9.00
DWD2	> 4 phi (1)	12.59	0.00	1.40	UN.SS (1)	ST I	ST I (1)	2.34	No	5.00	5.00

Abbreviations defined in Appendix A.

Table 3.2. Summary of REMOTS® Sediment-Profile Imaging Results for the Columbia River DWS, (September 2002). *Continued*

Station	Grain Size Major	Camera	Dredged Material	Boundary Roughness	Benthic Habitat	Highest Stage	Successional Stages	RPD Mean (cm)	Methane	OSI Mean	OSI Median
	Mode (# replicates)	Penetration Mean (cm)	Thickness Mean (cm)	Mean (cm)	(# replicates)	Present	Present (# replicates)		Present		
DWD3	3 to 2 phi (1)	10.58	0.00	0.62	SA.F (1)	ST I	ST I (1)	1.58	No	4.00	4.00
DWD4	3 to 2 phi (1)	7.25	0.00	0.92	SA.F (1)	ST I	ST I (1)	1.96	No	4.00	4.00
DWD5	3 to 2 phi (1)	7.12	0.00	1.43	UN.SS (1)	ST I	ST I (1)	2.40	No	5.00	5.00
DWD6	4 to 3 phi (1)	5.83	0.00	0.70	UN.SS (1)	ST I	ST I (1)	2.00	No	4.00	4.00
DWD7	3 to 2 phi (1)	3.97	0.00	0.48	SA.F (1)	ST I	ST I (1)	1.06	No	3.00	3.00
DWD8	3 to 2 phi (1)	9.33	0.00	1.94	SA.F (1)	ST I	ST I (1)	1.32	No	3.00	3.00
DWE1	4 to 3 phi (1)	10.73	0.00	1.04	UN.SS (1)	ST I	ST I (1)	2.10	No	4.00	4.00
DWE2	3 to 2 phi (1)	10.11	0.00	0.59	SA.F (1)	ST I	ST I (1)	2.11	No	4.00	4.00
DWE3	3 to 2 phi (1)	7.93	0.00	1.86	SA.F (1)	ST I	ST I (1)	2.17	No	4.00	4.00
DWE4	3 to 2 phi (1)	5.80	0.00	1.81	SA.F (1)	ST I	ST I (1)	1.51	No	4.00	4.00
DWE5	4 to 3 phi (1)	4.88	0.00	0.83	UN.SS (1)	ST I on III	ST I on III (1)	1.83	No	8.00	8.00
DWE6	3 to 2 phi (1)	7.87	0.00	0.81	SA.F (1)	ST I	ST I (1)	2.17	No	4.00	4.00
DWE7	3 to 2 phi (1)	6.07	0.00	1.46	SA.F (1)	ST I	ST I (1)	1.20	No	3.00	3.00
DWE8	4 to 3 phi (1)	5.64	0.00	0.91	SA.F (1)	ST I	ST I (1)	1.70	No	4.00	4.00
DWF1	> 4 phi (1)	10.93	0.00	1.72	UN.SI (1)	ST I	ST I (1)	2.86	No	5.00	5.00
DWF2	3 to 2 phi (1)	10.41	0.00	0.25	SA.F (1)	ST I	ST I (1)	2.32	No	5.00	5.00
DWF3	4 to 3 phi (1)	7.42	0.00	0.84	UN.SS (1)	ST I	ST I (1)	1.90	No	4.00	4.00
DWF4	3 to 2 phi (1)	7.45	0.00	3.71	SA.F (1)	ST I	ST I (1)	2.08	No	4.00	4.00
DWF5	3 to 2 phi (1)	7.23	0.00	0.77	SA.F (1)	ST I	ST I (1)	1.56	No	4.00	4.00
DWF6	3 to 2 phi (1)	5.42	0.00	0.62	SA.F (1)	ST I	ST I (1)	2.04	No	4.00	4.00
DWF7	3 to 2 phi (1)	7.65	0.00	1.09	SA.F (1)	ST I	ST I (1)	0.78	No	3.00	3.00
DWF8	3 to 2 phi (1)	4.95	0.00	1.95	SA.F (1)	ST I	ST I (1)	0.82	No	3.00	3.00
AVG		8.74	0.00	1.21				1.95		5.04	5.04
MAX		14.78	0.00	3.71				3.00		9.00	9.00
MIN		3.97	0.00	0.25				0.59		2.00	2.00

Abbreviations defined in Appendix A

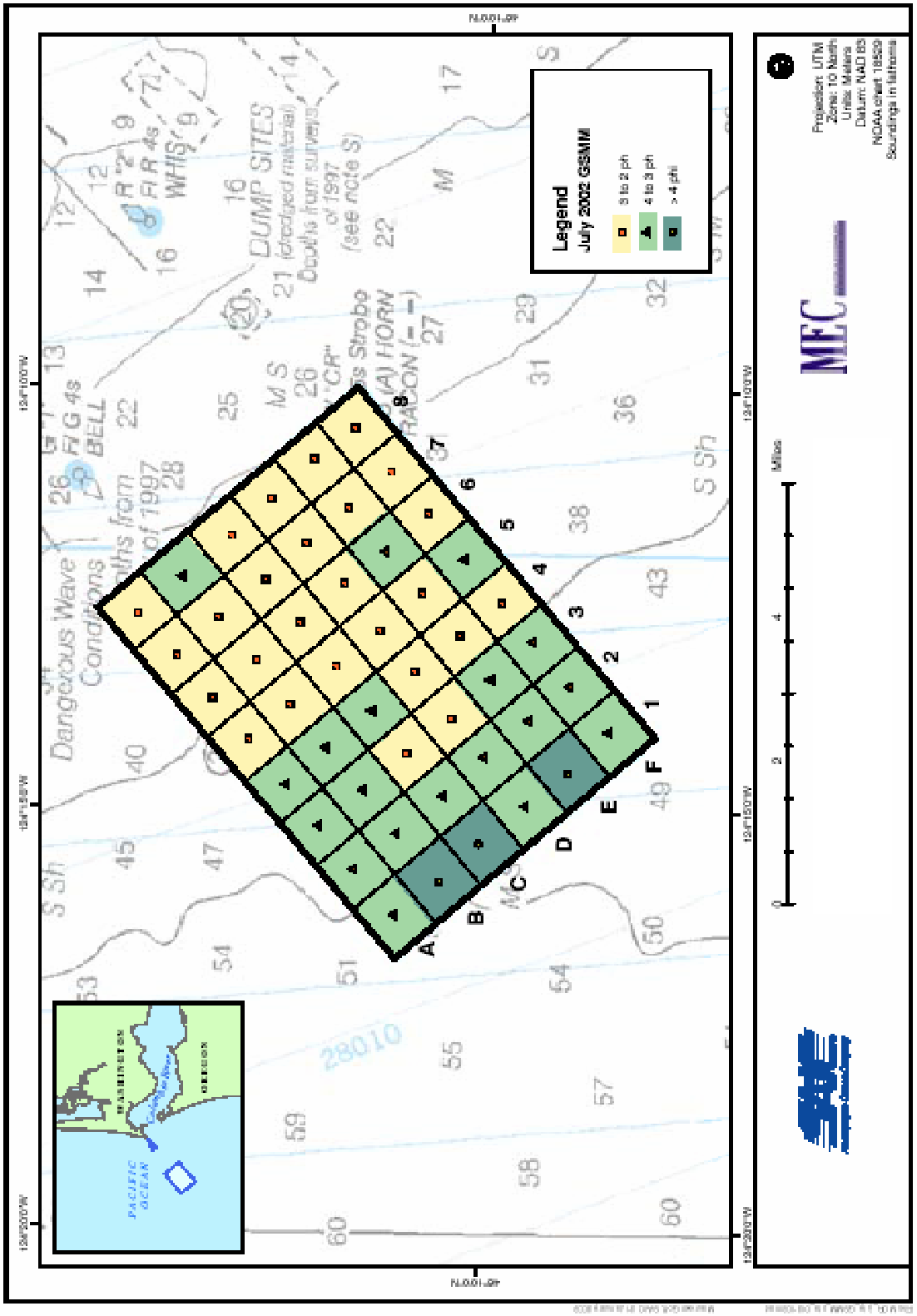


Figure 3.3. Grain Size Major Mode for SPI Survey, July 2002.

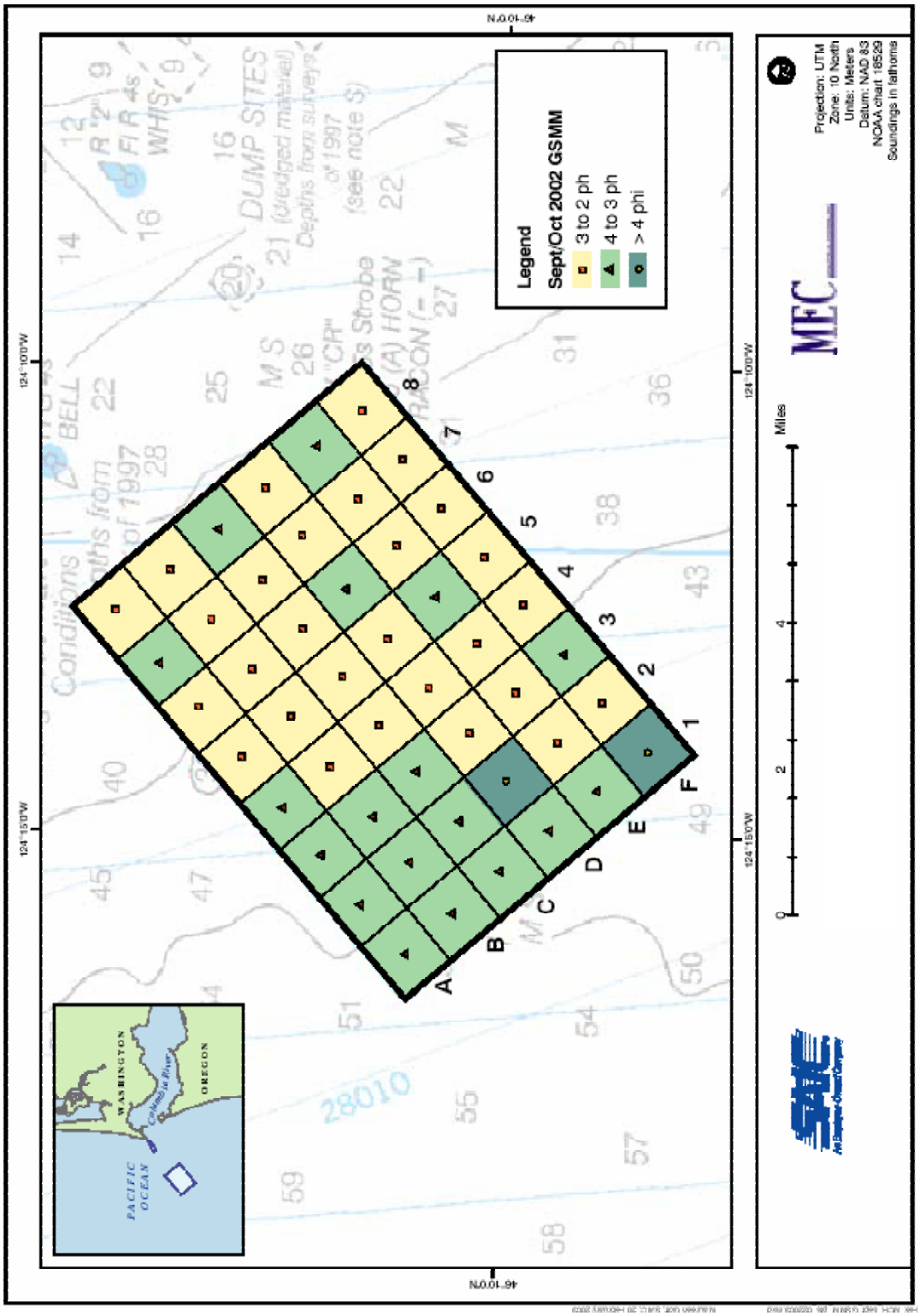


Figure 3.4. Grain Size Major Mode for SPI Survey, September 2002.

3.1.3 Mean Small-Scale Boundary Roughness

Small-scale boundary roughness features at the sediment surface are the result of depositional, erosional, and biogenic processes. Scouring of surface sediments, slope failure, or turbidite formation can also create physically induced boundary roughness (Hecker, 1992). For the July survey, the source of boundary roughness was determined to be physical for 24 of 48 replicates (50%). Biogenic activity which leads to boundary roughness includes the formation of fecal mounds, burrow excavation mounds, megafaunal foraging, or feeding pits. Biogenic activity was determined to be the source of boundary roughness in 20 of 48 replicates (42%). Four replicates (8%) were indeterminate as to the source of boundary roughness. The mean height (in a given image) of the boundary roughness for the July survey ranged from 0.36 to 2.26 cm, with an average height of 0.95 cm.

The source of boundary roughness in the September survey was determined to be physical in 29 of 48 (60%) replicates and biogenic in the remaining 19 replicates (40%). The mean height of the boundary roughness for the September survey ranged from 0.25 to 3.71 cm, with an average height of 1.21 cm. The relative increase (27%) in average boundary roughness appears to be attributable to seasonal depositional processes, and to a much lesser extent increased biogenic activity.

The boundary roughness coefficients and the source of the roughness (physical or biological) for July are depicted in Figure 3.5 and for September in Figure 3.6. Determining the source of the boundary roughness is based on visual analysis of the SPI images. It is likely that the higher roughness coefficients observed in the northeastern portion of the DWS were due to sand waves and the roughness in the southwest due to biogenic activity.

3.1.4 Mean Apparent Redox Potential Discontinuity (RPD) Depths

Apparent RPD depths at the DWS during the July 2002 survey had a mean depth (in a given image) ranging from 0.36 to 2.26 cm, with an average RPD depth of 1.17 cm throughout the site (Figure 3.7). During the September 2002 survey, the apparent RPD depths were generally greater with a range from 0.59 to 3.0 cm and a site average of 1.95 cm (Figure 3.8). The likely mechanism(s) for this relative increase in RPD depth are similar to those observed in changes to boundary roughness (Section 3.1.3); sedimentation of particles through the water column would provide additional oxidized material and increased *in situ* bioturbation, as benthic communities become more developed.

3.1.5 Benthic Habitat Type

Two basic types of benthic habitat (Figures 3.9 and 3.10) were identified in the images collected during the July survey: 1) fine sand (SA.F: 69%) and 2) fine sand/silty material (UN.SS: 31%) in the deeper, westernmost portion of the site with an area of unconsolidated soft bottom. The same habitat types were predominate during the September survey with fine sand (SA.F: 60%) and unconsolidated soft bottom of fine sand/silty material (UN.SS: 35%), as well as unconsolidated soft bottom of silty material (UN.SI: 4%). The slight changes in habitat type are reflective of increased sedimentation of silty material during the summer months.

3.1.6 Infaunal Successional Stage

The predominant infaunal successional stages observed in images collected in July were Stage I (77%) and to a lesser extent Stage I on III (21%), and one location identified as Stage I on II (2%); Figure 3.11. This indicates that the DWS is at a primary stage of infaunalization (i.e.,

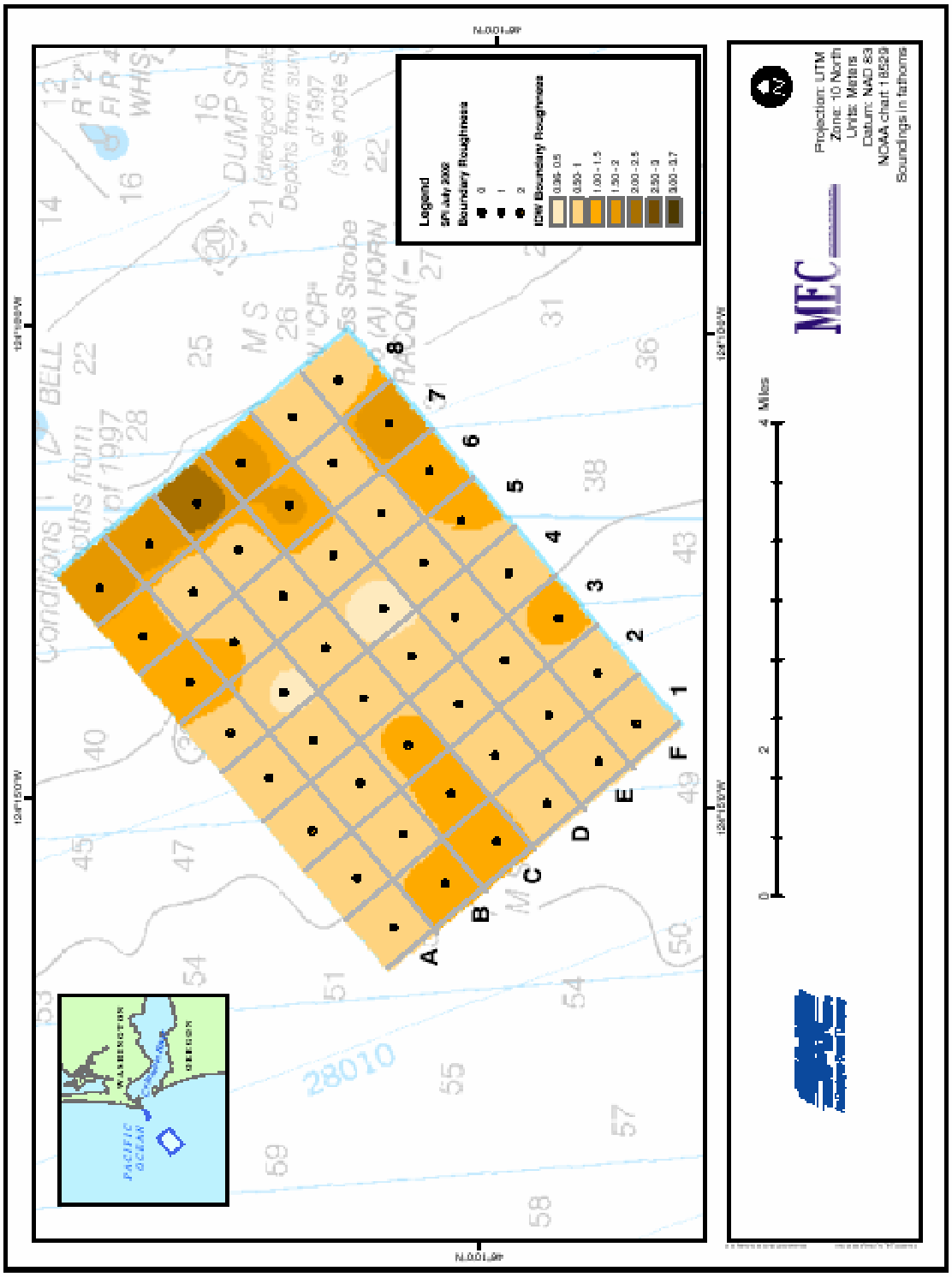


Figure 3.5. Boundary Roughness Characteristics Defined by SPI Survey at DWS in July 2002.

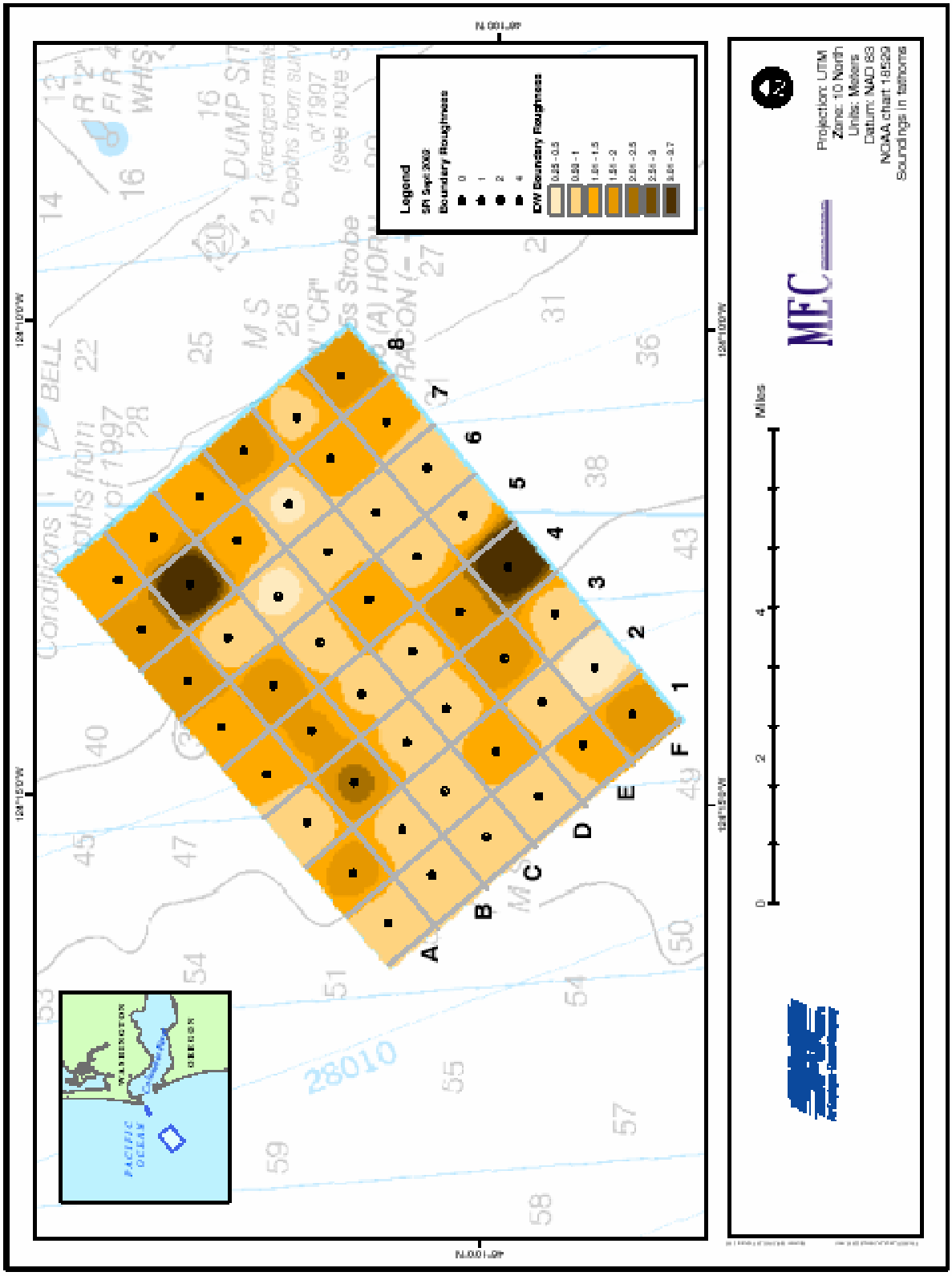


Figure 3.6. Boundary Roughness Defined by SPI Survey at DWS in September 2002.

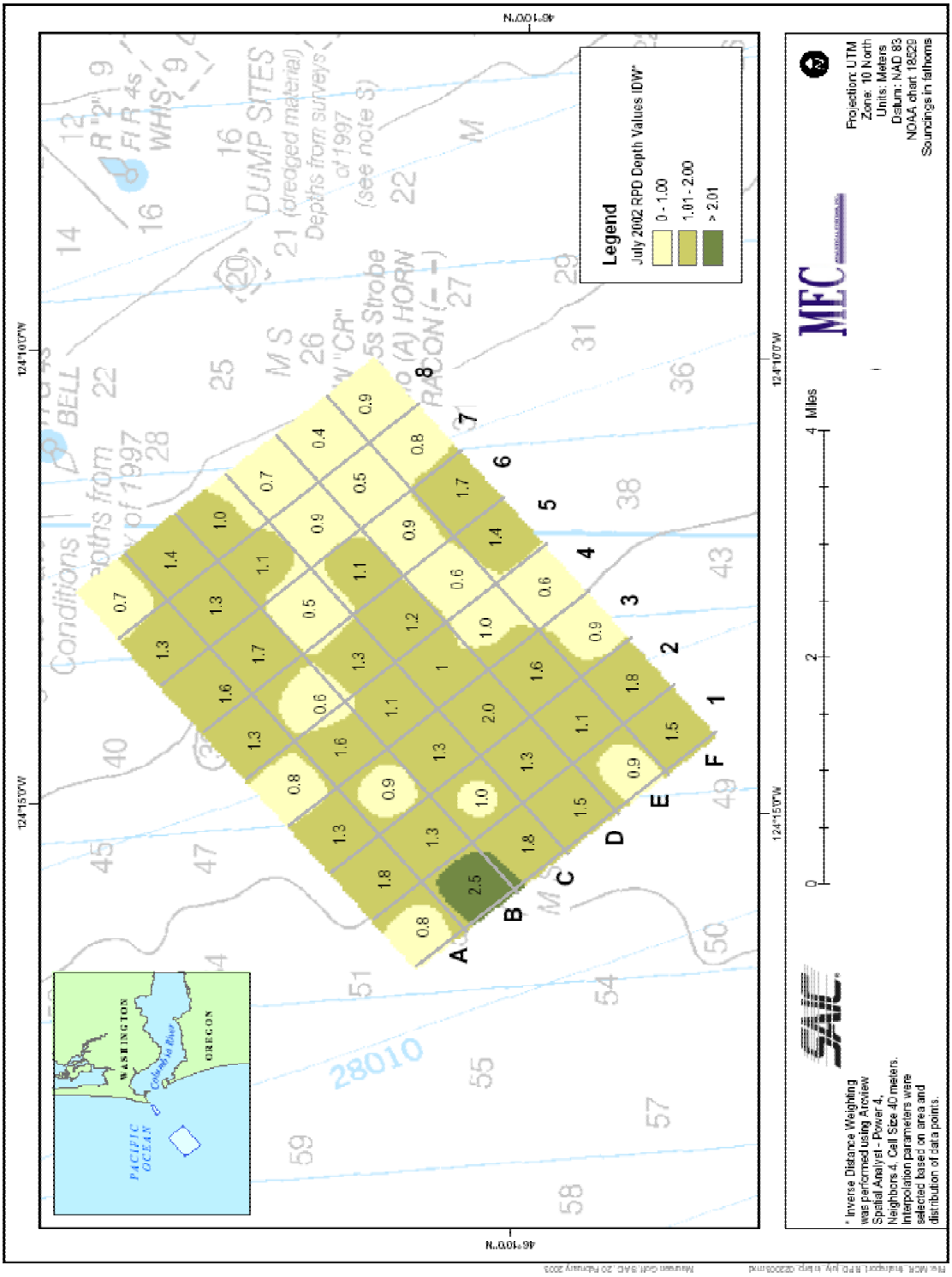


Figure 3.7. Mean Apparent Redox Potential Depths (RPD) Defined by SPI Survey for DWS in July 2002.

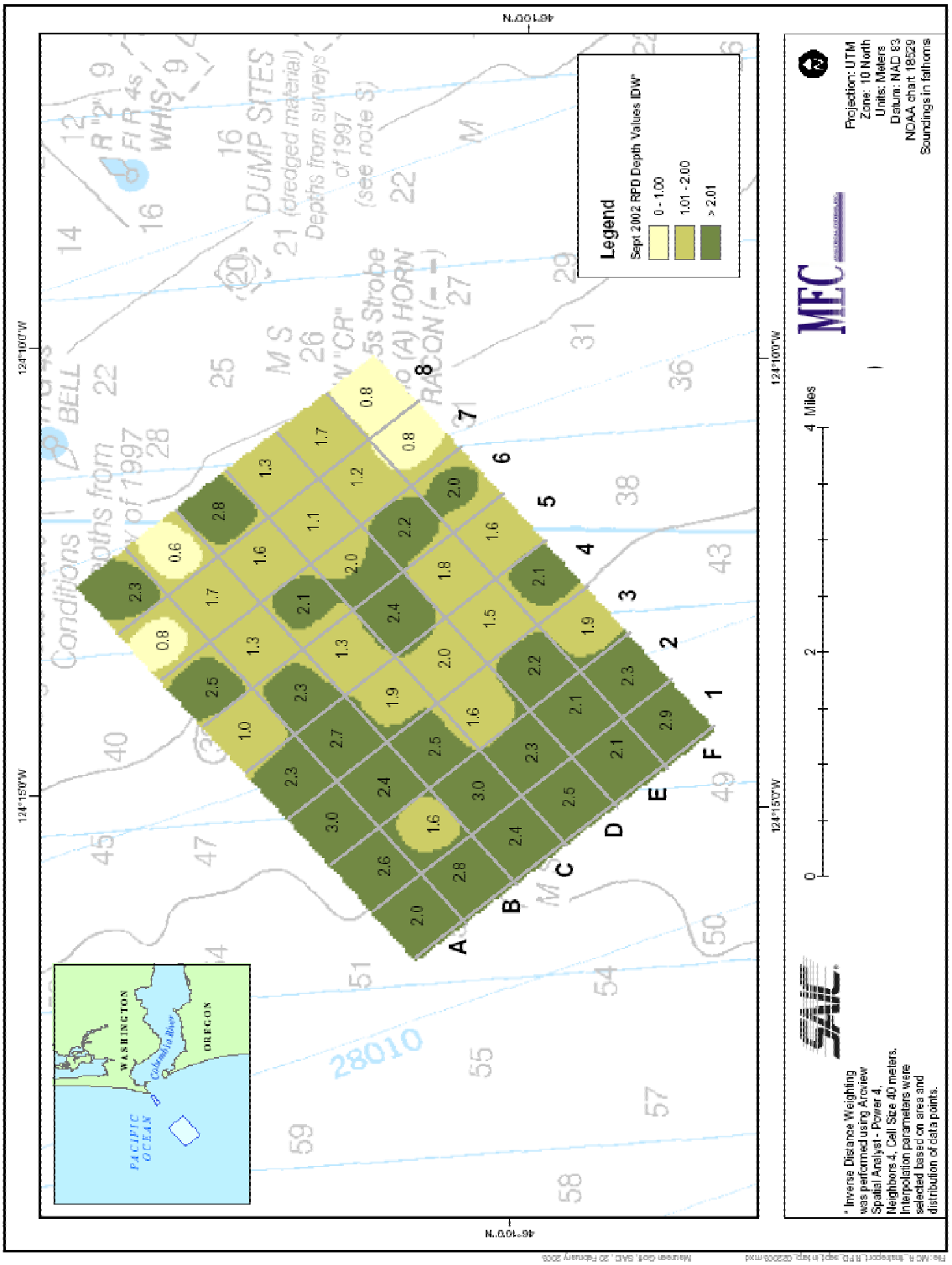


Figure 3.8. Mean Apparent Redox Potential Depths (RPD) Defined by SPI Survey for DWS in September 2002 .

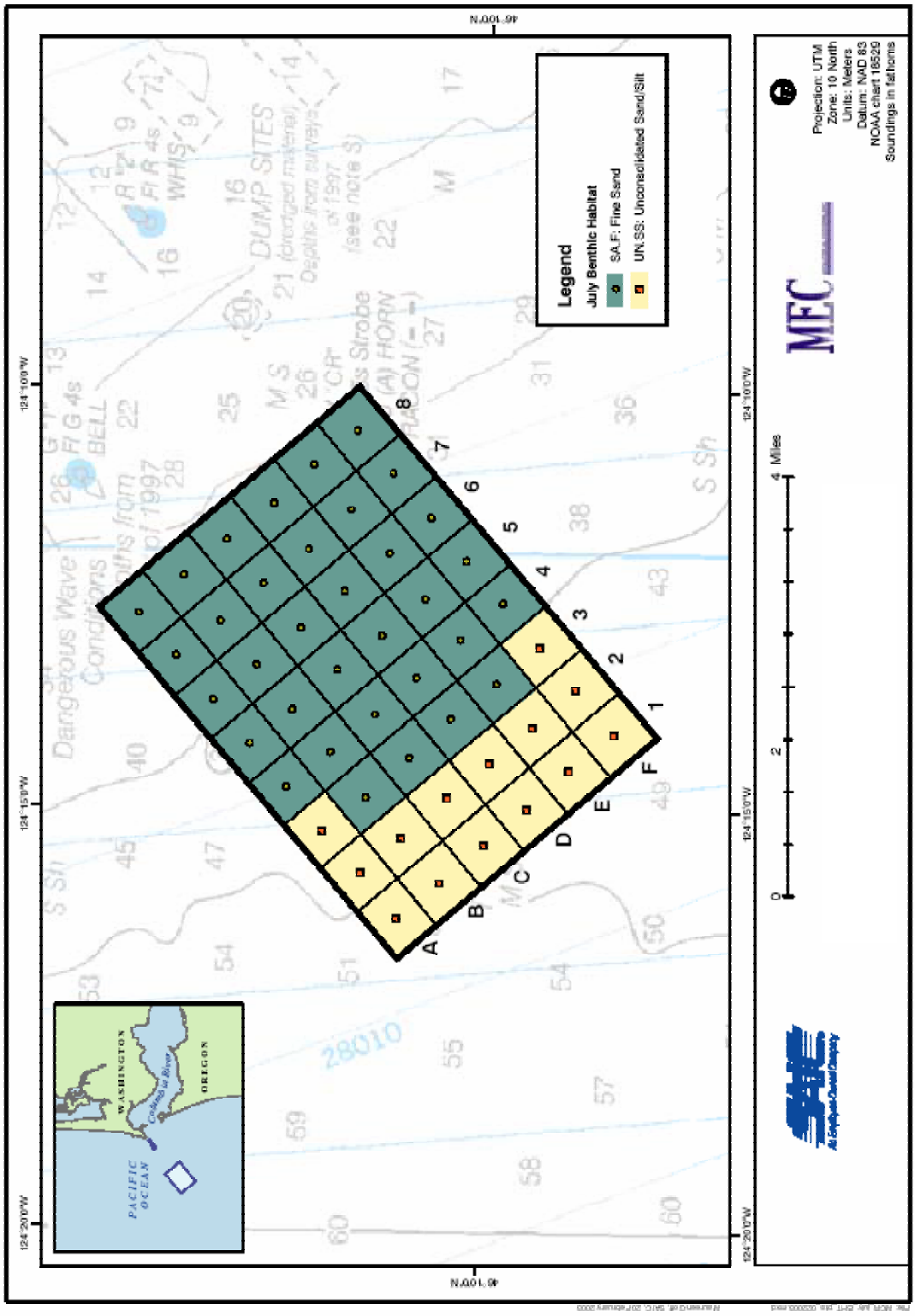


Figure 3.9. Benthic Habitat Type Defined by SPI Survey for DWS in July 2002.

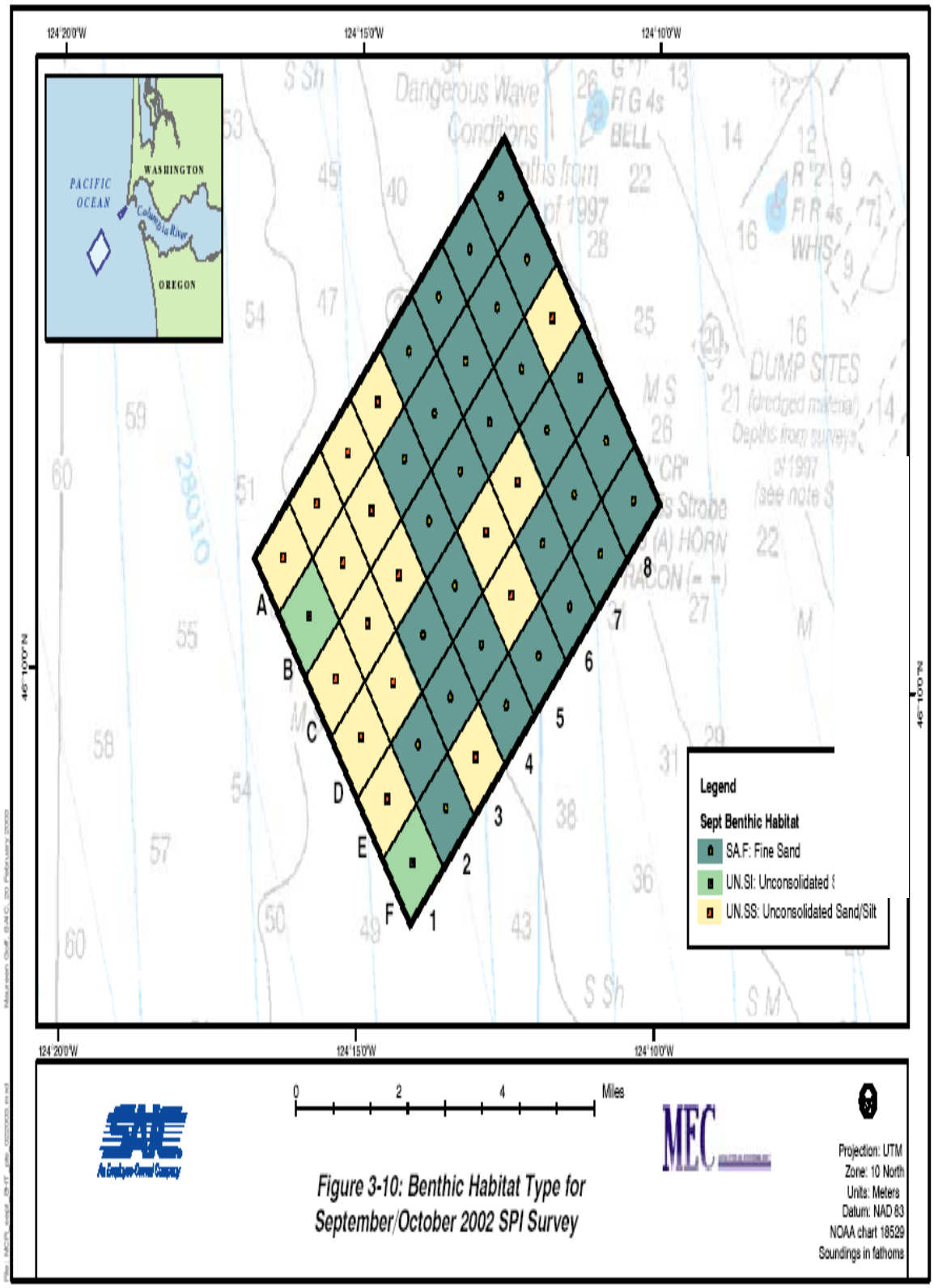


Figure 3-10: Benthic Habitat Type for September/October 2002 SPI Survey

Figure 3.10. Benthic Habitat Types Defined by SPI Survey for the DWS in September 2002.

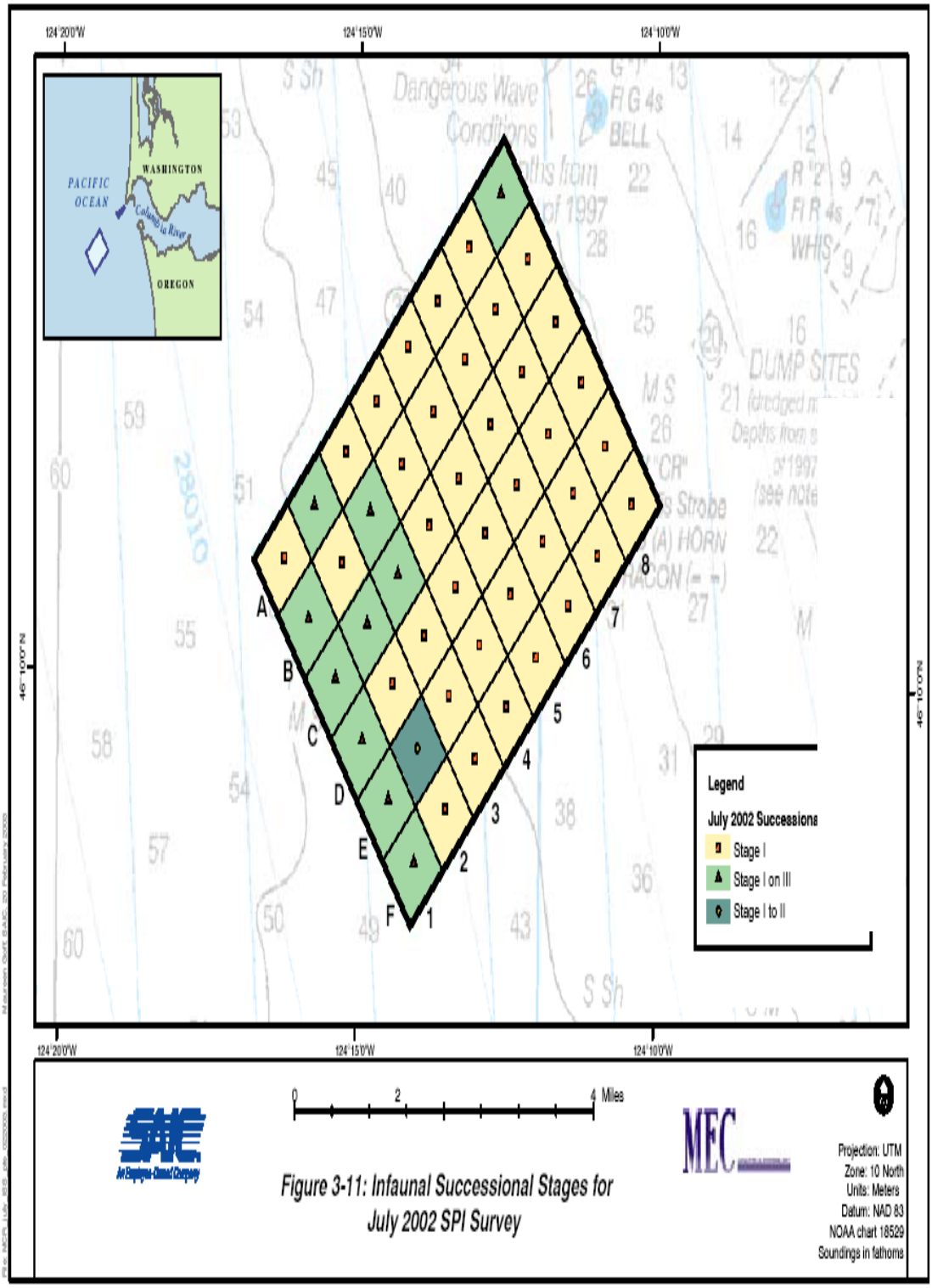


Figure 3.11. Infaunal Successional Stages Characterized by SPI Survey for DWS in July 2002.

Stage I), with a sediment-water interface composed of small, colonizing benthic organisms. The Stage I on III successional stage indicates that the infaunal community has been physically disturbed and is in the process of re-colonization. The September images are consistent with the July observations consisting of Stage I (77%) and Stage I on III (23%) infaunal successional stages (Figure 3.12). The similarities between the two surveys indicate that the infaunal community has not established itself to a higher order infaunal community during the time interval between surveys. This may be due in part to the relative short time frame between surveys (2-3 months), or that the seafloor conditions (i.e. substrate, bottom currents) limit the establishment of a higher order benthic community typically found in a depositional environment.

3.1.7 Organism-Sediment Index

The OSI, which incorporates the RPD, infaunal successional stage, DO conditions, and presence of methane, ranged from 0.5 to 8.0, with a mean value of 3.7 for the July survey. For the September survey the OSI ranged from 2.00 – 9.00, with a mean value of 5.0. In general, the higher OSI values are in the deeper westernmost portion of the site, gradually decreasing to the eastern, shallower end. The slight increases in the OSI values between July and September was largely due to the deepening of the RPD, since the infaunal successional stage remained relatively constant. Dissolved oxygen and methane are not an issue at the site, as anoxic conditions are not prevalent. OSI values less than 6 are typically indicative of recently disturbed areas. As evident in Figures 3.13 and 3.14, the OSI gradient shows an increasing trend across the site from the deeper (western) to the shallower (eastern) side of the site from July to September. The general increase in the OSI value is indicative of increasingly enhanced habitat conditions that are likely due to seasonal processes, with the shallower portions of the site subject to greater physical disturbances. In lieu of any widespread anthropogenic disturbances, the DWS may undergo dynamic or seasonal periods of disturbances such as winter storms, which in conjunction with a predominately sandy substrate, prevent the establishment of Stage III infaunalization, and instead creates a (seasonal) cycle of re-colonization by a climax community of Stage I organisms.

3.2 Sediment Conventional Results

Twelve sediment samples were evaluated for TOC and sediment grain size in July and September 2002 (Appendix H). A summary of these data is included in Table 3.3. The concentrations of TOC ranged from 0.17% to 0.80%, with increased TOC co-occurring with increasing depth (Figure 3.15). With the exception of Station A7 and the western corner (West), TOC concentrations in the fall samples were equal to or higher than TOC concentrations observed the summer samples. Stations A7 and West had the highest TOC concentrations during both sampling events, with TOC concentrations ranging from 0.67 to 0.80% TOC.

The dominant sediment grain size fractions were fine to very fine sand, with mean phi ranged from 2.75 to 4.35. As with TOC, mean phi size co-varied with depth; the highest phi sizes (very fine sand/silt) occurred in the deeper areas and the lower phi sizes (sand) occurred in the shallower portions of the DWS (Figure 3.16). This trend confirmed the sediment-type observations made with SPI habitat characterization (Figure 3.1 and 3.2). Finer sediment was observed during the September sampling, compared to the July sampling event, with higher phi sizes occurring at each of the stations in September, with the exception of Stations A7 and West. This shift towards finer size fractions resulted in increases in both the silt and clay fractions (Table 3.3). There was a highly significant relationship between mean phi and TOC for both sampling events and for all measurements made during the July and September/October analyses (Figure 3.17).

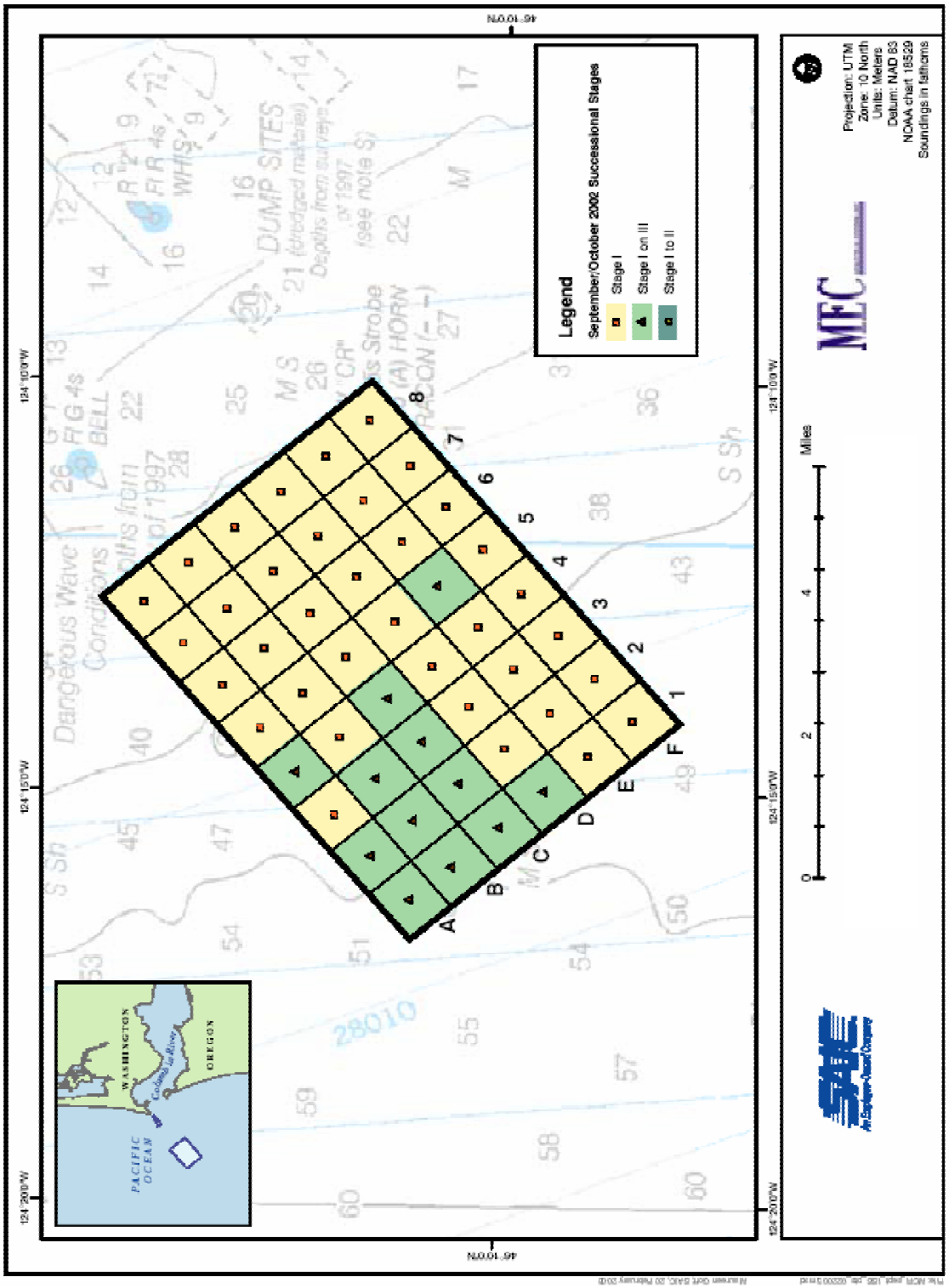


Figure 3.12. Infaunal Successional Stages Characterized by SPI Survey for DWS in September 2002.

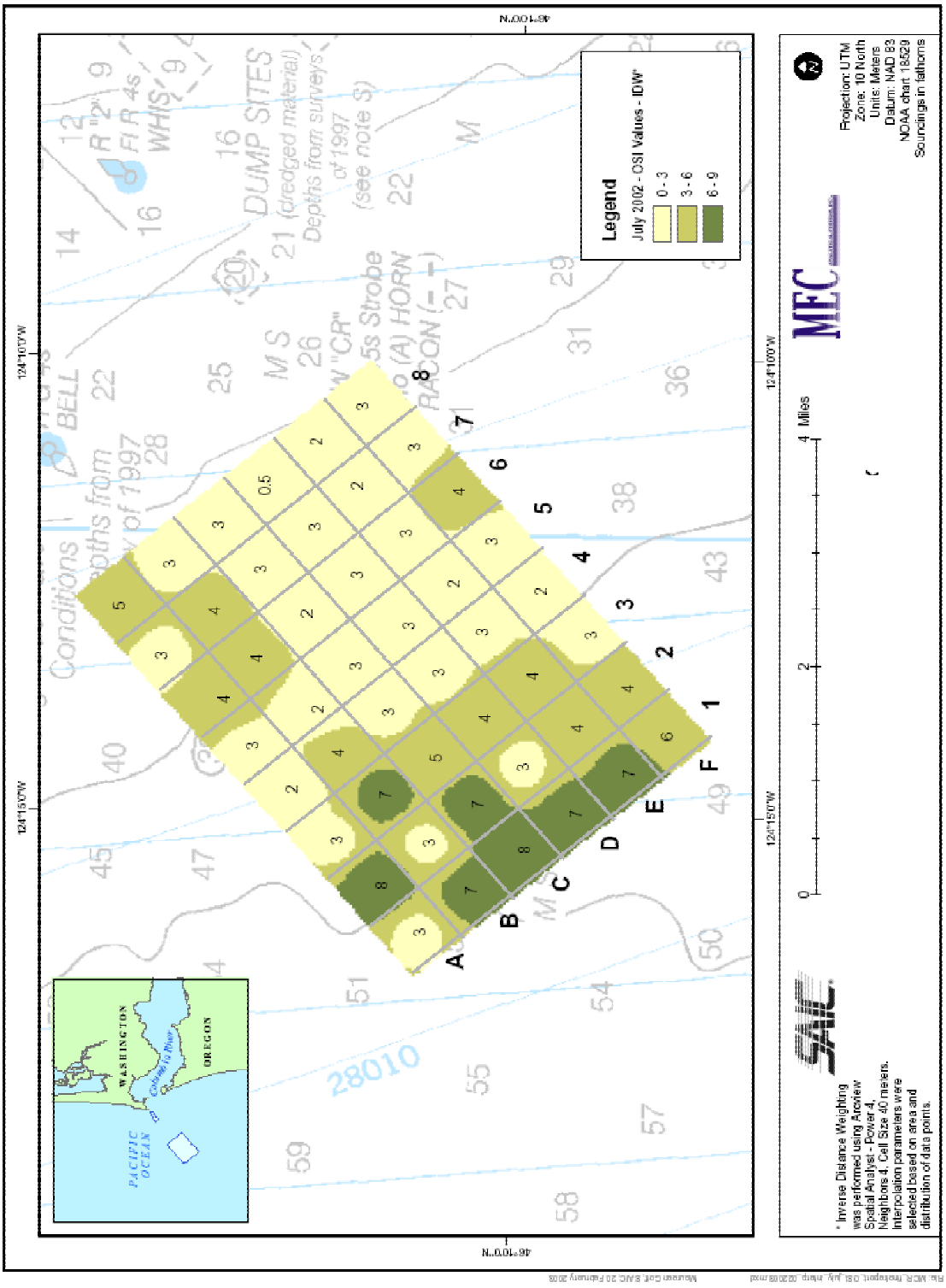


Figure 3.13. Organism-Sediment Index Characterized by SPI Survey for DWS in July 2002.

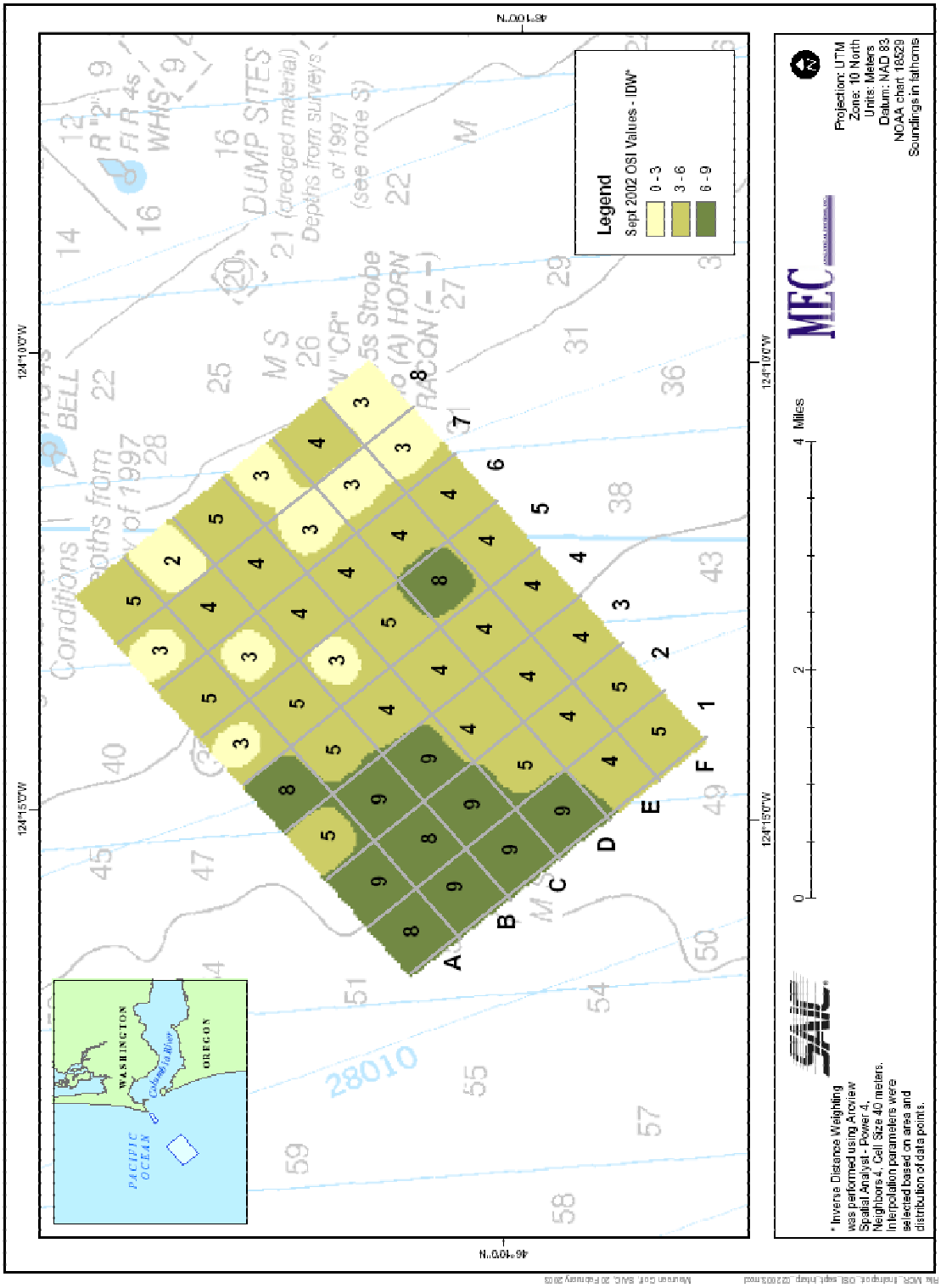


Figure 3.14. Organism-Sediment Index Characterized by SPI Survey for DWS in September 2002.

Table 3.3. Percent Mass of Total Organic Carbon and Grain Size Fractions of Sediment in July and September 2002.

Station	Total Organic Carbon		Sediment Grain Size											
			Gravel		Sand		Silt		Clay		Phi			
											Median		Mean	
	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
A3	0.45	0.43	0.12	0.03	85.1	83.3	8.0	9.7	6.8	7.0	2.79	2.76	3.04	3.22
A7	0.79	0.67	0.15	0.52	74.6	78.0	14.9	14.6	10.3	6.9	2.81	2.81	4.29	4.09
C2	0.55	0.54	0.22	0.05	85.8	83.4	7.36	10.0	6.6	6.5	2.82	2.85	3.00	3.26
C6	0.28	0.29	0.05	0.00	89.3	91.7	6.1	4.4	4.5	3.8	2.74	2.71	2.82	2.75
C8	0.27	0.46	0.00	0.01	88.0	81.9	7.2	10.6	4.8	7.5	2.76	2.77	2.87	3.46
D7	0.31	0.39	0.09	0.00	90.8	85.3	4.6	7.5	4.5	7.2	2.71	2.78	2.76	2.98
E2	0.42	0.52	0.27	2.23	87.3	79.9	6.1	10.0	6.3	7.9	2.80	2.85	2.90	3.46
F6	0.26	0.37	0.40	0.03	91.7	88.5	3.9	6.6	4.0	4.9	2.76	2.77	2.80	2.86
East	0.17	0.40	0.01	0.03	92.5	83.3	4.5	11.3	3.0	5.3	2.71	2.82	2.72	3.30
North	0.35	0.43	0.00	0.00	89.0	81.0	5.7	10.9	5.3	8.1	2.76	2.77	2.85	3.60
South	0.23	0.26	0.10	0.00	94.4	91.5	1.9	4.7	3.6	3.9	2.75	2.80	2.79	2.91
West	0.80	0.67	0.02	0.09	71.1	76.6	18.2	13.1	10.7	10.2	3.25	3.18	4.58	4.35

Measurements in % dry weight.

Shaded values indicate decreasing grain size or increasing TOC between July and September (Differences are at least 0.05% TOC or ~ 3% grain size increase)

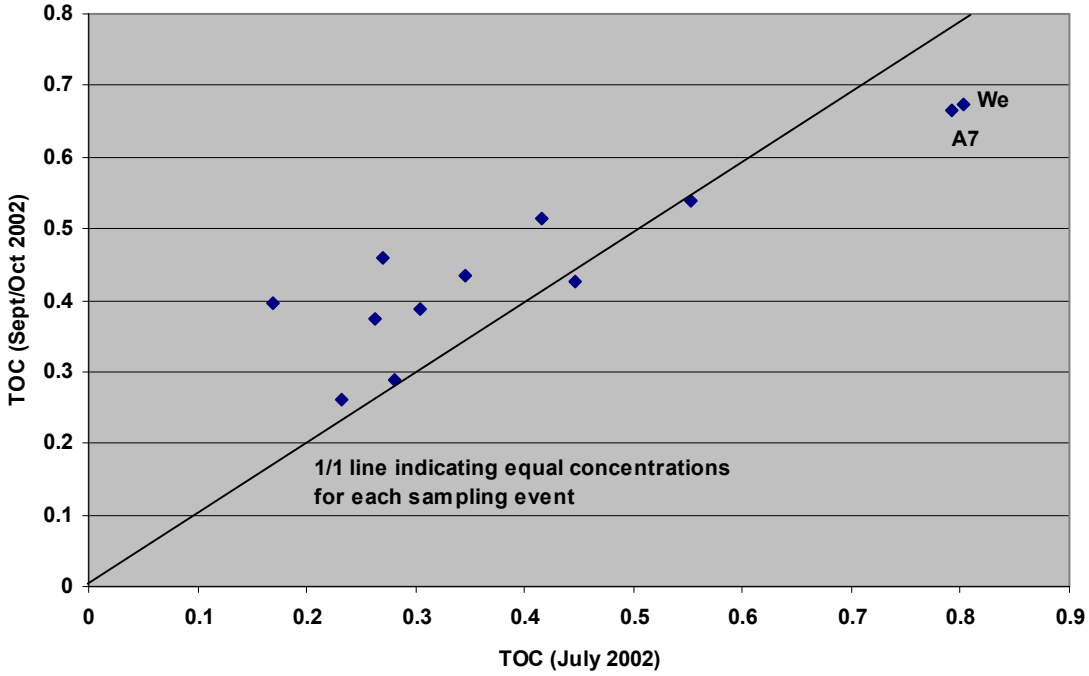


Figure 3.15. Seasonal Relationship of Total Organic Carbon at DWS.

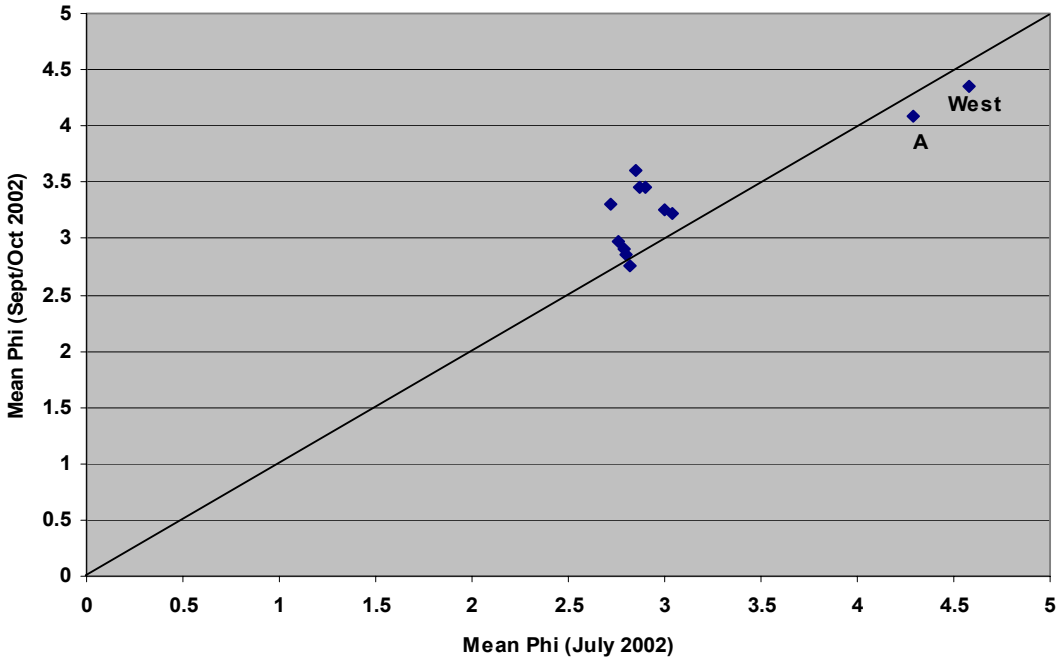


Figure 3.16. Mean Phi Grain Size Diameter at DWS (July and September 2002).

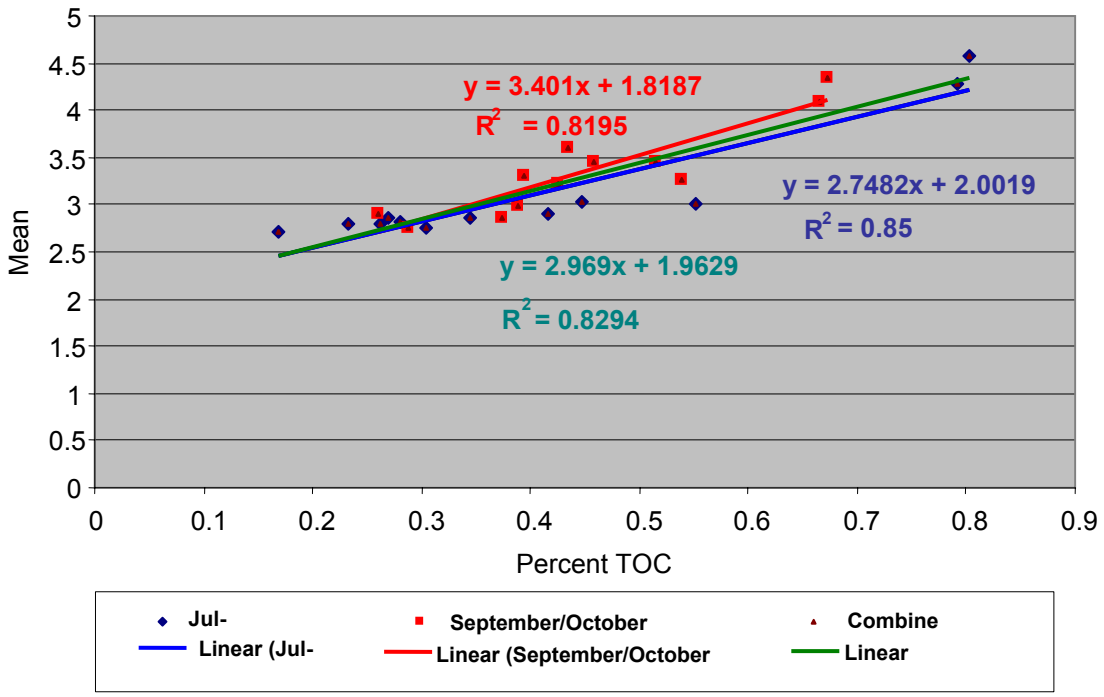


Figure 3.17. Relationship of Total Organic Carbon and Grain Size at DWS.

3.3 Benthic Invertebrate Community

A total of 28 grab samples were collected to evaluate the benthic community in the DWS at 12 stations (Figure 2.4, Table 3.4). Eight of the DWS stations were located within the DWS boundaries, and four stations were outside the DWS, to the north, south, east, and west. Samples were collected for benthos during both July and September surveys.

The average infaunal abundance in the DWS stations for July 2002 ranged from 142 to 478 individuals per $0.1m^2$ (Figure 3.18). The highest infaunal abundance was observed in the fine-grained material found in the southern and western portions of the DWS, particularly stations A3, C2, E2, and West. The lowest abundance was observed in the sand-dominated stations in the eastern portion of the DWS. Species richness (R), as measured by the average number of species occurring at a given station, ranged from 36 to 72 species (Figure 3.18). Trends in richness closely matched those in abundance, with the most diverse benthic communities occurring at stations in the south and western portions of the DWS.

In July, polychaetes and molluscs were the dominant taxa throughout the DWS, representing an average of 55% and 24% of the individuals observed across the site (Table 3.5). In the western portion of the site (stations A3, C2, E2, North and West), an average of 73% of the total number of individuals were polychaetes, while 18% were molluscs. In the remainder of the DWS, polychaetes represented 34% to 55% of the individuals observed, with molluscs comprising 27% to 50% of the individuals. It is also interesting to note that crustaceans were more important in the eastern portions of the DWS, making up 12% to 29% of the total number of individuals.

In the September samples, abundance and richness were substantially and consistently higher, with abundance ranging from 262 to 701 individuals per $0.1\ m^2$ and richness ranging from 38 to 82 species observed (Figure 3.19). As in July, abundance was highest in the more westerly stations (with the exception of station West) and decreased in the more easterly stations. However, in September, stations North, South, and A7 also had high invertebrate abundance, relative to the easterly stations. The lowest abundance was observed at Station C8. This trend was also observed in species richness, which was greater than 60 species at Stations North, West, A3, A7, C2, E2, and South. Richness was less than 60 species at all other stations, and was 38 species in Station East.

As in July, polychaetes and molluscs were the dominant taxa, representing 63% and 25% of the benthic community, respectively (Table 3.6). Similar to the trends observed in overall abundance, the characteristics of the western portions of the site in July were observed in some of the more easterly stations. An increase in polychaete abundance was observed at stations A7, C6, D7, C8, and F6, resulting in a shift in the community towards polychaetes and away from molluscs and crustaceans.

In order to better understand trends in the infaunal community across the DWS, Bray-Curtis similarity analysis was conducted for the July and September benthic infaunal datasets (Figures 3.20, 3.21). Cluster analysis was performed on all taxa that occurred at three or more stations. Abundance data were square-root transformed and then normalized by dividing each species-abundance by the mean abundance for all stations. These transformed values were used to calculate a Bray-Curtis dissimilarity matrix for each species and station. Cluster analysis utilized the transformed dissimilarity matrix to generate visual representations of among-station and among-species relationships that had similar characteristics. The analysis used an agglomerative,

Table 3.4. Location of Benthic Grabs Collected from the Deepwater Site in July and September 2002.

Date	Station	Rep.	Latitude	Longitude
July Sampling Locations				
13-Jul-2002	West	1	46 09.49	124 15.75
13-Jul-2002	C-2	1	46 10.36	124 14.95
13-Jul-2002	C-2	2	46 10.36	124 14.69
13-Jul-2002	E-2	1	46 09.66	124 13.92
13-Jul-2002	E-2	2	46 09.62	124 14.05
13-Jul-2002	A-3	1	46 11.32	124 15.25
13-Jul-2002	A-3	2	46 11.38	124 15.36
13-Jul-2002	C-6	1	46 11.56	124 12.79
13-Jul-2002	C-6	2	46 11.49	124 12.83
13-Jul-2002	East	1	46 12.21	124 10.89
14-Jul-2002	South	1	46 09.52	124 11.65
14-Jul-2002	F-6	1	46 10.55	124 11.34
14-Jul-2002	F-6	2	46 10.47	124 11.27
14-Jul-2002	D-7	1	46 11.41	124 11.98
14-Jul-2002	D-7	2	46 11.47	124 11.97
15-Jul-2002	D-7	3	46 11.44	124 11.95
15-Jul-2002	D-7	6	46 11.47	124 11.88
15-Jul-2002	D-7	8	46 12.26	124 11.88
15-Jul-2002	C-8	1	46 12.18	124 11.96
15-Jul-2002	C-8	2	46 12.21	124 11.79
15-Jul-2002	C-8	5	46 12.13	124 11.74
15-Jul-2002	C-8	6	46 12.59	124 11.98
15-Jul-2002	A-7	1	46 12.57	124 13.32
15-Jul-2002	A-7	2	46 12.57	124 13.17
15-Jul-2002	A-7	3	46 12.53	124 13.28
15-Jul-2002	A-7	4	46 12.57	124 13.09
15-Jul-2002	North	1	46 12.23	124 14.99
15-Jul-2002	North	2	46 12.26	124 14.98
September Sampling Locations				
15-Sept-2002	A7	1	46 12.592	124 13.215
15 Sept-2002	A7	2	46 12.544	124 13.211
15 Sept-2002	A7	3	46 12.590	124 13.251
15 Sept-2002	North	1	46 12.179	124 14.997
15 Sept-2002	A3	1	46 11.301	124 15.322
15 Sept-2002	A3	2	46 11.342	124 15.141
15 Sept-2002	A3	3	46 11.300	124 15.233
15 Sept-2002	C2	1	46 10.326	124 14.823
15 Sept-2002	C2	2	46 10.300	124 14.798
15 Sept-2002	C2	3	46 10.268	124 14.879
15 Sept-2002	West	1	46 09.363	124 15.617
15 Sept-2002	E2	1	46 09.586	124 14.079
15 Sept-2002	E2	2	46 09.578	124 14.053
15 Sept-2002	South	1	46 09.621	124 11.893
15 Sept-2002	F6	1	46 10.508	124 11.553
15 Sept-2002	F6	2	46 10.492	124 11.546
16 Sept-2002	C6	1	46 11.517	124 12.777
16 Sept-2002	C6	2	46 11.592	124 12.880
16 Sept-2002	D7	1	46 11.501	124 11.893
16 Sept-2002	D7	2	46 11.475	124 11.833
16 Sept-2002	C8	1	46 12.196	124 11.834
16 Sept-2002	C8	2	46 12.131	124 11.799
16 Sept-2002	East	1	46 12.263	124 10.933

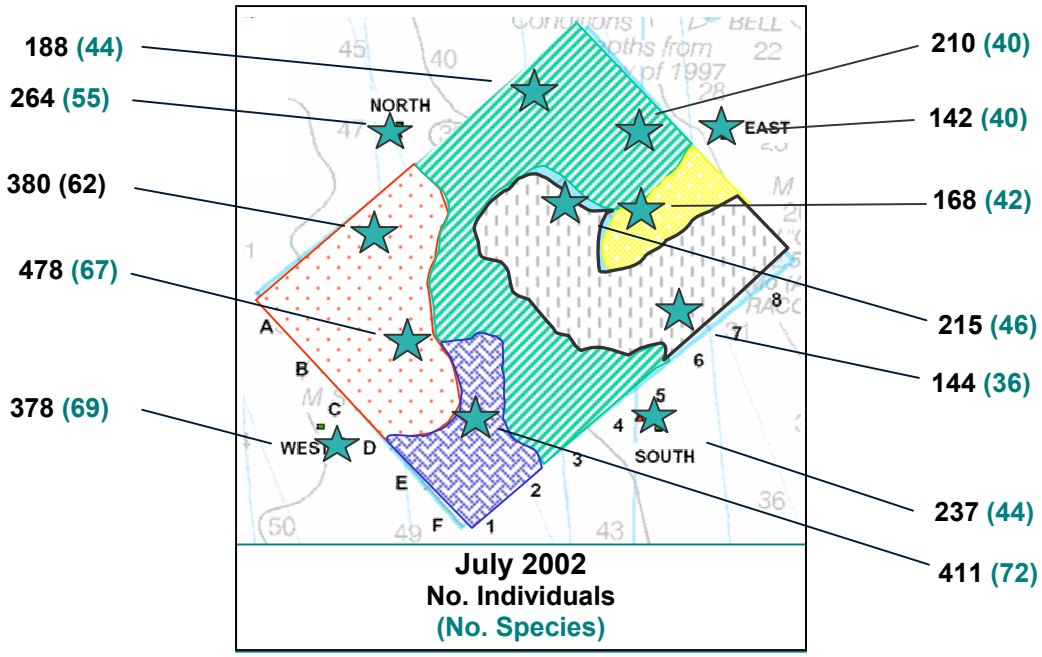


Figure 3.18. Representation of Abundance and Number of Species of Benthic Invertebrates from DWS (July 2002).
(see Figure 3.17 for base map legend).

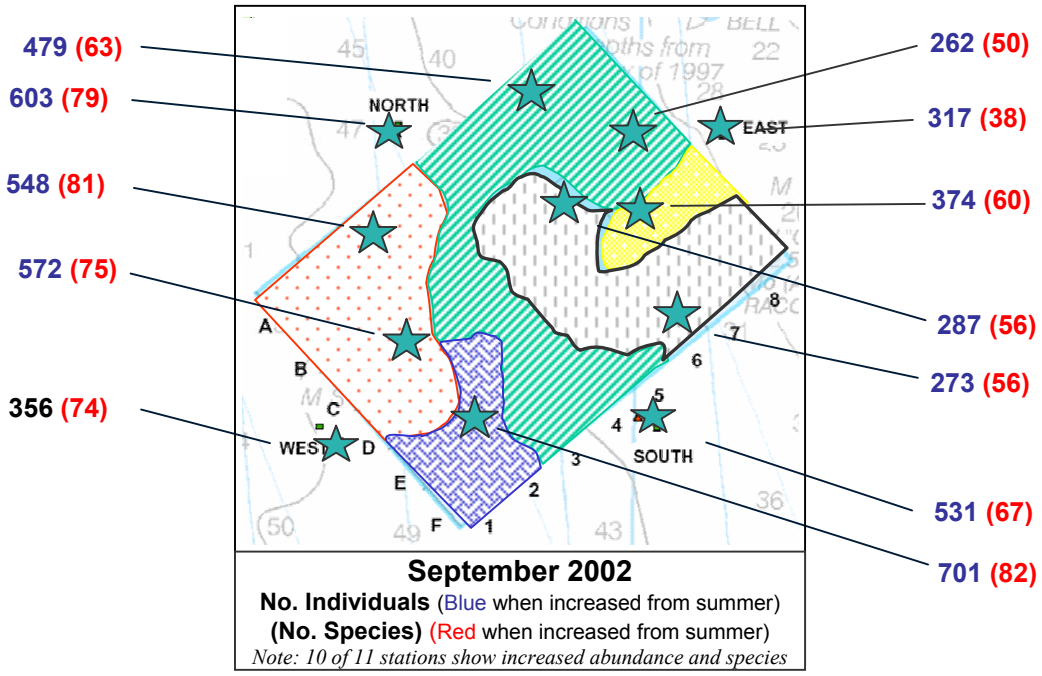


Figure 3.19. Representation of Abundance and Number of Species of Benthic Invertebrates from DWS. (September 2002)
(see Figure 3.17 for base map legend)

Table 3.5. Abundance and Number of Species of Invertebrates (July 2002).

Species	A3	C2	E2	North	West	C8	A7	C6	F6	D7	South	East
% Abundance												
Crustaceans	4	3	6	5	1	14	12	25	29	22	27	23
Echinoderms	2	1	3	6	1	1	3	3	2	1	3	1
Minor Phyla	2	2	4	2	2	1	1	1	0	1	2	0
Mollusca	16	17	22	17	19	50	30	30	30	34	27	31
Polychaeta	75	77	66	71	77	34	55	40	39	42	41	45
% Number of Species												
Crustaceans	13	10	15	13	6	24	17	21	20	25	19	21
Echinoderms	3	4	4	6	3	3	7	4	4	4	7	3
Minor Phyla	10	10	9	4	9	4	3	4	5	4	9	0
Mollusca	24	28	24	24	26	16	20	18	22	14	21	18
Polychaeta	51	49	49	49	54	56	53	53	52	53	44	59

Table 3.6. Abundance and Number of Species of Invertebrates (September 2002).

Species	A3	C2	E2	North	West	A7	C6	D7	C8	F6	South	East
% Abundance												
Crustaceans	7	4	5	10	6	8	11	16	19	17	16	26
Echinoderms	2	2	2	3	1	1	3	2	1	2	1	1
Minor Phyla	4	5	10	4	3	2	3	2	1	3	27	0
Mollusca	14	12	12	13	17	18	22	22	30	19	9	25
Polychaeta	73	77	70	70	73	70	60	57	49	59	47	48
% Number of Species												
Crustaceans	13	11	12	14	10	16	12	15	22	20	20	19
Echinoderms	5	3	5	3	3	2	2	2	3	2	3	5
Minor Phyla	10	11	12	13	8	10	10	9	4	7	8	3
Mollusca	21	22	21	17	16	15	13	12	12	12	18	8
Polychaeta	51	54	51	54	63	58	63	62	60	59	52	65

Numbers in red indicate increased numbers compared to July sampling period.

REPLACE WITH 11X 17 FROM WORD FILE “CLUSTER FIGURES 11X17 PORTRAIT” (PG. 1)

Figure 3.20. Bray-Curtis Similarity Cluster Analysis Performed on Benthic Infaunal Data from July 2002 Survey.

REPLACE WITH 11X 17 FROM WORD FILE “CLUSTER FIGURES 11X17 PORTRAIT” (PG. 2)

Figure 3.21. Bray-Curtis Similarity Cluster Analysis Performed on Benthic Infaunal Data from September 2002 Survey.

hierarchical method with flexible sorting (Beta = -0.025) because this produces well-defined "clusters" of entities. Stations that cluster together have similar species and distribution of abundance.

The similarity analysis performed on the July data revealed two primary infaunal communities, termed Group 1 and Group 2, that bore little taxonomic similarity to each other. Group 1 was comprised of stations A3, C2, E2, North and West. The general features of Group 1 were relatively high abundance, moderate numbers of species per sample, and moderate species richness. The most distinctive feature of the Group 1 stations was the dominance of the tube-building polychaete, *Magelona cerae*, which represented approximately 40% of the individuals (Table 3.7). Group 1 was then further divided into two groups of similar stations, Groups 1A and 1B. Subgroup 1A was defined as station A3, C2, and E2 and featured tube-building polychaetes and the mollusc, *Acila castrensis*. Subgroup 1B was defined as stations North and West and featured the clams *Axinopsida serricata* and *A.castrensis* as well as species of tube-building and free burrowing worms.

Group 2 was generally characterized by lower abundance and species richness, but with more evenness among the most common species. The clam, *A. serricata* was the most abundant species observed in Group 2, comprising approximately 20% of the individuals. Group 2 was further divided into three subgroups, 2A, 2B, and 2C. Subgroup 2A was further defined by the tube-building polychaete, *Galathowenia oculata*, and the clam *A. castrensis*. Subgroups 2B and 2C were further defined by the highly mobile ostracod, *Euphilomedes carcharodonta*, the polychaetes *G. oculata* and *Chaetozone columbiana.*

Similarity clusters based on the September infaunal data were remarkably similar to those of July. The infaunal community was divided into two dissimilar groups, Group 1 and Group 2. Group 1 consisted of stations A3, C2, E2, North and West and was characterized by high abundance, high species richness, and dominance by *M. cerae* (Table 3.8). Subgroups 1A and 1B consisted of the same stations as in July and were characterized by similar species dominance.

In September, Group 2 was characterized by lower abundance and species richness (relative to Group 1) and greater evenness in the distribution among species in the first 70% of individuals. The dominant species in Group 2 were *A. serricata* and *G. oculata*. In September, there were four subgroups, two of which were comprised of one station. Subgroup 2A (Stations A7, C6, and D7) was further defined by the relative abundance of tube-building Maldanid polychaete worms and ostracod, *E. carcharodonta*. Subgroups 2B and 2C (Stations C8 and F6, respectively) were further defined by the more opportunistic species *Diastylis dawsoni*, *E. carcharodonta*, and *C. columbiana*. Subgroup 2D (Stations South and East) was made distinct by a population of the tunicate, *Molgula* sp. which occurred at Station South.

When the Bray-Curtis Similarity Index was calculated for July and September data combined (Figure 3.22), the same stations were classified into Group 1 and Group 2. This confirms the premise that stations that are most similar to each other during one sampling event remain similar during a second sampling event, regardless of seasonal or broad-scale changes to the habitat or community.

Table 3.7. Percentage of Total Individuals For Benthic Invertebrate Species Occurring in Top 70% of Individuals in July Cluster Groups.

Species	Group 1		Group 2		
	1A	1B	2A	2B	2C
Magelona cerae	40%	35%			
Maldane sarsi	6%	6%			
Acila castrensis	6%	6%	9%	7%	
Scoletoma luti	4%	4%	2%	2%	
Prionospio jubata	2%	2%			4%
Notomastus sp A	2%	2%			
Sternapsis fossor	2%	2%			
Galathowenia oculata	3%	2%	14%	11%	10%
Axinopsida serricata	2%	2%	27%	19%	19%
Chaetozone columbiana			6%	6%	7%
Euphilomedes carcharodonta		2%	6%	16%	18%
Euclymeninae sp A			3%		
Spiophanes berkeleyorum			2%	3%	
Diastylus dawsoni		4%		2%	2%
Nephtys caecoides					2%
Leitoscoloplos pugettensis					5%
Cadulus aberrans	1%				
Glycera nani		2%			
Pholoe glabra		2%			
Trochochaeta multisetosa		2%	2%		
Maldanidae					
Molgula sp.					
Amphiodia periercta					
Melinna sp.					
Laonice cirrata					
Rhepoxynius dabouis					
Heteromastus filobenchus					

(Numbers in red >10%; species in blue indicate species present in September only).

Table 3.8. Percentage of Total Individuals For Each Species Occurring In Top 70% of Individuals In September Cluster Groups.

Species	% Total Number Individuals					
	Group 1		Group 2			
	1A	1B	2A	2B	2C	2D
Magelona cerae	36	34				
Maldane sarsi	4	4				
Acila castrensis	5	4	5	4	4	
Scoletoma luti	2	4	4		2	
Prionospio jubata	4	2				
Notomastus sp A	2	3				
Sternapsis fossor		3				
Galathowenia oculata	3	4	25	11	19	13
Axinopsida serricata	2	4	13	24	12	16
Chaetozone columbiana			4	6	8	6
Euphilomedes carcharodonta		2	6	7	6	11
Euclymeninae sp A			5	4	4	
Spiophanes berkeleyorum				3		
Diastylus dawsoni	3	4	2	7	3	4
Nephtys caecoides						
Leitoscoloplos pugettensis					3	
Macoma calcarea						
Cadulus aberrans						
Glycera nani						
Pholoe glabra						
Trochochaeta multisetosa						
Maldanidae	4		5		4	
Molgula sp.	4				2	16
Amphiodia periercta		2	2			
Melinna sp.				4		
Laonice cirrata					2	
Rhepoxynius dabouis					2	
Heteromastus filobenchus						9

(Numbers in red >10%; species in blue indicate species present in September only).

REPLACE WITH 11X 17 FROM WORD FILE “CLUSTER FIGURES 11X17 PORTRAIT” (PG. 3)

Figure 3.22. Bray-Curtis Similarity Cluster Analysis Performed on Benthic Infaunal Data from July and September 2002 Surveys.

3.4 Demersal Fish Community Results

3.4.1 Demersal Fish at DWS

Demersal fish were captured in two replicates at each of 5 trawl transects during the July and September 2002 sampling at the DWS. The locations of the trawls are indicated in Figure 2.6. Table 3.9 shows the average abundance and percent contribution by each species that was captured during July 2002. Table 3.10 shows the average abundance and percent contribution by each species that was captured during September 2002. Highlighted values in these two tables indicate numerically important characteristics of the trawls with green indicating greater than 10 but less than 100 individuals of this species, yellow indicates that more than 100 individuals of a species and blue indicates those species that represented more than 10% of the individuals captured in the 2 replicate trawls from each location during the July survey.

During the July and September sampling events, flatfish were the most abundant demersal fish observed in each of the trawls and included Rex sole, Pacific sanddab, Slender sole, English sole, Dover sole and Petrale sole. The Rex sole and Pacific sanddab were the most dominant species observed during the July sampling, with the addition of Dover sole during the September sampling. Trawl Transects III, V, and VIII had the highest abundance of all fish species for both the July and September sampling events. These transects are located near the center and to the north portion of the proposed disposal site (Figure 2.7). The southern (east and west) portion of the disposal site had fewer individuals but the same species of fish during both sampling events.

The biomass of the trawl caught fish at the DWS showed a similar pattern to that of abundance. Flatfish dominated the fish biomass in each of the trawls (Table 3.11, 3.12). Those species that represented more than 10% of the biomass are highlighted in blue, those with greater than 1 kg/trawl but less than 10kg/trawl were highlighted in green and those with more than 10 kg/trawl are highlighted in yellow. Pacific sanddab, Rex sole, Dover sole, English sole and Petrale sole comprised the majority of the fish biomass in both July and September trawls. Slender sole, Lingcod, Pacific Hake, and Sablefish each contributed significantly to overall biomass, with >1 kg/trawl for transects I and VII in the west and eastern portions of the DWS.

The distribution of flatfish across the DWS was centered in the center of the DWS. This was especially true of the the Pacific Sanddab, which showed a normal distribution centered about trawl transect V in both July and September (Figure 3.23). This same distribution was observed for the demersal shrimp population at the DWS (Section 3.5).

Epidermal tumors were observed on the dorsal and ventral surfaces of the body and fins of Rex Sole during both sampling events, with an incidence of ~10% of all Rex Sole collected during both sampling events. In some cases, intensity exceeded 3 tumors per individual (Figure 3.24).

Table 3.9. Average Abundance of Fish and Percent of Catch for each Trawl Transect at DWS (July 2002).

Species	Common Name	I		III		V		VII		VIII		DWS	
		#	%	#	%	#	%	#	%	#	%	#	%
Citharichthys sordidus	Pacific sanddab	14	21	254	77	451	77	40	29	267	54	205	63
Errex zachirus	Rex sole	32	47	31	9	62	11	56	41	129	26	62	19
Thaleichthys pacificus	Eulachon	0	0	0	0	0	0	0.5	0	1	0	2	1
Micropterus proximus	Pacific tomcod	5	7	6	2	4.5	1	5	4	4	1	5	2
Eopsetta exilis	Slender sole	3	4	6	2	22	4	13	10	34	7	16	5
Pleuronectes vetulus	English sole	1	1	6	2	12	2	16	12	41	8	15	5
Microstomus pacificus	Dover sole	8	12	10	3	18	3	3	2	15	3	11	30
Eopsetta jordani	Petrale sole	3	5	10	3	6	1	0	0	1	0	4	2
Stellerina xyosterna	Picklebreast poacher	0	0	0.5	0	0	0	0	0	0	0	0	0
Eptatretus stouti	Pacific hagfish	0.5	1	1	0	2	0	2	1	0	0	1	0
Radulinus asprellus	Slim sculpin	0	0	0	0	4	1	0.5	0	0	0	1	0
Ophiodon elongatus	Lingcod	0	0	1	0	0	0	0	0	2	1	1	0
Liparis pulchellus	Snailfish, showy	0	0	0.5	0	0.5	0	0.5	0	0	0	0	0
Lycodopsis pacifica	Blackbelly eelpout	1	1	0	0	1	0	0	0	0.5	0	0	0
Merluccius productus	Pacific hake	0	0	0.5	0	0.5	0	0	0	2	0	1	0
Anoplopoma fimbria	Sablefish	0	0	2	1	0	0	0	0	0	0	0	0
Occela verrucosa	Warty poacher	0	0	0	0	0	0	0.5	0	0.5	0	0	0
Gasterosteus aculeatus	Threespine stickleback	0	0	0	0	0.5	0	0	0	0	0	0	0
Hexagrammos decagrammus	Kelp greenling	0	0	0	0	0	0	0	0	0.5	0	0	0
Grand Total		68.5		328		584		137		497		324	
Number/ Hectare		79.6		381		679		159		577		377	
Number of Species		9		13		13		11		13		12	

[Highlighted values indicate abundance: between 10 and 100 (green), greater than 100 (yellow); > 10% of the total (blue)]

Table 3.10. Mean Abundance of Fish and Percent of Catch for each Trawl Transect at DWS (September 2002).

Species	Common Name	I		III		V		VII		VIII		DWS	
		#	%	#	%	#	%	#	%	#	%	#	%
Errex zachirus	Rex sole	51	23.6	119	56.8	131	33.7	71	35.1	150	59.9	104	40.9
Thaleichthys pacificus	Eulachon	0	0.0	1	0.2	0	0.0	34	16.7	28	11.0	13	5.1
Citharichthys sordidus	Pacific sanddab	45	21.0	66	31.7	179	46.3	72	35.6	40	16.0	80	31.5
Microstomus pacificus	Dover sole	86	40.0	14	6.5	42	10.9	7	3.5	24	9.4	35	13.8
Micropterus proximus	Pacific tomcod	0	0	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0
Eopsetta exilis	Slender sole	24	11	5	2.4	13	3.4	1	0.2	2	0.6	9	3.5
Pleuronectes vetulus	English sole	2	0.9	2	1.0	17	4.3	14	6.7	3	1.0	8	3.2
Platichthys stellatus	Starry flounder	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0	0	0.0
Eopsetta jordani	Petrale sole	3	1.2	0	0.0	4	0.9	2	0.7	2	0.8	2	0.2
Radulinus asprellus	Slim sculpin	3	1.2	2	0.7	1	0.1	0	0.0	0	0.0	1	0.1
Ophiodon elongatus	Lingcod	1	0.2	0	0.0	1	0.3	2	0.7	0	0.0	1	0.1
Clupea harengus	Atlantic herring	0	0.0	0	0.0	0	0.0	0	0.0	3	1.0	0	0.0
Eptatretus stouti	Pacific hagfish	1	0.2	1	0.5	1	0.3	0	0.0	0	0.0	1	0.1
Lycodes cortezianus	Bigfin eelpout	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lycodopsis pacifica	Blackbelly eelpout	1	0.2	1	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Merluccius productus	Pacific hake	0	0.0	0	0.0	0	0.0	1	0.2	1	0.2	0	0.0
Anoplopoma fimbria	Sablefish	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0	0	0.0
Grand Total		214		209		387		201		251		254	
Number / Hectare		249		243		450		234		292		295	
Number of Species		11		9		9		11		10		10	

[Highlighted values indicate abundance: between 10 and 100 (green), greater than 100 (yellow); > 10% of the total (blue)]

Table 3.11. Mean Biomass Data for Fish Collected at DWS (July 2002).

Species	Common Name	I		III		V		VII		VIII		DWS	
		Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%
Citharichthys sordidus	Pacific sanddab	0.79	17	21.2	70	39.8	79	4.89	48	26.0	58	18.5	66
Errex zachirus	Rex sole	1.56	33	1.12	4	3.07	6	2.14	21	6.12	14	2.80	10
Pleuronectes vetulus	English sole	0.30	6	1.53	5	2.21	4	2.24	22	6.33	14	2.52	9
Micropterus proximus	Pacific tomcod	0.01	0	0.01	0	0.01	0	0.01	0	0.01	0	0.01	0
Microstomus pacificus	Dover sole	0.83	18	2.08	7	1.66	3	0.22	2	1.98	4	1.35	5
Eopsetta jordani	Petrale sole	0.95	20	2.43	8	1.73	3	0.00	0	0.50	1	1.12	4
Eopsetta exilis	Slender sole	0.13	3	0.14	1	0.87	2	0.33	3	1.14	3	0.52	2
Merluccius productus	Pacific hake	0.00	0	0.29	1	0.62	1	0.00	0	1.24	3	0.43	2
Thaleichthys pacificus	Eulachon	0.00	0	0.00	0	0.00	0	0.01	0	0.01	0	0.01	0
Ophiodon elongatus	Lingcod	0.00	0	0.25	1	0.00	0	0.00	0	1.28	3	0.31	1
Anoplopoma fimbria	Sablefish	0.00	0	1.29	4	0.00	0	0.00	0	0.00	0	0.26	1
Eptatretus stouti	Pacific hagfish	0.08	2	0.12	0	0.40	1	0.37	4	0.00	0	0.19	1
Liparis pulchellus	Snailfish, showy	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Hexagrammos decagrammus	Kelp greenling	0.00	0	0.00	0	0.00	0	0.00	0	0.08	0	0.02	1
Lycodopsis pacifica	Blackbelly eelpout	0.02	0	0.00	0	0.01	0	0.00	0	0.02	0	0.01	0
Occela verrucosa	Warty poacher	0.00	0	0.00	0	0.00	0	0.02	0	0.01	0	0.01	0
Stellerina xyosterna	Picklebreast poacher	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Radulinus asprellus	Slim sculpin	0.00	0	0.00	0	0.01	0	0.00	0	0.00	0	0.00	0
Gasterosteus aculeatus	Threespine stickleback	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Grand Total		4.67	100	30.5	100	50.4	100	10.2	100	44.7	100	28.0	100

[Highlighted values indicate abundance, between 1 and 10 (green), greater than 10 (yellow); > 10% of the total (blue)]

Table 3.12. Mean Biomass Data for Fish Collected at DWS (September 2002).

`Species	Common Name	I		III		V		VII		VIII		DWS	
		Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%
Citharichthys sordidus	Pacific sanddab	2.92	16	4.65	32	21.6	57	6.27	41	7.31	37	8.56	37
Errex zachirus	Rex sole	2.25	12	6.37	44	7.81	21	4.99	33	7.52	38	5.79	30
Microstomus pacificus	Dover sole	11.2	61	2.13	15	4.21	11	0.75	5	3.07	16	4.26	22
Pleuronectes vetulus	English sole	0.40	2	0.93	6	2.43	6	1.22	8	0.40	2	1.08	5
Platichthys stellatus	Starry flounder	0.00	0	0.00	0	0.00	0	0.14	1	0.00	0	0.03	0
Eopsetta jordani	Petrale sole	0.69	4	0.00	0	1.03	3	0.53	3	0.62	3	0.57	3
Thaleichthys pacificus	Eulachon	0.00	0	0.01	0	0.00	0	0.31	2	0.24	1	0.11	1
Eopsetta exilis	Slender sole	0.61	3	0.21	1	0.40	1	0.00	0	0.11	1	0.26	1
Ophiodon elongates	Lingcod	0.16	1	0.00	0	0.26	1	0.64	4	0.00	0	0.21	1
Merluccius productus	Pacific hake	0.00	0	0.00	0	0.00	0	0.41	3	0.31	2	0.14	1
Eptatretus stouti	Pacific hagfish	0.02	0	0.09	1	0.20	1	0.00	0	0.00	0	0.06	0
Clupea harengus pallasi	Pacific Herring	0.00	0	0.00	0	0.00	0	0.00	0	0.24	1	0.05	0
Radulinus asprellus	Slim sculpin	0.06	0	0.01	0	0.00	0	0.00	0	0.00	0	0.01	0
Anoplopoma fimbria	Sablefish	0.00	0	0.00	0	0.00	0	0.05	0	0.00	0	0.01	0
Lycodes cortezianus	Bigfin eelpout	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Micropterus proximus	Pacific tomcod	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Lycodopsis pacifica	Blackbelly eelpout	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Grand Total		18.3	99.0	14.4	99.0	37.9	101	15.3	100	19.8	101	21.1	100

[Highlighted values indicate abundance, between 1 and 10 (green), greater than 10 (yellow); > 10% of the total (blue)]

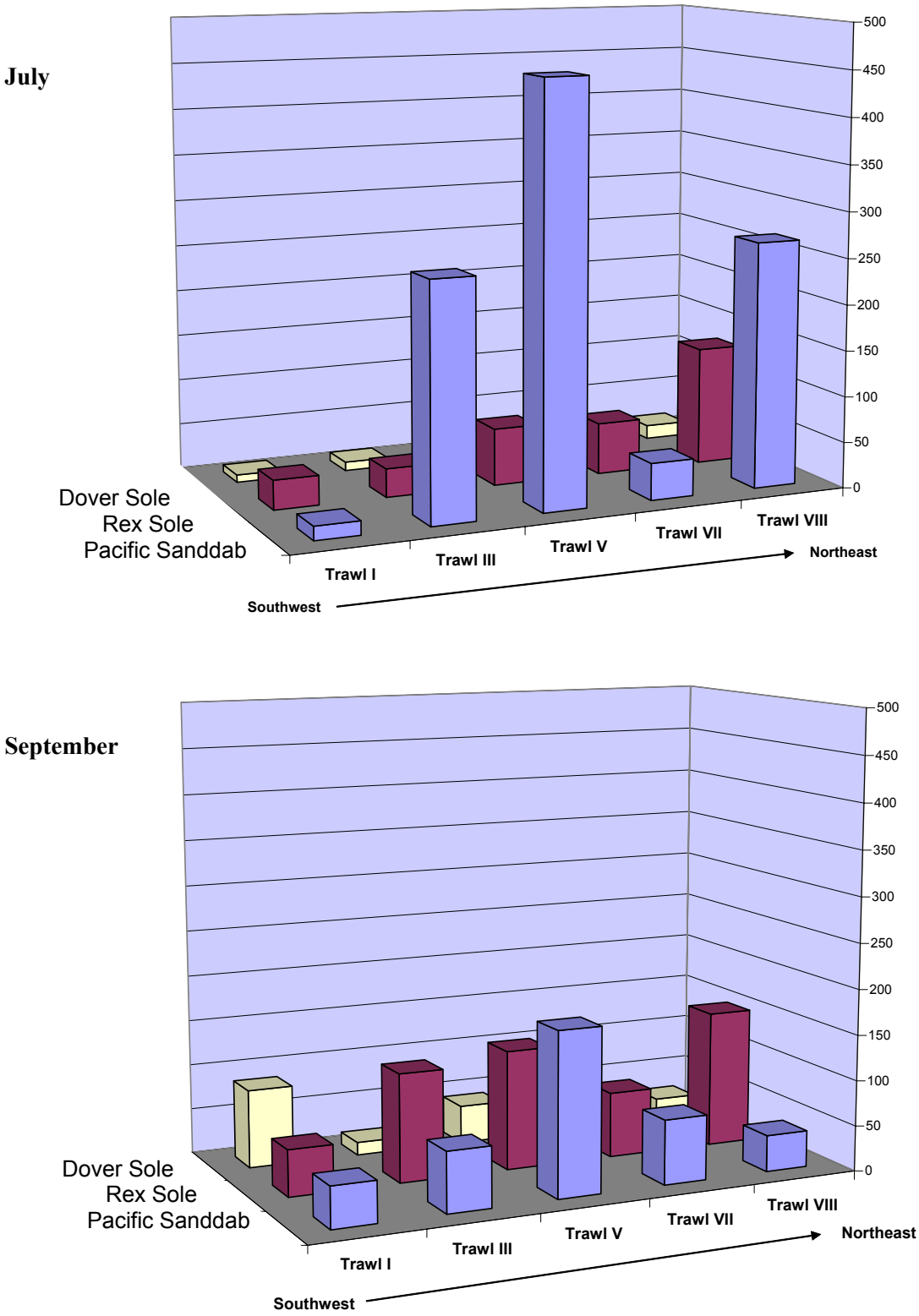


Figure 3.23. Comparison of Abundance of Pacific Sanddab, Rex Sole and Dover Sole from July and September.

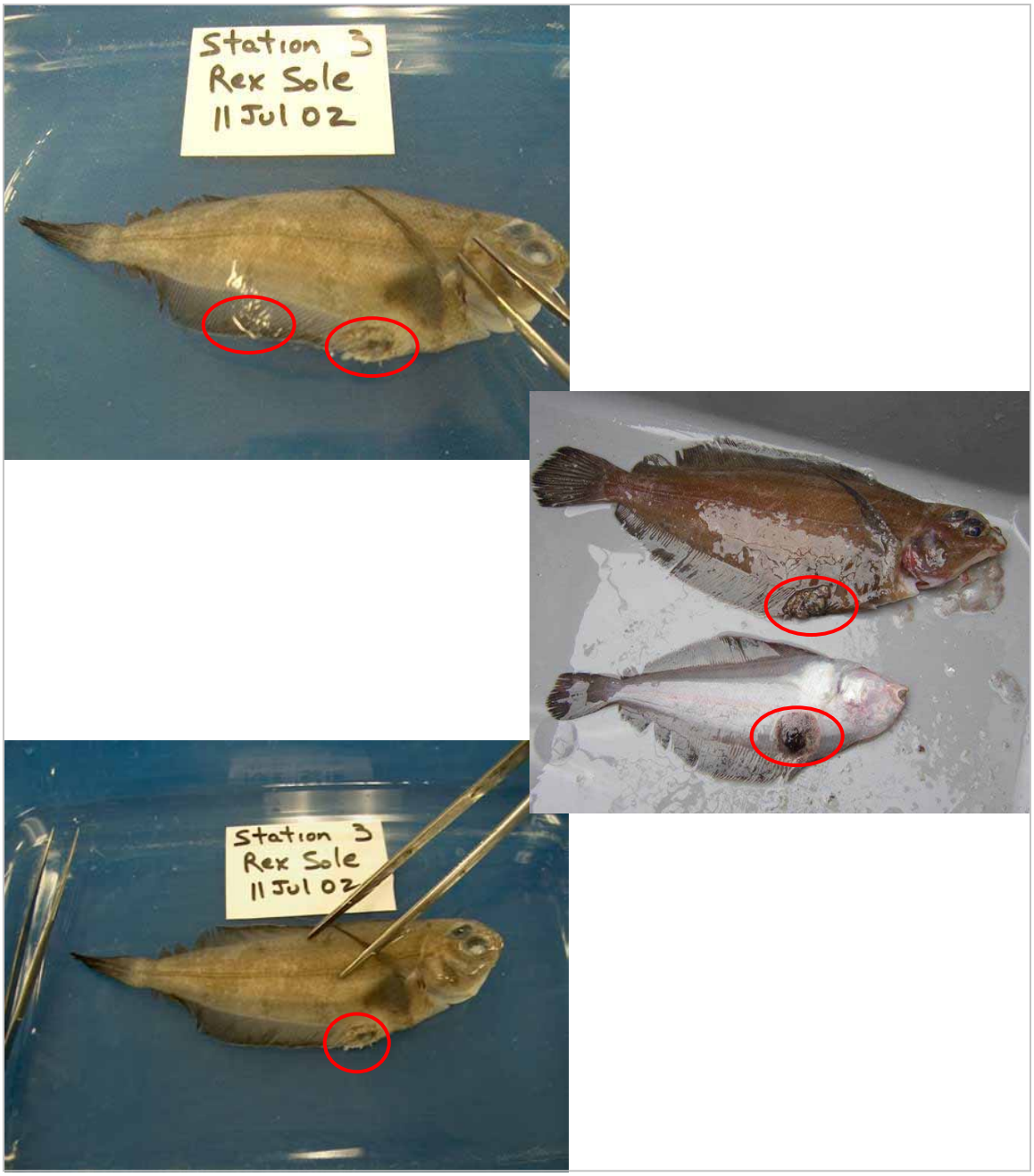


Figure 3.24. Photographs of Tumors on Rex Sole, Dorsal and Ventral Sides (July 2002).

3.4.2 Demersal Fish Community Results at SWS

Demersal fish were collected from two replicate trawls in each of two transects located in the SWS (Figure 2.2) in July, September, and October 2002. A summary of demersal fish abundance and biomass are presented for the July, September, and October sampling events in Tables 3.13 through 3.18. As in Section 3.3.1, highlighted values indicate abundance greater than 100 (yellow), between 10 and 100 (green), and greater than 10% of the total (blue). Overall fish average abundance in the SWS trawls ranged from 108 to 645 individuals per trawl and the number of species ranged from 8 to 17 species. The dominant fish species observed in the SWS trawls were eulachon (*Thaleichthys pacificus*) and pacific tomcod (*Micropterus proximus*), comprising a combined percentage of 63% to 94% of the fish caught in the SWS trawls. The dominance by these two species was observed in each of the three sampling events.

Biomass in the SWS trawls collected in July was dominated by the big skate (*Raja binoculata*), pacific tomcod, and starry flounder. Although the skate biomass was 57% of the biomass in transect B, skate were observed in only one trawl of the four conducted in the SWS. Fish biomass in the September SWS transects was dominated by sand sole, English sole, and Starry flounder, as well as Euchelon, and Pacific tomcod. Flatfish species comprised 54% and 91% of the total fish biomass in transects B and C, respectively. In October, fish biomass was dominated by pacific tomcod, which comprised nearly 70% of the total biomass.

As in the DWS, epidermal tumors were observed on both the ventral and dorsal surfaces of flatfish captured at the SWS (Figure 3.25); however, tumors at the SWS occurred in the English sole, rather than Rex sole. The incidence rate was approximately 10% of the sole captured with an intensity of up to five tumors per individual.

Figure 3.25. Photographs of English Sole Exhibiting Tumors (Ventral and Dorsal Surfaces) July 2002.

Table 3.13. Mean Abundance of Fish Collected at SWS (July 2002).

Species	Common Name	Transect B		Transect C		SWS	
		#	%	#	%	#	%
Citharichthys sordidus	Pacific sanddab	2	0	0	0	1	0
Thaleichthys pacificus	Eulachon	185	41	64	56	124	44
Micropterus proximus	Pacific tomcod	164	37	44	38	104	37
Pleuronectes vetulus	English sole	2	0	0	0	1	0
Leptocottus armatus	Staghorn sculpin	32	7	2	2	17	6
Platichthys stellatus	Starry flounder	20	4	2	1	11	4
Engraulis mordax	Northern anchovy	14	3	0.5	4	7	2
Raja binoculata	Big skate	9	2	0	0	4	1
Stellerina xyosterna	Picklebreast poacher	6	2	0	0	3	1
Clupea harengus pallasi	Pacific herring	6	1	0	0	3	1
Psettichthys melanostictus	Sand sole	4	1	0.5	0	2	1
Pleuronectes bilineata	Rock sole	3	1	1	1	2	1
Liparis pulchellus	Snailfish, showy	0.5	0	0.5	0	0.5	0
Liparis rutteri	Snailfish, ringtail	0.5	0	0	0	0	0
Pholis ornata	Saddleback gunnel	0.5	0	0	0	0	0
Sebastes hopkinsi	Squarespot rockfish	0	0	0.5	0	0	0
Squalus acanthias	Spiny dogfish	0	0	0.5	0	0	0
Grand Total		448		116		280	
No./ Hectare		521		147		334	
No. Species		15		10		13	

[Highlighted values indicate abundance: between 10 and 100 (green), greater than 100 (yellow); > 10% of the total (blue)]

Table 3.14. Mean Abundance of Fish at SWS (September 2002).

Species	Common Name	Transect B		Transect C		SWS	
		#	%	#	%	#	%
Thaleichthys pacificus	Eulachon	40	38	404	87	222	78
Micropterus proximus	Pacific tomcod	26	25	28	6	27	9
Pleuronectes vetulus	English sole	1	0.5	0	0	1	0
Psettichthys melanostictus	Sand sole	17	16	8	2	12	4
Leptocottus armatus	Staghorn sculpin	8	8	15	3	12	4
Platichthys stellatus	Starry flounder	12	11	2	0	7	2
Clupea harengus pallasi	Pacific herring	1	0.5	3	1	2	1
Stellerina xyosterna	Picklebreast poacher	3	2	1	0	2	1
Engraulis mordax	Northern anchovy	0	0	2	0	1	0
Liparis pulchellus	Snailfish, showy	0	0	1	0	1	0
Cymatogaster aggregata	Shiner surfperch	0	0	1	0	1	0
Pholis ornata	Saddleback gunnel	0	0	1	0	1	0
Raja binoculata	Big skate	0	0	1	0	1	0
Grand Total		108		467		287	
Number/ Hectare		126		543		334	
Number of Species		8		12		13	

[Highlighted values indicate abundance: between 10 and 100 (green), greater than 100 (yellow); > 10% of the total (blue)]

Table 3.15. Mean Biomass Data for Fish Collected at SWS (July 2002).

Species	Common Name	Transect B		Transect C		SWS	
		Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%
Citharichthys sordidus	Pacific sanddab	0.25	1	0.00	0	0.12	1
Raja binoculata	Big skate	24.0	57	0.00	0	12.0	51
Pleuronectes vetulus	English sole	0.03	0	0.00	0	0.02	0
Micropterus proximus	Pacific tomcod	6.30	15	1.68	46	3.99	17
Platichthys stellatus	Starry flounder	5.26	12	0.66	18	2.96	13
Leptocottus armatus	Staghorn sculpin	2.85	7	0.21	6	1.53	6
Thaleichthys pacificus	Eulachon	1.72	4	0.33	9	1.02	4
Pleuronectes bilineata	Rock sole	0.68	2	0.18	5	0.86	4
Psettichthys melanostictus	Sand sole	0.61	1	0.05	1	0.33	1
Squalus acanthias	Spiny dogfish	0.00	0	0.50	14	0.25	1
Engraulis mordax	Northern anchovy	0.34	1	0.01	0	0.18	1
Clupea harengus pallasi	Pacific herring	0.28	1	0.00	0	0.14	1
Liparis pulchellus	Snailfish, showy	0.09	0	0.05	1	0.07	0
Stellerina xyosterna	Picklebreast poacher	0.01	0	0.00	0	0.00	0
Pholis ornata	Saddleback gunnel	0.00	0	0.00	0	0.00	0
Liparis rutteri	Snailfish, ringtail	0.00	0	0.00	0	0.00	0
Grand Total		42.4		3.67		23.5	

[Highlighted values indicate abundance, between 1 and 10 (green), greater than 10 (yellow); > 10% of the total (blue)]

Table 3.16. Mean Biomass Data for Fish at SWS (September 2002)

Species	Common Name	Transect B		Transect C		SWS	
		Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%
Psettichthys melanostictus	Sand sole	4.83	55.4	4.48	47.8	4.66	51.4
Pleuronectes vetulus	English sole	0.01	0.1	0.00	0.0	0.01	0.0
Platichthys stellatus	Starry flounder	3.15	36.1	0.54	5.8	1.84	20.4
Thaleichthys pacificus	Eulachon	0.34	4.0	1.75	18.6	1.05	11.5
Micropterus proximus	Pacific tomcod	0.07	0.84	1.65	17.6	0.86	9.5
Leptocottus armatus	Staghorn sculpin	0.40	4.6	0.46	4.9	0.44	4.8
Raja binoculata	Big skate	0	0.0	0.40	4.2	0.20	2.2
Clupea harengus pallasi	Pacific herring	0.00	0.1	0.05	0.6	0.03	0.3
Engraulis mordax	Northern anchovy	0	0.0	0.02	0.3	0.01	0.1
Liparis pulchellus	Snailfish, showy	0	0.0	0.02	0.2	0.01	0.1
Stellerina xyosterna	Picklebreast poacher	0.01	0.1	0.00	0.0	0.01	0.1
Cymatogaster aggregata	Shiner surfperch	0	0.0	0.00	0.0	0.00	0.0
Pholis ornata	Saddleback gunnel	0	0.0	0.00	0.0	0.00	0.0
Grand Total		8.81		9.37		9.1	

[Highlighted values indicate abundance, between 1 and 10 (green), greater than 10 (yellow); > 10% of the total (blue)]

Table 3.17. Mean Abundance of Fish Collected at SWS (October 2002)

Species	Common Name	Transect B		Transect C		SWS	
		#	%	#	%	#	%
Micropterus proximus	Pacific tomcod	365	73.0	495	76.8	430	75.2
Clupea harengus pallasi	Pacific herring	42	8.5	18	2.8	30	5.3
Thaleichthys pacificus	Eulachon	28	5.6	27	4.2	28	4.8
Leptocottus armatus	Staghorn sculpin	20	4.1	29	4.5	25	4.3
Stellerina xyosterna	Picklebreast poacher	14	2.9	21	3.3	18	3.1
Occela verrucosa	Warty poacher	20	3.9	4	0.6	12	2.1
Liparis pulchellus	Snailfish, showy	1	0.2	12	1.9	7	1.2
Cymatogaster aggregata	Shiner surfperch	0	0.1	12	1.8	6	1.0
Psettichthys melanostictus	Sand sole	0	0.1	6	1.0	4	0.6
Raja binoculata	Big skate	0	0.0	6	0.9	3	0.5
Pleuronectes bilineata	Rock sole	1	0.2	4	0.6	3	0.4
Platichthys stellatus	Starry flounder	2	0.3	2	0.4	2	0.3
Pleuronectes vetulus	English sole	2	0.5	2	0.2	2	0.3
Citharichthys sordidus	Pacific sanddab	0	0.1	2	0.4	2	0.3
Alosa sapidissima	American shad	0	0.0	2	0.3	1	0.2
Engraulis mordax	Northern anchovy	1	0.2	2	0.2	1	0.2
Eopsetta jordani	Petrale sole	1	0.2	0	0.0	1	0.1
Grand Total		500		645		575	
Number/ Hectare		581		750		669	
No. Species		12		16		14	

[Highlighted values indicate abundance, between 10 and 100 (green), greater than 100 (yellow); > 10% of the total (blue)]

Table 3.18. Mean Biomass of Fish Collected at SWS (October 2002)

Species	Common Name	Transect B		Transect C		SWS	
		Biomass (Kg)	%	Biomass (Kg)	%	Biomass (Kg)	%
Micropterus proximus	Pacific tomcod	8.46	67.3	25.2	70.4	16.8	69.4
Raja binoculata	Big skate	0.00	0.0	5.70	15.9	2.85	11.8
Leptocottus armatus	Staghorn sculpin	1.13	9.0	1.67	4.7	1.40	7.4
Eopsetta jordani	Petrale sole	1.30	10.3	0.00	0.0	0.65	2.7
Platichthys stellatus	Starry flounder	0.52	4.1	0.64	1.8	0.58	2.4
Clupea harengus pallasi	Pacific herring	0.41	3.3	0.21	0.6	0.31	1.3
Pleuronectes bilineata	Rock sole	0.15	1.2	0.47	1.3	0.31	1.3
Psettichthys melanostictus	Sand sole	0.05	0.4	0.51	1.4	0.28	1.2
Thaleichthys pacificus	Eulachon	0.20	1.6	0.27	0.8	0.24	1.0
Liparis pulchellus	Snailfish, showy	0.04	0.3	0.38	1.1	0.21	0.8
Citharichthys sordidus	Pacific sanddab	0.08	0.6	0.20	0.6	0.14	0.6
Cymatogaster aggregata	Shiner surfperch	0.01	0.1	0.25	0.7	0.13	0.6
Alosa sapidissima	American shad	0.00	0.0	0.20	0.6	0.10	0.4
Pleuronectes vetulus	English sole	0.16	1.3	0.03	0.1	0.09	0.4
Stellerina xyosterna	Picklebreast poacher	0.03	0.2	0.06	0.2	0.04	0.2
Engraulis mordax	Northern anchovy	0.02	0.1	0.02	0.0	0.02	0.0
Occela verrucosa	Warty poacher	0.02	0.2	0.01	0.0	0.02	0.0
Grand Total (kg)		12.6		35.8		24.2	

[Highlighted values indicate abundance, between 1 and 10 (green), greater than 10 (yellow); > 10% of the total (blue)]

3.5 Demersal Invertebrate Community Results

3.5.1 Characterization of Demersal Invertebrate Community at DWS

Mean abundance and mean biomass for the species captured in each of the five DWS trawls during the July 2002 surveys are presented in Tables 3.19 and Table 3.20, respectively. Relative abundance and relative biomass, expressed as percentage of the total, are also presented.

The number of species observed in the July 2002 trawls ranged from 7 to 13 species, with the average total number of individuals ranging from 43.5 to 95 in the five stations. Overall, the shrimp *Crangon nigricauda*, *C. communis*, *Neocrangon resima*, the starfish *Luida foliolata* and the sea whip *Acanthoptilum* sp. were the most common species observed in the deep water trawls. There did not appear to be any strong trends in abundance across the deepwater site, however, shrimp were more common in the central portion of the deepwater site (Station III), a pattern that was similar to flatfish species observed at the DWS (Section 3.4). Less mobile species (*Luida* and *Acanthoptilum*) were more common in the deeper stations (Station I and II).

Biomass was dominated by the Dungeness crab, *Cancer magister*, the starfish *L. foliolata*, *Pyncnopodia helianthoides*, and *Rathbunaster californicus*, the anemone *Metridium senile*, the sea whip*, Acanthoptilium* sp. and the opisthobranch sea slug, *Tritonia diomedea*. In the case of *C. magister*, *P. heliothoides*, *R. californicus*, and *T. diomedea*, the biomass was represented by 1 to 3 individuals.

Invertebrate abundance and biomass observed in trawls conducted in September 2002 are presented in Tables 3.21 and 3.22. Mean abundance and number of species at each station were dramatically lower than those of the July trawls. Mean abundance ranged from 17 to 57.5 individuals per trawl and number of species observed was 3 or 4 species per trawl. *C. magister*, *M. senile*. *L. foliolata*, and *C. franciscorum* were most common species observed in the September trawls. Dungeness crab were more common than in the July trawls, with 11 to 20 crab per trawl in central and eastern portions of the DWS (Stations II through V), as opposed to one or two per trawl observed in July. *C. magister* also dominated the invertebrate biomass in each of the trawls comprising greater than 95% of the sampled biomass at Stations II – V. Station I was dominated by the starfish *L. foliolata* and *M. senile*. As in July, crab and shrimp were more abundant in the shallower sites and *L. foliolata* and *M. senile* were more common in the deeper, SW corner of the DWS.

3.5.2 Characterization of Demersal Invertebrate Community Results at SWS

Mean abundance and mean biomass for the species captured in each of the two shallow water stations during the July, September, and October 2002 surveys are presented in Tables 3.23 and 3.24, respectively. Relative abundance and relative biomass, expressed as percentage of the total, are also presented.

Table 3.19. Mean Invertebrate Abundance and Relative Abundance in DWS Trawls, July 2002.

Species	I		III		V		VII		VIII	
	# Indiv.	% Total	# Indiv.	% Total	# Indiv..	% Total	# Indiv.	% Total	# Indiv.	% Total
Crangon nigricauda			23	24.2	51	56.4	31.5	55.8	27.5	63.2
Luidia foliolata	20	34.2	27	28.4	4.5	5.0	14	24.8	7	16.1
Cancer magister					1	1.1	1.5	2.7	1	2.3
Crangon communis	17	29.1	10.5	11.1	7	7.7	4.5	8.0	1	2.3
Neocrangon resima	2	3.4	11	11.6	9	9.9	2	3.5		
Metridium senile	2	3.4	7	7.4						
Acanthoptilum sp	9.5	16.2	7.5	7.9					1	2.3
Bopyridae			4	4.2	5	5.5				
Paguridae					3	3.3			4	9.2
Pycnopodia helianthoides			1	1.1	3	3.3				
Rathbunaster californicus			1	1.1	3	3.3				
Pandalus danae	1	1.7			2	2.2				
Spirontocaris sp	1	1.7	1	1.1						
Eualus barbatus	1	1.7								
Octopus sp			1	1.1			1	1.8		
Pinnixa occidentalis									1	2.3
Ptilosarcus gurneyi							2	3.5		
Actiniaria					1	1.1				
Armina californica			1	1.1		1.1				
Asteronyx	1	1.7								
Cyclocardia ventricosa					1	1				
Idotea resecata	1	1.7								
Pagurus sp	1	1.7								
Pinnotheridae									1	2.3
Spirontocaris lamellicornis	1	1.7								
Tritonia diomedea	1	1.7								
Total No. Individuals	58.5		95		90.5		56.5		43.5	
No./ Hectare[1]	68.0		110		105		65.7		50.6	
No. Species	13		12		12		7		8	

Species shaded in gray and data in red represent predominant species
[1] Number/ Hectare, trawl area = 1.2 ha.

Table 3.20. Mean Biomass and Relative Biomass for DWS Trawls, July 2002.

Species	I		III		V		VII		VIII	
	Biomass (g)	% Total	Biomass (g)	% Total	Biomass (g)	% Total	Biomass (g)	% Total	Biomass (g)	% Total
Cancer magister					276	15.9	827	73.1	600	74.3
Luidia foliolata	35	13.6	500	25.0	275	15.8	200	17.7	175	21.7
Metridium senile	97.5	38.0	900	45.1						
Rathbunaster californicus			350	17.5	500	28.8				
Pycnopodia helianthoides			160	8.0	613	35.3				
Crangon nigricauda			23	1.2	51	2.9	31.5	2.8	27.5	3.4
Acanthoptilum sp	41	16.0	35	1.8					0.5	0.1
Octopus sp			5	0.3			62.5	5.5		
Tritonia diomedea	67.5	26.3								
Crangon communis	6.5	2.5	10.5	0.5	7	0.4	4.5	0.4	0.5	0.1
Neocrangon resima	1	0.4	11	0.6	4.5	0.3	2	0.2		
Pandalus danae	3.5	1.4			7	0.4				
Ptilosarcus gurneyi							4	0.4		
Actiniaria					2.5	0.1				
Olivella pycna										
Paguridae					0.5	0.0			2	0.2
Armina californica			2	0.1						
Eualus barbatus	1.5	0.6								
Pinnixa occidentalis									1.5	0.2
Spirontocaris sp	1	0.4	0.5	0.0						
Bopyridae			0.5	0.0	0.5	0.0				
Asteronyx	0.5	0.2								
Cancer jordani										
Cyclocardia ventricosa					0.5	0.0				
Idotea resecata	0.5	0.2								
Olivella biplicata										
Pagurus sp	0.5	0.2								
Pinnotheridae									0.5	0.1
Siliqua sp										
Spirontocaris lamellicornis	0.5	0.2								
Grand Total	257		1998		1737		1131		808	

Species shaded in gray and data in red represent predominant species
[1] *Number/ Hectare, trawl area = 1.2 ha.*

Table 3.21. Mean Demersal Invertebrate Abundance and Relative Abundance in DWS Trawls, September 2002.

Species	I		III		V		VII		VIII	
	Abund	% Total	Abund	% Total	Abund	% Total	Abund	% Total	Abund	% Total
Cancer magister	1	1.7	17	59.6	8.5	42.5	11	64.7	20	87.0
Luidia foliolata	50.5	87.8	9.5	33.3	5.5	27.5	3	17.6	1	4.3
Crangon franciscorum	0	0.0	0	0.0	5	25	3	17.6	1	4.3
Metridium senile	6	10.4	2	7.0	1	5	0	0	0	0.0
Pleurobranchaea californica	0	0	0	0	0	0	0	0	1	4.3
Total No. Individuals	57.5		28.5		20.0		17.0		23.0	
No/ Hectare	66.9		33.1		23.2		19.8		26.7	
Number of Species	3		3		4		3		4	

Species shaded in gray and data in red represent predominant species
[1] Number per hectare, trawl area = 0.86 ha.

Table 3.22. Mean Demersal Invertebrate Biomass and Relative Biomass in DWS Trawls, September 2002.

Species	I		III		V		VII		VIII	
	Biomass (g)	% Total	Biomass (g)	% Total	Biomass (g)	% Total	Biomass (g)	% Total	Biomass (g)	% Total
Cancer magister	500	24.9	8850	96.7	5450	98.9	2800	98.8	8663	99.7
Crangon franciscorum	0	0.0	0	0.0	0	0.0	2	0.1	5	0.1
Crangon nigricauda	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Luidia foliolata	260	12.9	265	2.9	53	1.0	30	1.1	4	0.1
Metridium senile	1250	62.2	35	0.4	10	0.2	0	0.0	0	0.0
Olivella biplicata	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Olivella pycna	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pleurobranchaea californica	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1
Grand Total	2010		9150		5513		2832		8673	

Species shaded in gray and data in red represent predominant species

Table 3.23. Mean Abundance and Relative Abundance of Demersal Invertebrates in SWS Trawls (July, September/October 2002).

Species	Transect B		Transect C	
	Abundance (#/trawl)	% Total	Abundance (#/trawl)	% Total
July 2002				
Crangon nigricauda	117	71.8	79.5	72.3
Cancer magister	46	28.2	12.5	11.4
Olivella pycna			14	12.7
Cancer jordani			2	1.8
Olivella biplicata			1	0.9
Siliqua sp			1	0.9
Total No. Individuals	163		110	
No./ Hectare[1]	190		128	
No. Species	2		6	
September 2002				
Crangon nigricauda	109.5	51.4	102.5	53.1
Cancer magister	57.5	27.0	85	44.0
Luidia foliolata	20	9.4	2	1.1
Olivella biplicata	23	10.8	2.5	1.3
Olivella pycna	3	1.4	1	0.5
Total No. Individuals	213		193	
No./ Hectare	248		224	
No. Species	5		5	
October 2002				
Crangon sp	74	56.3	66	58.7
Cancer magister	43	32.7	46.5	41.3
Crangon nigricauda	11.5	8.8		
Olivella biplicata	3	2.2		
Total No. Individuals	132		112	
No./ Hectare	153		130	
No. Species	4		2	

Species shaded in gray and data in red represent predominant species

[1] Number per hectare, trawl area = 0.86 ha.

Table 3.24. Mean Biomass and Relative Biomass of Demersal Invertebrates in SWS Trawls (July and September/October 2002).

Species	Transect B		Transect C	
	Biomass (g)	% Total	Biomass (g)	% Total
July 2002				
Cancer magister	11200	98.1	6088	98.4
Crangon nigricauda	218	1.9	97	1.6
Olivella pycna			3	<0.1%
Cancer jordani			1	<0.1%
Olivella biplicata			1	<0.1%
Siliqua sp			1	<0.1%
September 2002				
Cancer magister	27150	99.6	32950	99.8
Crangon nigricauda	76	0.3	60	0.2
Luidia foliolata	11	0.0	8	0.0
Olivella biplicata	17	0.1	1	0.0
Olivella pycna	1	0.0	1	0.0
October 2002				
Crangon sp	ND		ND	
Cancer magister	9300		12400	
Crangon nigricauda	ND			
Olivella biplicata	ND			

Species shaded in gray and data in red represent predominant species
ND: No data, not recorded.

Invertebrate abundance increased in September 2002, with approximately 200 individuals per trawl. This was due to an increase in *C. magister* in the Transect C trawls and an increase in *Olivella biplicata* in the Transect B trawls. As with the July trawls, *C. magister* and *C. nigricauda* dominated the demersal invertebrate community in September 2002. In the October trawls, the abundance was slightly lower, with an average of 131.5 and 112.5 individuals per trawl in transects B and C, respectively. As in September, Crangon shrimp and Dungeness crab were the dominant species.

3.6 Dungeness Crab Survey Results

Dungeness crab data were collected at the SWS and DWS in the months of July, September, and October (SWS only). Results and seasonal comparisons are presented separately for each site. The data results are evaluated with respect to location, season, sex, size, and distribution (Tables 3.25 and 3.26).

Size frequency distributions were created to allow for visual representation of the population structure of crabs present during sampling. Crab data were categorized into five size-classes, similar to those assigned by McCabe and McConnell (1989), but revised to provide more even distribution for older crab populations: I (< 0 mm), II (50-99 mm), III (100-129 mm), IV (129-159 mm), and V (>159 mm). As discussed by McCabe and McConnell (1989) different age groups of Dungeness crabs often have overlapping carapace width distributions, due to sampling during, and immediately following molting periods, particularly the larger crabs. Since the MCR sampling occurred during the molting season, which would lead to inconsistencies in assigning age groups, the crab data were separated into specific size classes, rather than age-classes.

Due to discontinuous growth patterns and necessary assumptions concerning molting rates, frequency, and cohort overlap it has been difficult to accurately determine chronological age of crustaceans captured in the field using modal analysis (Rothschild *et al*. 1992). Crustaceans molt their exoskeleton to accommodate future growth and, as a result, abandon any external evidence of age or previous size. While size frequency distributions allow for a visual representation of the abundance and size trend in measured crabs, they are not able to determine the number of crabs that have reached their terminal molt (maximum size), skipped a molt, or molted more frequently than the cohort trend. As a result, older populations of crabs have a degree of age class overlap, making age class determination for older populations less reliable than for newer cohorts.

3.6.1 Shallow Water Site

Crab pots were considered non-recoverable when the marker buoys could not be found at, or near, their deployed locations. It was assumed missing pots were displaced by commercial shipping traffic (i.e. buoy lines severed or entangled with vessels); buoys remained below the surface due to high flows, or were otherwise missing. Out of a total of 48 pots deployed, 8 pots were not recoverable for the SWS, with 3 non-recoverable events (i.e., 24-hr period) in the July survey (88% recovery rate), and 5 non-recoverable events during the September survey (79% recovered). Crab pot Catch per Unit Effort (CPUE) was determined as the number of crabs caught per 24-hr period. Combined CPUE for the total catch of Dungeness crabs increased slightly from the July survey (649 crabs, CPUE = 33.36) to the September survey (905 crabs, CPUE = 42.1) at the SWS (Figures 3.26 and 3.27).

Crabs caught in pots at the SWS showed an increase in the abundance, size, and number of legal-sized males between the July and September surveys (Tables 3.25 and 3.26). Mean crab size

Table 3.25. Summary of Dungeness Crab Catch (July and September/October 2002).

Site	Date	Method	Males[1]	Females[1]	Total Measured[1]	Total Caught[2]	% Male[1]	# Legal Males[1]	% Legal Male[1]
DWS	July	Pot	17	64	81	81	21%	8	10%
		Trawl	2	3	5	5	40%	0	0%
		Total Catch	19	67	86	86	22%	8	9%
	September	Pot	958	106	1064	1314	90%	356	33%
		Trawl	109	1	110	116	99%	47	43%
		Total Catch	1067	107	1174	1430	75%	403	28%
SWS	July	Pot	124	327	451	624	28%	8	2%
		Trawl	18	37	55	55	33%	0	0%
		Total Catch	142	364	506	679	21%	8	1%
	September/ October	Pot	174	390	564	905	31%	119	21%
		Trawl	74	41	115	179	64%	31	17%
		Total Catch	248	431	679	1084	23%	150	14%

Notes:

1: Sampling protocol dictated that up to thirty random crabs be measured and sexed from each sampling location; (catches greater than 30 crabs were simply enumerated). These numbers are based on those thirty measured individuals.

2: This column includes the total number of crabs caught (measured and unmeasured).

Table 3.26. Size Class Distribution and Shell Strength.

Site	Date	Method	Gender	Total Crabs Measured[1]	Min CW[1] (mm)	Max CW[1] (mm)	Mean CW[1] (mm)	Size Class Distribution Percentages (based on measured crabs)[1]					% Soft[1]
								I (<50mm)	II (50-99mm)	III (100-129mm)	IV (130-159mm)	V (>159mm)	
DWS	July	Pot	Female	64	118	160	137.5	0%	0%	17%	81%	2%	9%
			Male	17	102	189	149	0%	0%	29%	24%	47%	47%
			Total	81	102	189	139.9	0%	0%	20%	69%	11%	17%
		Trawl	Female	3	120	163	144.3	0%	0%	33%	33%	33%	100%
			Male	2	95	141	118	0%	50%	0%	50%	0%	100%
			Total	5	95	163	133.8	0%	20%	20%	40%	20%	100%
	Sept.	Pot	Female	106	63	182	135.8	0%	10%	14%	66%	9%	72%
			Male	958	54	201	149.2	0%	4%	15%	44%	37%	15%
			Total	1064	54	201	147.9	0%	5%	15%	46%	34%	20%
		Trawl	Female	1	91	91	91	0%	100%	0%	0%	0%	0%
			Male	109	58	190	143	0%	15%	13%	31%	41%	1%
			Total	110	58	190	142.5	0%	15%	13%	31%	41%	1%
SWS	July	Pot	Female	327	87	169	133.2	0%	6%	28%	63%	3%	43%
			Male	124	72	182	122.5	0%	15%	48%	30%	6%	35%
			Total	451	72	182	130.3	0%	8%	33%	54%	4%	41%
		Trawl	Female	37	93	155	120.4	0%	11%	28%	32%	0%	19%
			Male	18	95	150	113.5	0%	33%	48%	17%	0%	22%
			Total	55	93	155	118.1	0%	18%	33%	27%	0%	20%
	Oct.	Pot	Female	390	57	190	144	0%	<1%	11%	78%	11%	98%
			Male	174	107	212	166.5	0%	0%	46%	28%	68%	71%
			Total	564	57	212	150.9	0%	<1%	9%	62%	29%	89%
		Trawl	Female	41	66	155	114.6	0%	12%	68%	20%	0%	49%
			Male	74	47	193	148.7	1%	5%	14%	38%	42%	47%
			Total	115	47	193	136.5	1%	8%	33%	31%	27%	48%

[1] *Sampling protocol dictated that up to thirty random crabs be measured and sexed from each sampling location; (Catches greater than 30 crabs were simply enumerated). These numbers are based on those thirty measured individuals.*

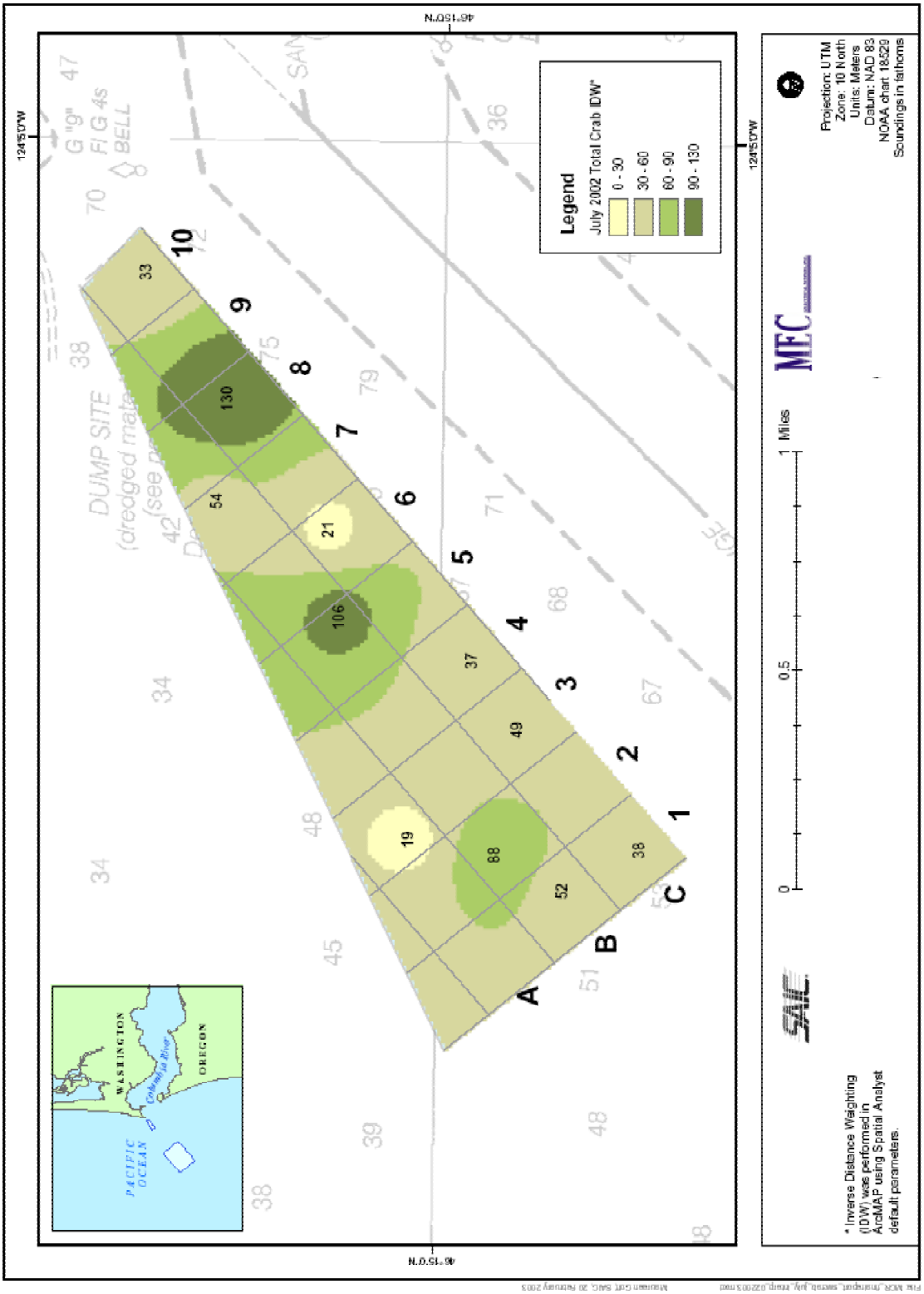


Figure 3.26. Dungeness Crab Abundance at SWS in July 2002.

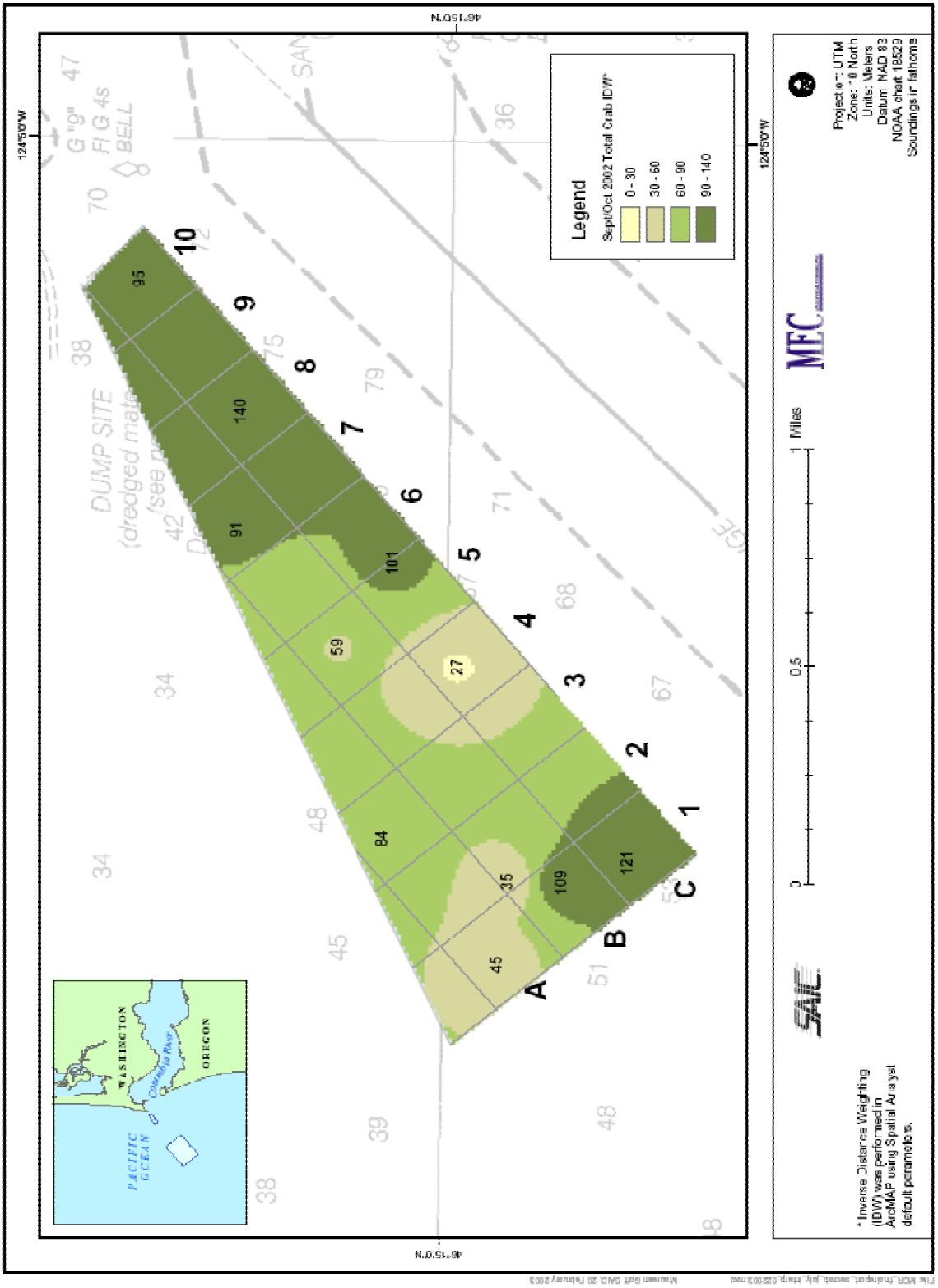


Figure 3.27. Dungeness Crab Abundance at SWS in September/October 2002.

(measured as carapace width) increased from July (130mm mean CW) to September (151mm mean CW), with an 8.2 % size increase in females and a 35.8% size increase in males. From a fishery perspective, the number of legal male crabs caught increased from 8 (2% of the measured catch) in July to 119 (21% of the measured catch) in September. Similarly, the bottom trawls conducted at the SWS also demonstrated an increase between surveys in the number of crabs caught (from 55 to 179 total crab), mean carapace width size (from 115 to 137 mm), and legal males (from 0 to 31; 17% of the measured catch in October).

The SWS trawl data indicates that the number of male Dungeness crab caught was higher in October (74) than it was in July (18), whereas female catch was similar for both October (41) and July (37). The SWS July trawls captured 55 Dungeness crabs, ranging from 93-155 mm CW (Range= 55mm) during the July survey, while the October survey captured 179 crabs ranging from 47-193 mm CW (Range= 146mm). The mean size for trawl-caught male crabs increased at the SWS from the July (114mm CW) to the October (149mm CW), whereas female mean size was similar in both the July (120mm CW) and October (115mm CW).

The July SWS crab pot size frequency distributions revealed multiple cohorts of female Dungeness crabs with a peak in frequency occurring at 145 mm. Male crabs were also represented by multiple cohorts, but did not reveal any distinct peaks. The September SWS crab pot data shows the similar peak in female crabs (145 mm), but with fewer crabs representing smaller cohorts. Male crabs, however, demonstrated a general increase in size, with a peak occurring at 185 mm (Appendix G).

Fewer crabs were caught in the trawls making interpretation of the size frequency distributions less obvious. However, for the SWS the distribution is similar to the crab pot data showing an increase in the size and number of male crabs caught in October compared to the smaller numbers caught in July (Figure 3.28 and 3.29). This apparent concurrence for abundance and size using with trawls or pots increases the strength of the observations.

3.6.2 Deepwater Site

A total of 3 non-recoverable pot events occurred in the July survey resulting in a recovery rate of 97%, whereas all 96 pots were recovered (100%) during the September survey. Total catch for Dungeness crabs at the DWS increased markedly from the July survey (81 crabs, CPUE= 1.68) to the September survey (1314 crabs, CPUE= 27.29; Figures 3.30 and 3.31).

Crab pot data from the DWS (Tables 3.25 and 3.26) also demonstrated increases from the July survey to the September survey in the number (81-1314 total crab), mean carapace width (140mm -148mm) and number of legal males (8; 10% of the measured catch to 356; 33% of the measured catch). The percent males present at the DWS increased dramatically between surveys (from 21%-90%). The number of crabs caught using the bottom trawl at the DWS increased from 5 in July to 116 in October. The mean carapace widths were similar to the crab pot data (134 and 143 mm mean CW respectively). The limited number of crab caught at the DWS using bottom trawls in July, combined with the few individuals collected in the pots, substantiates the conclusion that few crab were available for capture at the DWS in July. There was a seasonal increase in the number of legal male crabs, which increased from 0 to 47 (43% of the measured catch) in September.

The mean size for male Dungeness crab was the same for both July (149mm CW) and the September (149mm CW), although the total number of measured male crabs caught increased from 17 in July to 958 for September. DWS male crabs showed a greater range in size for both the July survey (87) and September survey (147) compared to July (42) and September (119) females. The total number of legal-size male Dungeness crab caught at the DWS was 8, (10%) in July, and 356 (33.5%) in September.

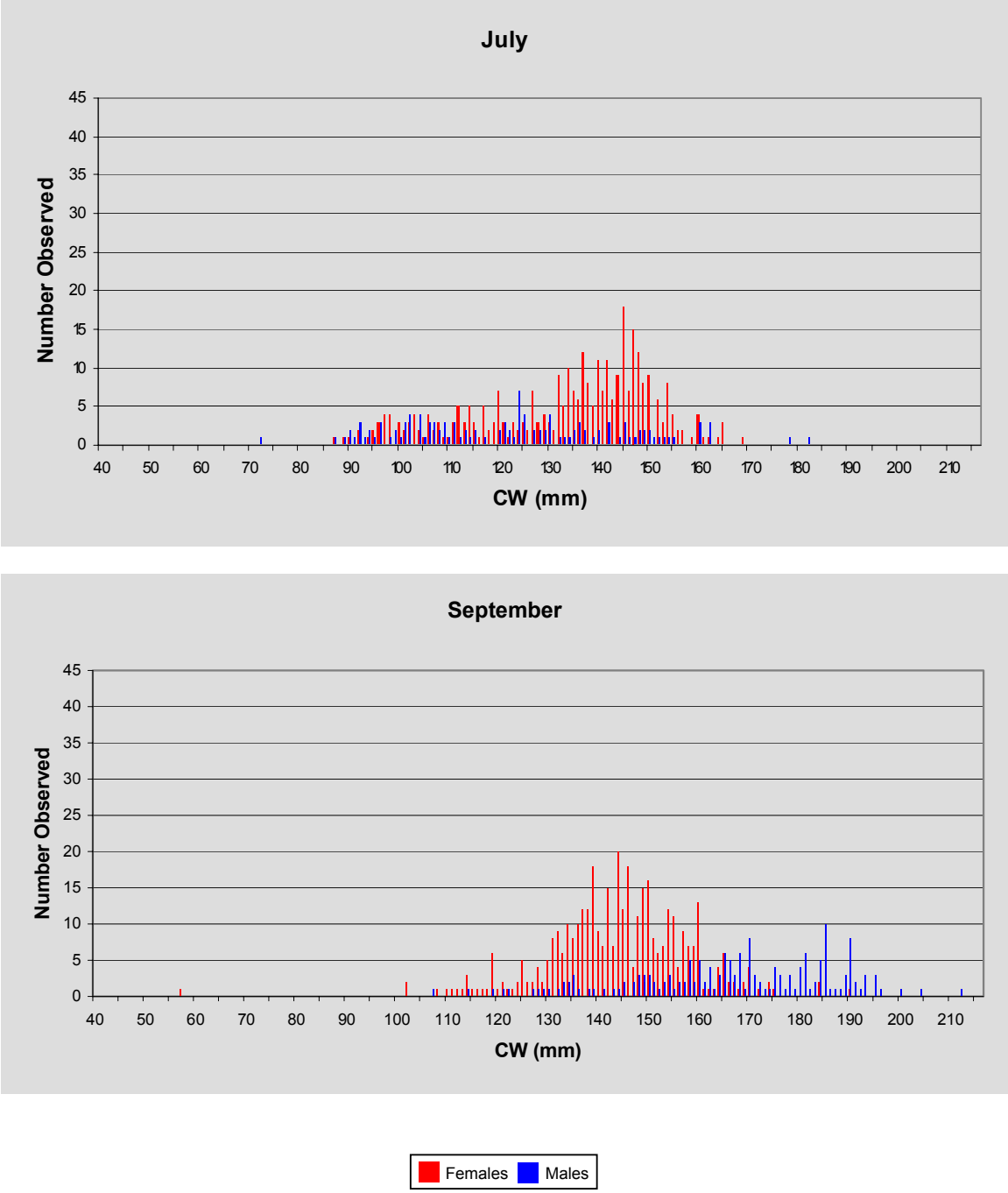


Figure 3.28. Dungeness Crab Size Frequency Distributions at the SWS for the July and September Crab Pot Surveys.

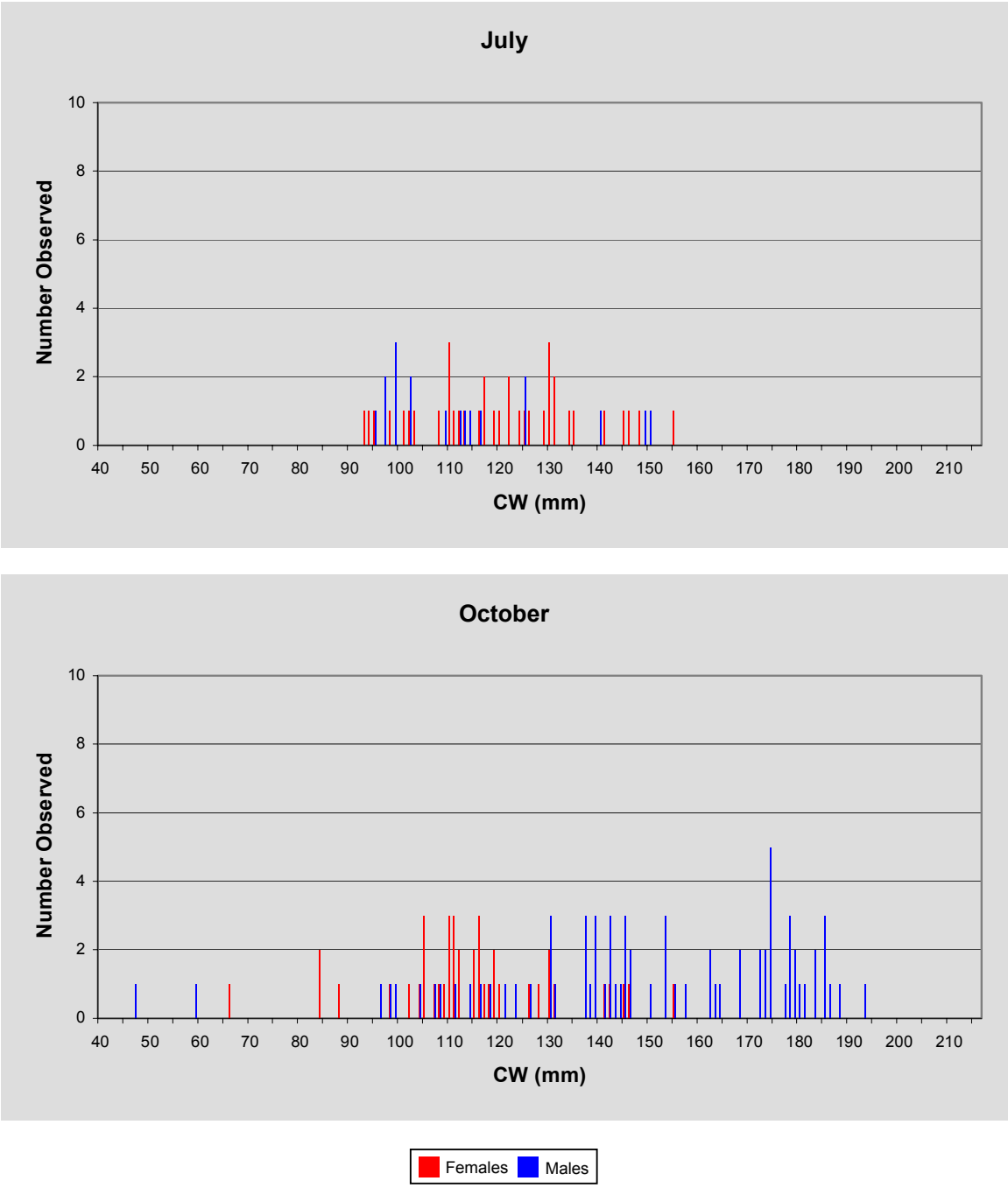


Figure 3.29. Dungeness Crab Size Frequency Distributions at the SWS for the July and October Bottom Trawl Surveys.

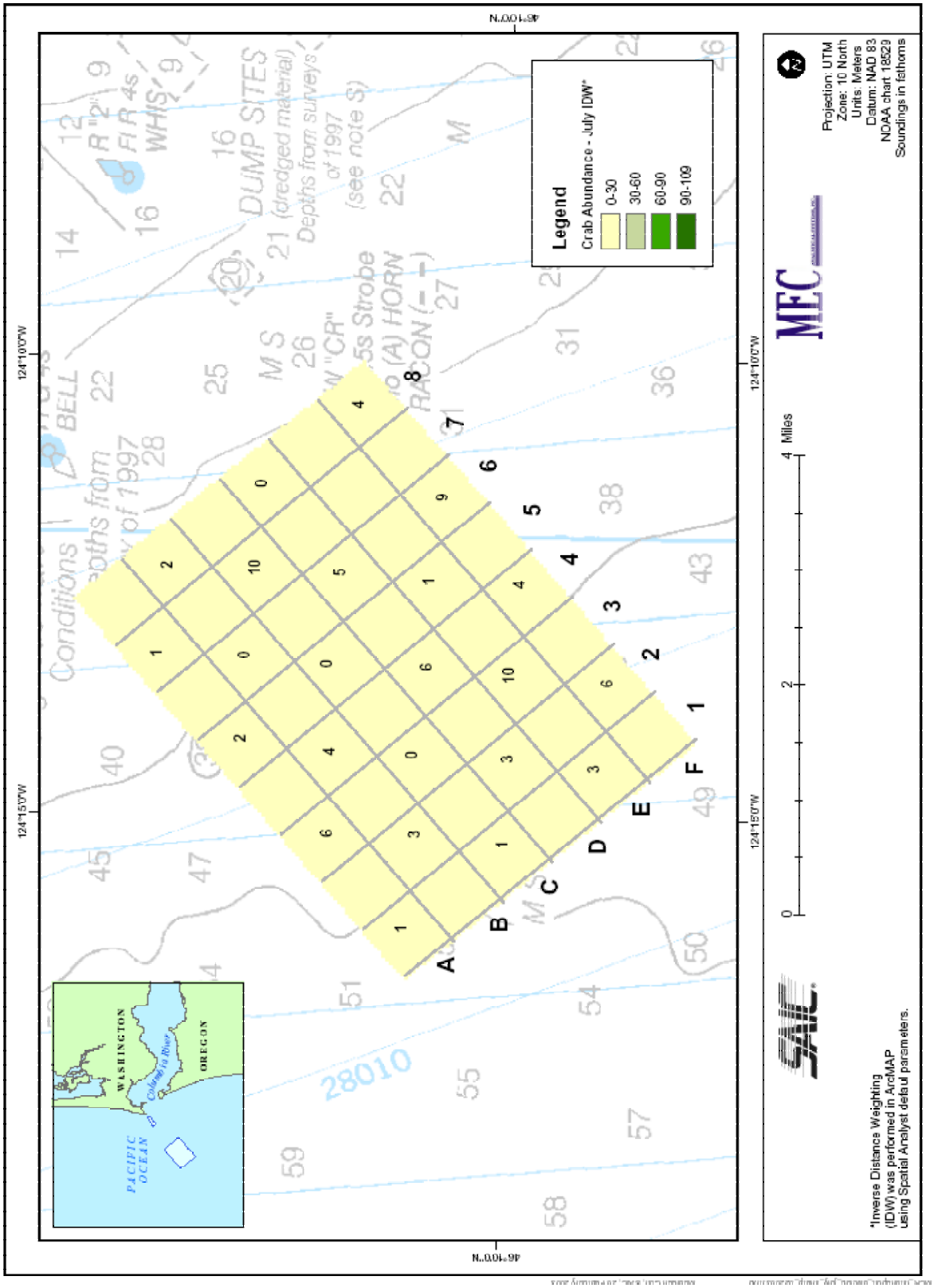


Figure 3.30. Dungeness Crab Abundance at DWS in July 2002.

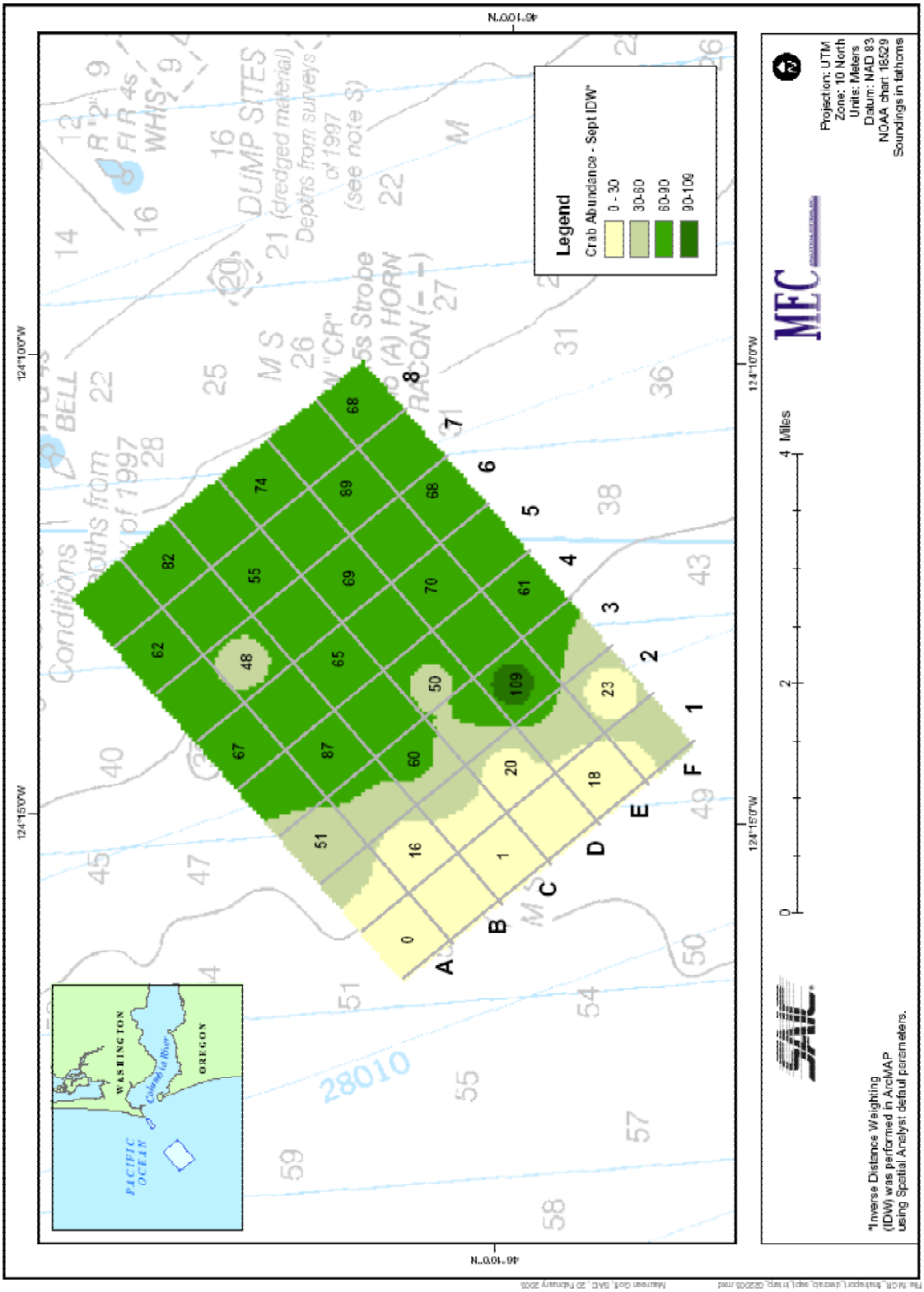


Figure 3.31. Dungeness Crab Abundance at DWS in September/October 2002.

The bottom trawls at the DWS captured only 5 Dungeness crabs, ranging from 68-95 mm CW during the July survey, while the September survey captured 116 crabs ranging from 58-190 mm CW. A total of 4 female crabs were caught for both sampling events combined. Yet, the number of trawl caught males increased dramatically from July (2) to September (109). Further, the September trawl survey at the DWS only captured 1 female to the 109 male Dungeness crab. This increase in male crabs caught during the September trawl survey demonstrated a peak for Size-Class IV and V crabs. No legal-sized male Dungeness crabs were caught in trawls at the DWS during the July survey, whereas 47 (42.7%) legal-size males were caught in September.

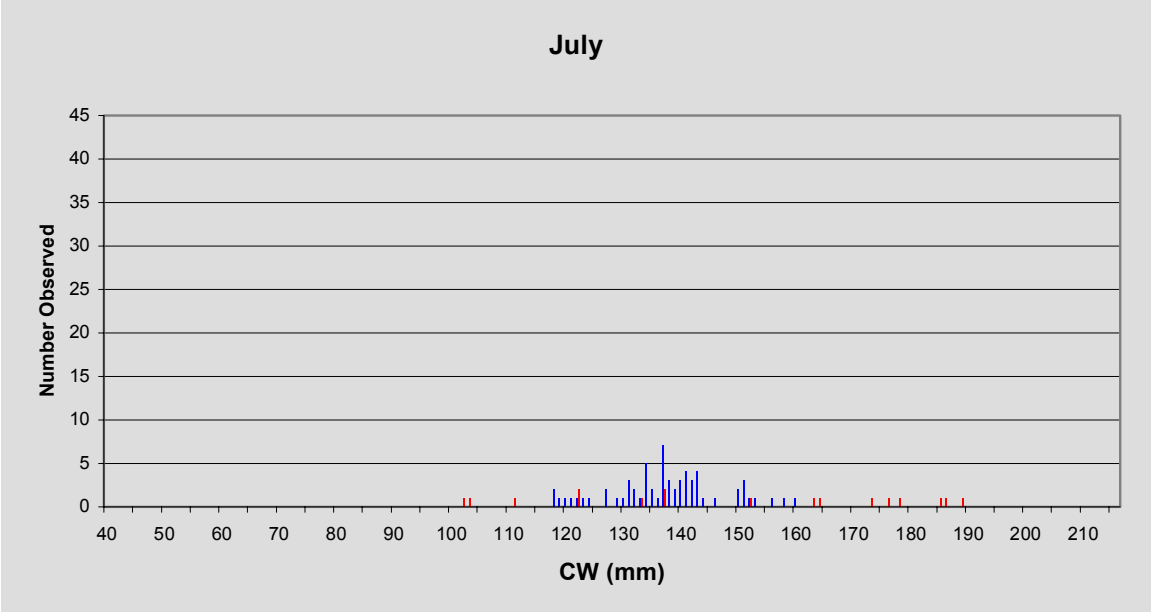
The size frequency distribution plots for the July DWS crab data provided limited insights due to the relatively lower catch totals for both the crab pot and trawl surveys. Male crabs appear over a relatively small range with a peak at 137 mm, whereas no distribution patterns were discernable for female crabs. The September DWS crab data indicate an increase in the number, size, and distribution for both male and female crabs. The size frequency distribution plots show an increased utilization of the DWS by multiple cohorts of both sexes in September as compared to July (Figures 3.32 and 3.33).

3.6.3 Comparison between Crab Sampling Methods

Comparisons between sampling techniques indicates that crab pot deployment, on average, caught more and slightly larger crabs than the otter trawls. For example, during the July sampling event at the SWS, four 5,000-meter trawls resulted in 55 crabs caught (~14/trawl) with a mean CW of 118 mm, whereas the 19 recovered crab pots caught 649 crabs with a mean CW of 130 mm. The DWS yielded similar numbers during the July Sampling event with trawls capturing a total of 5 crabs (0.5 crabs/trawl) with a mean CW of 130 mm, while 93 recovered commercial pots resulted in the capture of 81 crabs (0.87 crabs/pot) with an average CW of 140 mm. This pattern was consistent in the September/October data as well with 179 trawl-caught crabs (~45 crabs/trawl; 137 mean CW) compared to 905 crabs (~43 crabs/pot; 151 mean CW at the SWS and 116 trawl-caught crabs (~12 crabs/trawl; 143 mean CW) compared to 1,314 crabs (~14 crabs/pot; 148 mean CW; Appendix G).

Multiple cohorts were present at both sites during each season sampled regardless of sampling method. Crab population structure at these two sites is primarily comprised of adult crabs (Size Class III, IV, and V), with almost all sampling periods detecting some sub-adult (Size Class II) crabs, and no sampling period detecting more than 1% juvenile (Size Class I) crabs. Trawls on average caught smaller size classes of crabs than did the modified crab pots although there was evidence that the smaller size class was available for capture (see footnote Section 2.7). Crab pots, in general, were more efficient in total catch and showed a slightly larger range in size of crabs captured and measured.

A likely explanation for the differences in catch totals between the trawls and pots is their active vs. passive fishing methods. The trawls only capture the crabs that are present on the bottom at the time the net sweeps past. The crab pots are deployed for a full 24 hours at a time (for this study) and attract any foraging crabs that pass through the odor corridor of the baited traps. It should also be noted that the sampling efficiency of the modified Willis otter trawl is unknown, and, as noted in McCabe *et al*. (1985), sampling efficiencies for different size classes of crabs may also differ. Gotshall (1978a) estimated the sampling efficiency for his 4.9m bottom trawl in Humboldt Bay, California was about 50%.



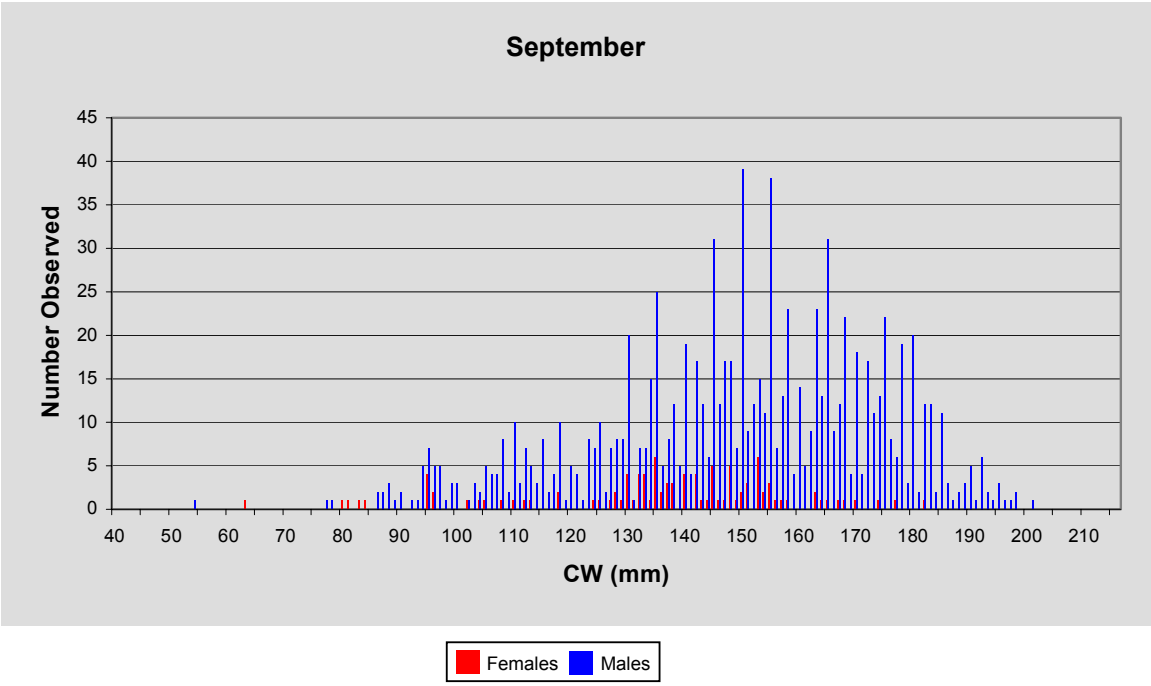
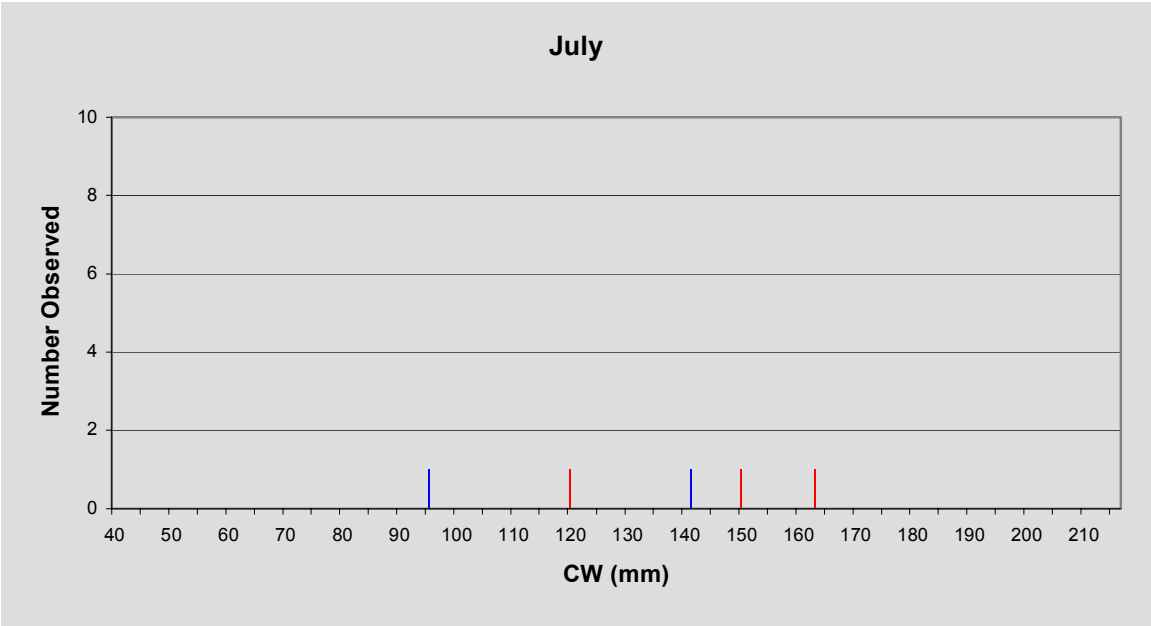


Figure 3.32. Dungeness Crab Size Frequency Distributions at the DWS for the July and September Crab Pot Surveys.



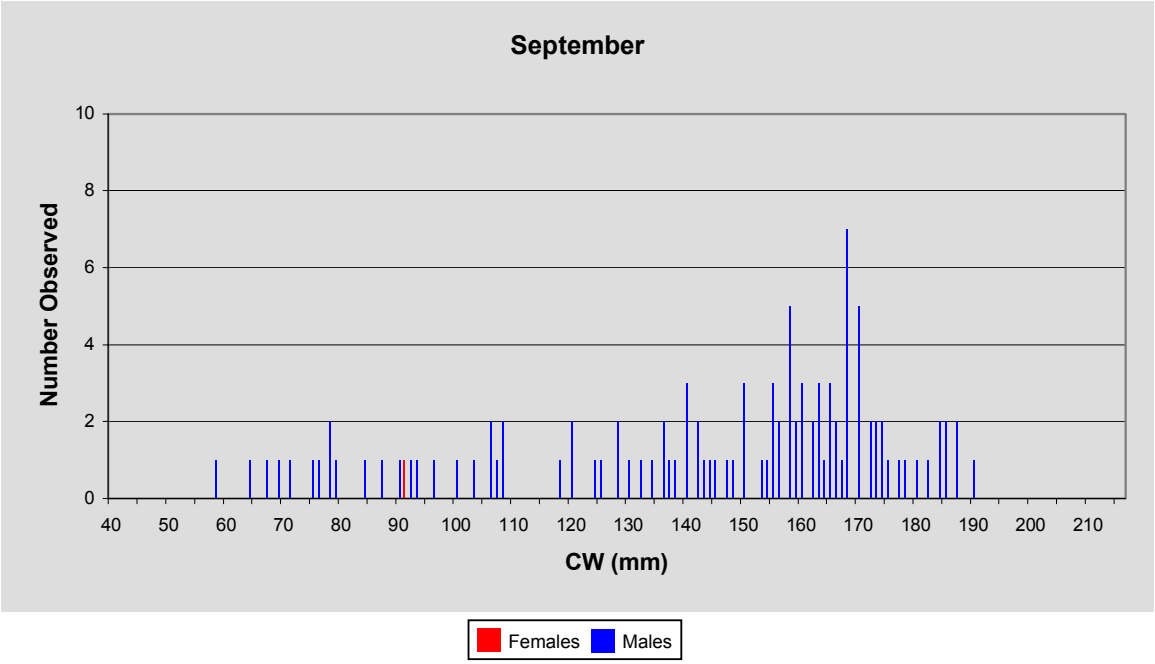


Figure 3.33. Dungeness Crab Size Frequency Distributions at the DWS for the July and September Bottom Trawl Surveys

4 Discussion

The objectives of this study were to provide a physical characterization of the benthic habitat at the DWS; characterize the benthic invertebrate community at the DWS; characterize the demersal fish and invertebrate community at the DWS and SWS; characterize the assess the crab population at the DWS and SWS; assess the uniqueness of the site to the rest of the coastal area; and provide a basis of comparison for any future monitoring efforts required by the Portland District Ocean Disposal Site Management plan. Data collected at the SWS reflect current conditions that persist during dredged-material disposal; whereas data collected for the DWS are considered baseline conditions since the site is proposed for but has received dredged materials. The studies were designed to be able to discern differences in the physical and biological attributes of each site.

4.1 Benthic Habitat and Community Structure at the DWS

The benthic community at the DWS is typical of sand-dominated inner shelf environments in Washington and Oregon. This habitat is dynamic, with large, high-energy waves occurring during the winter storms and calmer waters during the summer months. The influence of these high energy waves is most noticeable near shore but can also be seen in the deeper water. The sampling efforts that were performed in 2002 demonstrated this winter to summer transition toward TOC-rich fine-grained material accumulation.

Between the July and September sampling periods, fine-grained material settled throughout the DWS (as evidenced by SPI images showing a thicker depth of finer-grained reworked sediment at the surface of these sites). This settlement was most apparent at the shallower portion of the DWS with stations showing an relative percent increase in TOC of approximately 50% (0.297% to 0.43%). This resulted in the entire site having essentially the same TOC during September as was seen at the deeper portions of the site in July (~0.43 to 0.45%). Similarly, the relative percent sand decreased across the site, while the relative percentage of silts and clays increased.

Benthic invertebrates have adapted various strategies for living in this type of habitat. Some of the strategies include rapid colonization after a change in sediment characteristic, shallow-tube building to aid in the capture of suspended particles and to aid in holding settled detrital materials, and rapid burrowing and movement from one location of settled detritus to another (e.g., mobile epifauna such as ostracods, cumaceans, crab, shrimp, and fish). Adaptive feeding strategies include deposit feeders that capitalize on eddies created by tubes that help to settled organic rich materials around the tubes or burrows and flexible appendages that can search the surface of the adjacent sediment for organically enriched particles. Although these communities may not feature characteristics typically associated with late successional communities (deep-burrowing tubes, deep-feeding clams, and deep redox horizons), they should not be considered "unstable" communities. Rather the cycles in TOC and finer-grained material create a niche for those species adapted to those environments.

The benthic habitat and community structure in the DWS were generally represented by two areas, Area 1 and 2, based on a summary of physical and biological characteristics of the DWS (Figure 4.1). The characteristics of the two areas for July and September are presented in Table 4.1.

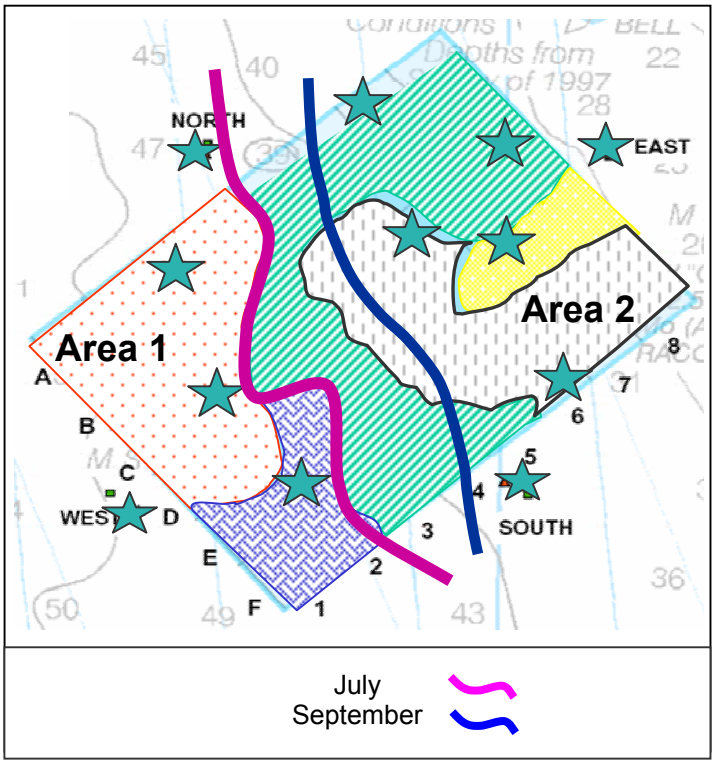


Figure 4.1. Division Between Area 1 And Area 2 In The DWS, Based on a Summary of Physical and Biological Characteristics.

Table 4.1. Summary of Physical Features and Fish and Invertebrate Fauna for Areas 1 and 2.

Area	Phi	TOC	RPD	OSI	IA[1]	IR[2]	Group	Dominant Fish	Dominant Epifauna	Dominant Infauna	Trappable Fauna
July 2002											
Area 1	3.3	0.51%	1.4	5.1	382	65	1A, 1B	Pacific sanddab	*Luida*	*Magelona*	Hagfish
		(0.7)	(0.4)		(78)	(7)		Rex sole	*Acanthoptilum*		
									Crangon		
Area 2	2.7*	0.33%	1.0	2.9	186	42	2A,2B, 2C	Pacific sanddab	*Crangon*	*Axinopsida*	Hagfish
		(0.6)	(0.4)		(37)	(3)		Rex sole	*Neocrangon*	*Galathowenia*	
									Luida	*Euphilomedes*	
September 2002											
Area 1	3.6	0.51%	2.2	6.0	552	78	1A, 1B	Rex sole	*Luida*	*Magelona*	Cancer
	(0.5)	(0.5)	(0.5)		(127)	(4)		Pacific sanddab	*Cancer*	Maldanidae spp.	
								Dover sole	*Metridium*		
Area 2	3.2	0.4%	1.5	3.8	336	56	2A, 2B,	Rex sole	*Cancer*	*Axinopsida*	Cancer
	(0.5)	(0.5)	(0.6)		(105)	(10)	2C, 2D	Pacific sanddab	*Crangon*	*Galathowenia*	
								Eulachon		*Euphilomedes*	
										Diastylus	

[1]*IA: Infaunal abundance, individuals per 0.1 m²*
[2]*IR: Species richness*

4.1.1 Characterization of DWS in July 2002

In July, Area 1 was located in the deeper, western portion of the DWS and included the North and West reference sites. Water depths were generally greater than 45 meters. Area 1 habitat was characterized by very fine sand with greater than 10% silt and clay fractions with an average TOC of ~0.5%. The apparent redox boundary was 1.41 cm and an OSI of 5.1, indicating a moderate level of biological activity and more established benthic community. The general features of the infaunal invertebrate community were greater infaunal abundance and species richness than at the Area 2 locations. The dominant taxon was the shallow, tube-building polychaete, *Magelona cerae*, which represented approximately 40% of all infauna in the area. The appearance of the benthic habitat and dominant invertebrate community are characterized by SPI in Figure 4.2.

Figure 4.2. Magelona Tubes in Area 1.

The demersal invertebrate community was dominated by the starfish *Luida foliolata*, the sea whip, *Acanthoptilum* sp. and shrimp of the genus *Crangon* spp. There was a general trend of decreased abundance of the highly mobile shrimp species and increased abundance of the more sessile starfish and anemone species in the deeper portion of the DWS, represented by Area 1.

There were virtually no trawlable or trappable Dungeness crab using this area, but there were a large number of trappable hagfish (Figure 4.3). The dominant fish within Area 1 were flatfish, including the Rex Sole and the Pacific Sanddab as the most abundant. The abundance of these fish was lower at the deeper water portion (biological community Area 1) of the DWS than in the middle section of the site.

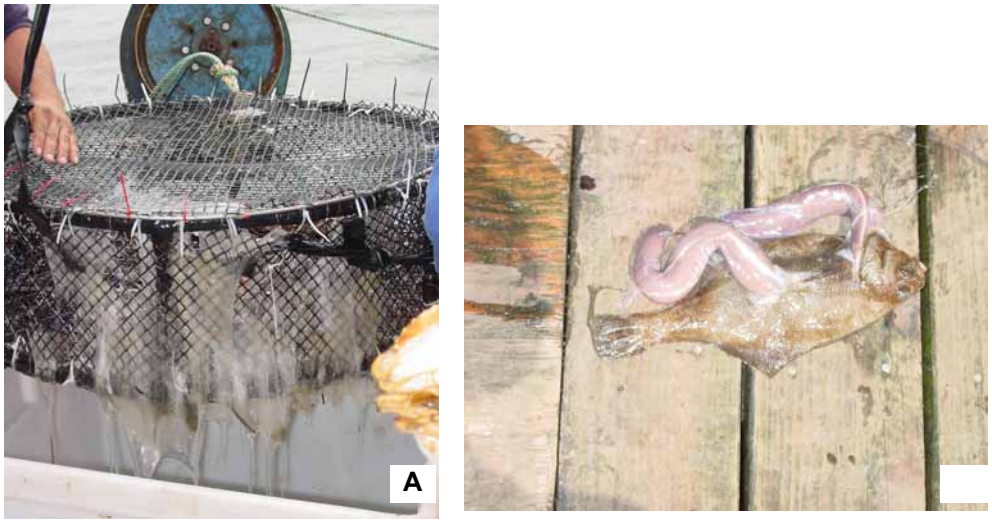
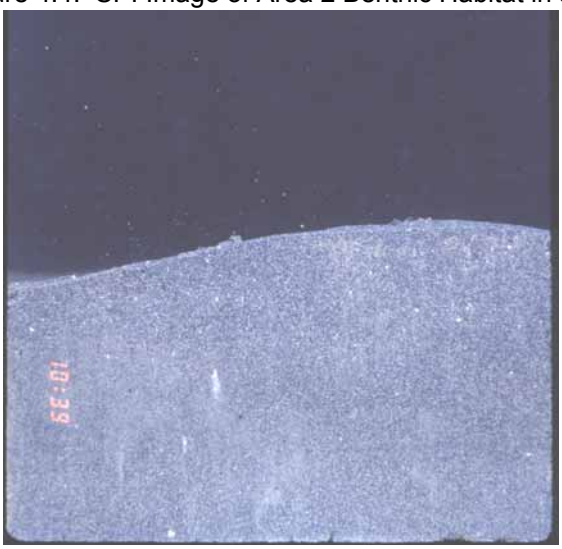


Figure 4.3. Photograph of Typical Catch of 3 to 4 Hagfish in Trap (A), and Photograph of a Hagfish Preying on Pacific Sanddab Captured in Trap (B).

Area 2 was located in the shallower central and eastern portions of the site and included reference stations South and East. Depths ranged from 25 to 45 fathoms. The benthic habitat was generally characterized by very fine sand with some evidence of consolidation and lower surface roughness. TOC was lower than in Area 1, with an average TOC of 0.33%. However, there was a fair amount of variability in TOC across Area 2, from 0.79% at station A7 to 0.17% at station East. The apparent redox boundary was relatively shallow, with a mean RPD of 1.0 and an OSI of 2.9, indicative of less established, early successional communities. The general features of the benthic infaunal community were lower abundance and species richness and slightly more evenness among the more dominant taxa. The dominant infaunal taxa were the clam *Axinopsida serricata*, the tube-building polychaete, *Galathowenia oculata,* and the ostracod *Euphilomedes carcharodonta*. The benthic habitat in Area 2 is characterized by SPI in Figure 4.4.

Figure 4.4. SPI Image of Area 2 Benthic Habitat in July 2002.



Shrimp in the family crangonidae were the dominant taxa in the demersal invertebrate community with the highest abundance occurring in the central portion of the DWS. As in Area 1, there were few trawlable or trappable Dungeness crab using this area, but there were a large number of

trappable hagfish. The dominant fish in this area of the DWS were the Pacific Sanddab and the Rex Sole, both in higher abundance than in Area 1 of this DWS, especially in the central area where the crangonidae shrimp abundance was also higher.

In July, the demersal fish community at the deepwater site indicated moderate abundance, with mean total fish of 377/ha. Fish abundance varied across the site, with the highest abundance occurring in the northern and central portions of the site and the lowest abundance occurring in the deeper, southwestern corner of the DWS. Flatfish dominated the fish assemblage, representing >75% of all individuals. Pacific sanddab were dominant in the central portion of the site (77% of all fish in Trawls III and V). Rex sole were also common throughout the site, representing a larger proportion of fish captured in the northern portion of the site. The distribution of flatfish resembled that of the epibenthic shrimp population. Rex sole also showed two types of tumors on their dorsal and ventral surfaces with epidermal papillomas being the most common.

4.1.2 Characterization of DWS in September 2002

In September there was a shift in habitat characteristics across the entire DWS towards finer-grained sediment and higher TOC. This was likely due to the deposition of fine-grained, higher TOC material that was visible at the surface of the SPI images (Figure 4.5). As a result the division between Area 1 and Area 2, based on habitat characteristics, shifted shoreward (Figure 4.1). Area 1 in September was characterized by slightly higher TOC and reduced grain size, with a higher RPD and OSI, possibly indicating later successional stages. The benthic infaunal community showed increased abundance and species richness throughout the DWS site; however, *M. cerae* remained the dominant species along with Maldanid worms.

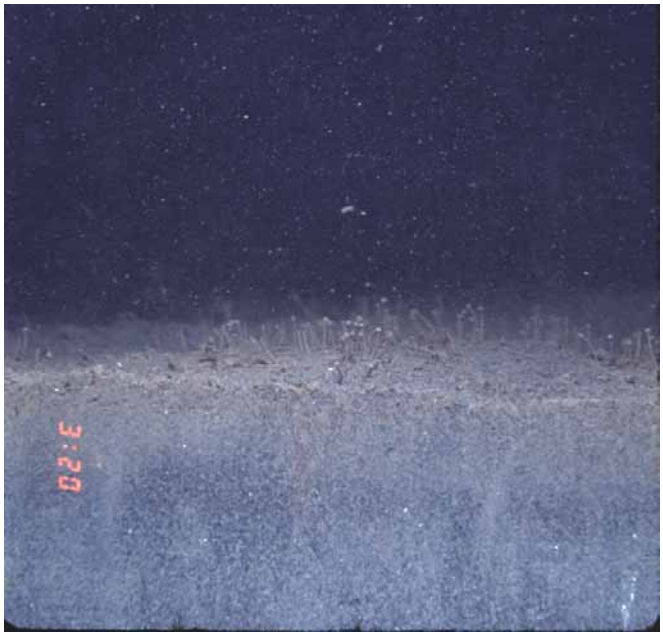


Figure 4.5. Surface Deposits of Fine-Grained, Organically Rich Material, September 2002.

Epifaunal abundance was similar to that in July at the deepest portion of Area 1 and decreased substantially in the more central portion of the DWS. This was largely due to the absence of

large numbers of shrimp that were observed in July. There were few Dungeness crab in the western portion of the DWS, however small numbers of crab were captured in the trawls in the central portion of the site, within Area 1 (Trawl III).

The habitat characteristics of Area 2 shifted towards finer-grained sediment and slightly higher TOC (~50%). The RPD and OSI for Area 2 increased, relative to July, but remained lower than Area 1. The change in RPD and OSI were likely a result of the seasonal fine-grained deposits. Infaunal abundance and richness increased, relative to July, but remained lower than that of Area 1. Infaunal abundance was lowest at the eastern most margin of the site, which coincided with the areas of coarser sand and sand waves. Dominant taxa in Area 2 were *Axinopsida*, *Euphilomedes*, *Galathowenia*, and *Diastylus*.

The epifaunal community changed substantially between July and September, with a marked decrease in shrimp across the area and an increase in Dungeness crab. Crab density was highest in the shallower stations. Fish abundance was similar in September; however, there was less variability across the DWS. The demersal fish assemblage remained dominated by flatfish species. Pacific sanddab and Rex sole were the dominant taxa; however, the distribution of individuals between species was more even. Eulachon were more common at the northern portion of the site. Fish abundance observed at the DWS during both surveys was similar to those observed by Durkin and Lipovsky (1977).

It is important to note, that despite the changes in habitat characteristics and infaunal abundance and richness across the DWS, the stations that were clustered together based on common species distributions in July were again grouped together in September. This supports the concept that despite seasonal or annual changes in the communities at the DWS, stations that were originally grouped together remained similarly grouped. It is our theory that these groupings will be conserved provided there are no localized changes in depth or physicochemical properties of the sediment (e.g. dredged-material placement). These station groupings may then be used for monitoring shifts in the community following dredged material disposal.

The sediment characteristics found at the DWS were similar to those found in previous studies at the MCR. The USACE (1999) has shown the DWS to lie in portion of the MCR characterized by fine grained sands with 10 to 15% silt/clay, with percent fines increasing with depth. The trend towards increased finer grained sediment with increasing depth has been observed in previous studies of the DWS and surrounding areas (Hancock 1997). Seasonal increases in finer-grained sediment occur during the summer months; however this material appears to be removed during the winter storms (USACE 1999). This study confirms the seasonal trend of increasing deposition of TOC-rich, fine-grained sediment over the summer period.

TOC appeared to be an important factor in controlling the infaunal community at the DWS. Figure 4.6 shows the relationship between percentage of TOC and infaunal abundance across the DWS for July and September. The changes in the Area 2 community are likely a result of the TOC deposited during the summer, which nearly doubled the amount of available organic carbon. This cycle in nutrient-rich deposits have been previously noted at the MCR (Hancock 1997) and is believed to be due to nutrient influx from the rivers, upwelling from the deep ocean, and the calmer summer waters which allow for settlement and deposition. More opportunistic species and rapid colonizers then respond to these deposits, increasing the late season abundance and species richness. It is anticipated that winter storms will generally remove the TOC-rich deposits, shifting the community towards the July habitat and community characteristics.

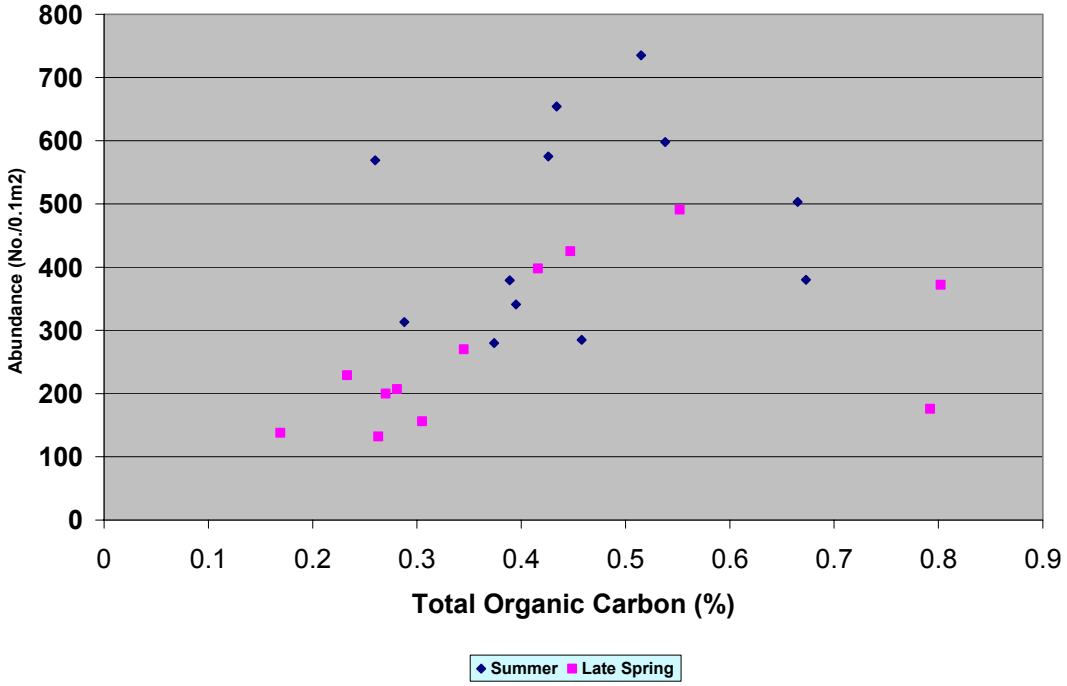


Figure 4.6. Relationship between Total Organic Carbon and Infaunal Abundance at DWS, July and September 2002.

Station A7, located in Area 2 appears to be an outlier station. This station lies on the transition zone between Area 1 and Area 2. The habitat characteristics are similar to those of stations in Area 1; however the infaunal community was similar to that of the Area 2 stations in both the July and September sampling periods.

Overall, the DWS benthic infaunal abundance was considered high for areas off of the mouth of the Columbia River (Hancock 1997), with abundance generally exceeding 2000/m^2 for the DWS in both July and September. Infaunal abundance was similar to that observed by Richardson et al. (1977). The infaunal assemblage was also similar, with sediment in the area of the DWS being dominated by *A. serricata*, *Myriochele oculata* (= *G. oculata*), *Lumbrineris luti* (= *S. luti*), *and A. castrensis*. Although Richardson et al. did not note the dominance of *Megalona*, Emmett and Hinton (1994) and Hinton and Emmett (1996) observed *Megalona* in the areas of the DWS.

The epifaunal invertebrate abundance observed in the trawls was lower than those observed previously near the DWS. Trawl shellfish densities were relatively low across the site, ranging from 20 to 110 individuals/ha. Previous studies have indicated higher invertebrate abundance; however these studies were not at the DWS (Siipola et. al.1993). Previous studies on the benthic assemblages at the MCR showed a similar dominance by shrimp and crab (Richardson et al. 1977, Durkin and Lipovsky 1977). The co-occurrence of Crangon shrimp and flatfish abundance is also consistent with observations by Durkin and Lipovsky (1977) who indicated that shrimp are important prey items off the MCR.

Crab were not found in the DWS in great numbers during the July survey but were quite abundant during the September sampling episode. Increased abundance of crab in trawls and pots was observed primarily at the shallower portion of the site in September. This confirmed observations from previous studies by McCabe et al. (1983, 1984, and 1985) who found densities ranging from 4 to 20 crab per hectare (USACE 1999) with much higher densities observed within the estuary.

Epidermal tumors were observed on Rex sole during both sampling events, with an approximate incidence rate of 10%. Two classes of tumors were identified. The first were epidermal papillomas, which are fairly small and are common among Pleuronectids in the northeastern Pacific (Mearns and Sherwood 1977). These tumors have not been linked to anthropogenic inputs. The second class of tumors was similar to large, dark colored invasive tumors that Mearns and Sherwood (1977) indicated to be an invasive squamous cell carcinoma. The cause for these tumors is unknown. Future studies should be directed to better determine the incidence rate and intensity of these tumors in the vicinity of the MCR and areas further along the Oregon and Washington coast. Such a study should be directed at determining relationship between incidence and the Columbia River discharge. It should be noted that these tumors were observed prior to dredged-material disposal at this site.

4.2 Shallow-Water Site

The SWS was evaluated for epifaunal invertebrates and demersal fish, only. No benthic habitat or benthic infauna samples were evaluated at the SWS. Similar species were found in the September and October sampling cruises, however the crab abundance increased 4-fold in Transect C. These observations are consistent with those made by Richardson et al. (1977), who characterized the nearshore epibenthic invertebrate assemblage as being dominated by shrimp and Dungeness crab.

The fish community was dominated by eulochon and tomcod. In July, the abundance of fish was 521/ha and 147/ha in Transects B and C, respectively. The fish assemblage was dominated by Eulachon and Pacific tomcod, comprising >75% of all fish observed. In September, the fish assemblage was characterized by higher abundance (571 per hectare) and dominance by Pacific tomcod. Tomcod comprised >75% of all fish observed, with small numbers of eulochon, herring, and sculpin. Additional samples taken in October showed even greater dominance by Pacific tomcod with many of them appearing sexually ripe (small orange colored eggs being extruded from vents). An anecdotal observation made during the October sampling event revealed the presence of orange smears on the maxillipeds of the Dungeness crab captured in the trawls. This observation was most common when large numbers of Pacific tomcod were captured at the same time as larger numbers of crab. Whether the crabs were eating the roe of the Pacific tomcod after they were captured in the net or during their time on the bottom is not known.

The size and numbers of adult male crab captured during the October trawls was unexpected and probably not related to molting of crab that had continuously occupied the SWS over the summer. This conclusion was based on the fact that relatively few legal-market sized crab were captured during both July and September, the hard shell characteristics of the October individuals, and their extreme size. It is unlikely that these crab represented newly molted individuals of SWS crab or crabs that had been undergoing harvest by the commercial and sport fisheries in the area. It is possible that these large individuals had been attracted to this area, potentially as a result of the large number of spawning Pacific tomcod. Where they were attracted from, nearby unharvested areas up or downcoast, from within the estuaries associated with the Columbia River or from localized deep water areas that act as reservoirs for these crabs is unknown.

Previous studies have noted large numbers of smelt and tomcod in the area of the SWS (Hancock 1997). Eulachon are known to occur at the MCR in spring to early summer, whereas tomcod are common from August to November (Durkin and Lipovsky 1977). Epidermal tumors were observed on English sole at the SWS. Although the estimated incidence rate was 10%, few fish were caught in the SWS trawls.

4.3 Dungeness Crab

This section provides a discussion of the Dungeness crab life history, an interpretation of the data results of the crab survey, and conclusions based on the findings of the crab studies at the two sites.

4.3.1 Life History

Dungeness crabs inhabit a wide variety of habitats and environmental conditions, extending from Pt. Conception, California, north to Prince William Sound, and west to Amchitka Island in the Aleutians (Jensen and Armstrong 1987). Adult Dungeness crabs commonly occur subtidally to 90 m (295 ft), on sandy bottoms, but have been found as deep as 230 m (750 ft; Jensen 1995). Male Dungeness can reach a maximum carapace width of 230 mm, (immediately anterior of the tenth anterolateral spine) and weights of over 2 lbs. Female Dungeness crab, are typically smaller, with a maximum size (165 mm) resulting from more energy devoted to egg-production rather than growth.

Under constant conditions, molting rates and frequencies decrease with age (Hankin et al. 1985). Adult female Dungeness crab molting probabilities have been shown to decrease after reaching a relatively distinct size, with molt probabilities going from near 0.90 at 131 mm CW to 0.08 at 143.5 mm CW (Xue and Hankin 2002). Adult female crabs are known to exhibit a well-defined molting season from mid-February through mid-May, just prior to mating (MacKay 1942,

Cleaver 1949, Butler 1960, Hankin et al. 1985, Gilbert et al. 1989). On the other hand, male Dungeness crabs tend to molt from June through August. This ensures that male crabs will have hard shells and therefore able to compete for, and successfully mate with, molting female crabs in the spring. Gravid female Dungeness crab generally extrude eggs in October and November (Cleaver 1949, Reilly 1983, McConnaughey et al. 1992), at which time they become more frequently and more strongly aggregated than male or non-ovigerous female Dungeness crab (O'Clair et al. 1996). Ovigerous (i.e., egg-bearing) female Dungeness crab aggregations almost always occur at depths of less than 10m, where they remain partially to completely buried in the sediment and occasionally are observed stacked on top of each other (O'Clair et al. 1996). Dungeness crab larvae are released between January and March off the Washington State coastline (Cleaver 1949, Reilly 1983, McConnaughey et al. 1992).

Juvenile estuarine and coastal settlement generally occurs from May to June (Stevens and Armstrong 1984, Gunderson et al. 1990). Young crabs have been observed to molt multiple times a year and can experience molt increment increases as large as 25-30% per molt, whereas mature crabs tend to molt less frequently (1 or fewer) (Schultz et al. 1996), and at a reduced molt increment rate of 10-15% per molt (Hankin *et al*. 1985). Juvenile Dungeness crab, in general move out into oceanic waters from estuaries following their second summer, having reached an average carapace width of 100 mm for females, and 116 mm for males (Butler 1960, 1961). Dungeness crab generally reach market size (159 mm) by about four years of age (Cleaver 1949, Butler 1960, Gilbert et al. 1989).

4.3.2 Dungeness Crab Study Data Interpretation

In general, the DWS showed relatively no difference in Dungeness crab sex composition and only a small increase in mean CW from July (140mm) to September (148mm). However, the number of males increased from 21% to 90% of the measured catch and the total number of crabs caught increased from 81 crabs to 1,314 from July to September. The July sampling event likely coincided at a time when the majority of male crabs were molting. Pre-molt and recently molted crabs are unlikely to enter traps where they may be subject to predation by other crabs. The shell strength data indicates that a greater percentage of male crab caught in pots were hard-shelled (47%) in July than in September (15%; 1% for trawl caught crabs). This is an indication that the few adult male crabs were molting or preparing to molt at the DWS in July. By September many of the adult crabs caught had recently undergone molting. After the initial hardening of the new soft shell Dungeness crabs forage heavily to fill out their new shell. An interpolation of the July and September DWS crab pot data shows that crabs were not abundant at the site in July, and that the majority of the 1,314 crabs caught in September were in the shallower and closer to shore portions of the DWS site. Life history may explain the pattern observed, with crabs undergoing their molting phase staying closer to shore (July), but as their need and ability to forage following molting increases, they move out from shallow water habitats into deeper water (September).

Conversely, the much more dynamic SWS showed relatively constant percentages of males in pots from the July (28%) to September (31%) even as the catch increased from 649 in July to 905 in September. Additionally crabs were larger in September (151mm mean CW), at the end of the molting season, than they were in July (130mm mean CW). For the SWS no pattern of differential site use is detected, as observed at DWS. However it is important to note that there is not a decrease in relative abundance of crab from July to September, despite the placement of dredged material within the SWS.

The four bottom trawls at the SWS exhibited an increase in the number of crabs and percentage of males from July (55 per hectare; 33% male) to October (179 per hectare; 64% male). In

addition, an increase in the number of hard crab present in trawls was observed from July (20%) to October (48%). These seasonal differences in catch characteristics are likely the result of the dynamic conditions at the SWS, it's location along the migratory corridor for crabs leaving the Columbia River estuary, and the timing of the sampling events relative to the seasonal Dungeness crab molting period.

The fact that no gravid females were caught in crab pots or otter trawls at either site was not unexpected, as ovigerous female Dungeness crabs in this region are most frequently captured in commercial crab pots during the months of December and January (Hankin et al. 1985). Additionally, ovigerous female crabs remain closer to the shoreline (P. Dinnel pers. comm. 2002), and rarely occur in habitat greater than 30 m in depth (O'Clair et al. 1996).

4.4 Comparison of the DWS with Coastal Areas of Washington and Oregon

The habitat of the DWS is typical of the inner to middle continental shelf of Oregon and Washington. The continental shelf along the coast of Washington and Oregon is roughly 25 to 60 km wide with a shelf break occurring at 200 to 250 m. The MCR represents a widening of the shelf, formed by the historic sedimentary deposits of the Columbia River. The inner continental shelf (to a depth contour of approximately 75m) is characterized by a smooth sloping sediment wedge against the coast (McManus 1972). South of the MCR, this inner shelf gives way to a rougher outer shelf which features positive and negative relief. This rougher outer shelf is not as prevalent north of the MCR. A series of submarine canyons cut across the shelf along the Oregon and Washington coasts and head at approximately 130 m depth. The Astoria Canyon lies at the MCR and was historically the primary pathway for sediment flow from the river. The predominant modern sediment flow is northward along the shelf (Kachel and Smith 1989). The predominant sediment type on the continental shelf is sand. The median phi size of the inner shelf south of the MCR is 2 to 3ø, whereas north of the mouth the predominant range is 3 to 4ø. This difference reflects both an increase in silt content and finer sand particle sizes north of the MCR. Silt content increases with depth beyond the 75 m contour, becoming silty-sand with 20% to 40% silt towards the shelf break. Silt content is as high as 60 to 80% in portion of the Astoria and Willapa Canyons, however this distribution is limited to discrete regions. The DWS is located along the southern margin of the Astoria Canyon. As such, the habitat within the DWS is a combination of the "inner-shelf sand wedge" and the "outer shelf silty sand", which is primarily in the southwest corner of the DWS. This is a transition, from sand to silty-sand that is not uncommon along the length of the Oregon and Washington coast.

The Pacific Coast is subject to heavy winter storms with waves capable of moving sandy and silty sediments (Kachel and Smith 1989). The waves not only serve to resuspend bottom sediment, but also to increase the rate of sediment transport by currents. At the MCR this resuspension is coupled with a strong northward flow across the shelf (Small et al. 1989), which would likely result in net loss along the southern margin of the MCR. In the summer, the prevailing winds are from the north-northwest and an upwelling current brings colder more saline outer shelf waters. This, coupled with weak storm events, low wave energy and high early summer flow from the Columbia River served to increase the deposition rates of finer grained sediment and associated organics (Hamilton 2001, Hancock 1997). This pattern is typical of river mouths along the Pacific coast and was an important feature observed at the DWS.

The infaunal invertebrate community at the DWS was characterized by two distinct communities; however, neither of these communities was unique to the Oregon and Washington continental shelf. Richardson et al. (1977) found *A. serricata*/*G. oculata* and *Megalona* sp. dominated communities throughout much of middle shelf in the vicinity of the MCR, from 46° 05' to 46° 20'. In coastal Washington, Lie and Kisker (1969) observed *Magalona* sp as a dominant species in the intermediate depth sand-bottom communities. *A. serricata* was also a dominant species, however, Lie and Kisker observed *A. serricata* in the mud-bottom deep communities. Carey (1972) noted a progression of polychaete species with depth across the Oregon Coast shelf, with *Megalona* sp. occurring in the 50-100 m depth range, a depth range similar to that of the DWS. Infaunal densities at the DWS ranged from 1400 to 6000 individuals/m^2. This is similar to those observed by Richardson et al. (1977) for the MCR area and is within the range of abundance observed by Lie and Kisker (1970) on the Washington coast and Carey (1972) for the central Oregon coast. Absolute comparisons of abundance are approximate, as differences in sampling methodology and sieve sizes vary between studies. While there may be some distinct areas

within the DWS, the benthic community does not appear to be unusual for the inner continental shelf of Washington and Oregon.

Flatfish, the dominant demersal fish taxa in the DWS, are a dominant inner shelf species along the entire west coast. Resident populations have been noted in the vicinity of the MCR (Durkin and Lipovsky 1977) and the Pacific Sanddab, English sole, Dover sole, and Rex sole were all among the dominant species observed in the bottom fish surveys conducted in California, Oregon, Washington, and Southern British Columbia (NOAA 2001). Pacific hake, occurring in moderate numbers in the DWS trawls, was the most common fish species observed by NOAA. This difference in relative abundance of hake may be due in part with location, interannual variation in populations, or habitat trawled. The assemblage observed in the DWS resembles that typical of the area south of the MCR (Durkin and Lipovsky 1977). Demersal fish densities observed in the DWS trawls were generally less than 700 individuals/ha, this is lower than previous studies by Siipola et al (1993) which observed demersal fish densities of 1,702 to 3,564 individuals/ha. While previous surveys have indicated that young of the year flatfish may be found in the vicinity of the DWS (Durkin and Lipovsky 1977), this survey found no evidence that the DWS could be considered a unique nursery ground.

The epifaunal invertebrate community of the DWS is similar to that observed in the inner continental shelf of Oregon and Washington. Epifaunal abundance is typically low along the inner shelf and and increases with increasing depth. Carey (1972) noted epifaunal invertebrate densities of less than 50 individual/ha at depths of 50 m and 100 m along the central Oregon coast. Dominant epifaunal species along the Oregon and southern Washington coast include Crangonid shrimp, starfish and Dungeness crab (Carey, 1972; McCauley 1972). Shrimp and starfish were also dominant epifauanal species in trawls at locations in Washington, Oregon and California conducted by NOAA (2001) as part the triennial groundfish surveys.

Very few comprehensive studies have been published on coastal Dungeness crab populations in Oregon and Washington, with the regional scientific focus on estuarine recruitment, entrainment, and habitat loss. In addition, commercial Dungeness crab catch data for the region is aggregated and managed for very large areas and cannot be used to determine site-specific crab habitat conditions. The Columbia estuary is similar to other large estuaries in the region (e.g. Willapa Bay and Grays Harbor), with respect to providing Dungeness crab nursery habitat and supporting relatively large Dungeness crab year classes. The dynamic high-flow conditions of the Columbia River provide unique physical conditions in the nearshore coastal waters of Washington and Oregon. It is does not appear that either the DWS and SWS are unique crab habitat relative to other coastal areas offshore of large estuaries; however, due to the limited Dungeness crab population data for this coastal region it is difficult to make a definitive statement.

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