Monitoring of dredged upper Santa Cruz Harbor mixed sand and mud sediment released into the nearshore area of Santa Cruz, California

Prepared by:

Steve Watt and Dr. H.G. Greene
Center for Habitat Studies
Moss Landing Marine Laboratories
8272 Moss Landing Road
Moss Landing, CA 95039
(831) 771-4140
December 19, 2001

Prepared for:

the
Santa Cruz Harbor Port District
135 Fifth Avenue
Santa Cruz, CA 95062

and the

California Department of Boating and Waterways

Table of Contents

List of Figures

List of Tables

Executive Summary

In late March of 2001 the Santa Cruz Small Craft Harbor was permitted to dredge approximately 3,000 yd^3 (2,300 m^3) of upper harbor mixed sand, silt and clay sediment into the surf-zone approximately 70 yards (64 m) from the shore of Twin Lakes Beach**.**

A monitoring program was designed and implemented by the authors of this report to determine if sedimentary changes occurred in the beaches and nearshore benthic habitats in the vicinity of the Santa Cruz Harbor due to the retention of the mud rich dredged sediment. In addition to a comprehensive scientific literature review, a variety of data was collected to monitor the experimental dredging event and the natural processes occurring in the study area during the monitoring period from February 18 to April 14, 2001. San Lorenzo River stream flow data were used to calculate sediment discharge estimates. Oceanographic swell information was downloaded to monitor wave conditions and to calculate littoral drift estimates. Over 300 sediment samples were collected and grain-size analyses performed. Over 300 water samples were collected to observe changes in turbidity over time. Two separate ~7 km^2 geophysical surveys were executed to describe and quantify benthic habitats and sedimentary changes that may have occurred during the monitoring period.

The complete integration and analyses of all the data types collected during the monitoring period leads us to the conclusion that the dredged upper harbor sediment released into the surf-zone during the experimental dredging event (including sediment derived from other nearby sources), did not significantly change, alter, or impact the beaches or nearshore marine benthic habitats in the study area.

1. Introduction

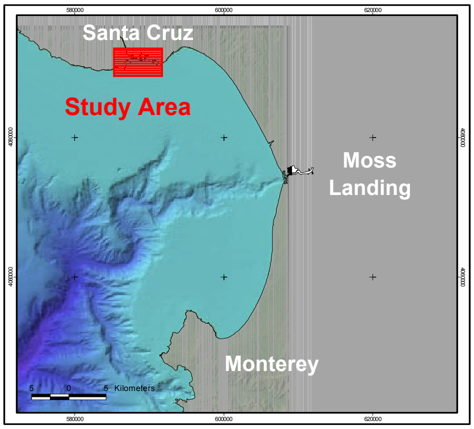
On March 28, 29, and 30 2001 the Santa Cruz Small Craft Harbor was permitted to release approximately 3,000 yd^3 (2,300 m^3) in 500-700 yd^3 increments (approximately 380-540m^3) of mixed sand, silt and clay sediment into the surf-zone. The material was excavated near J-Dock in the upper Santa Cruz Harbor and released approximately 70 yards (64 m) from the shore of Twin Lakes Beach (Figure 1) near the east jetty**.** The mud-rich sediment was dispersed between the hours of 7:00 pm to 12:00 am.

The upper harbor sediment was composed of ~60% silt and clay (or mud) and 40% sand (Sullivan & Krcik, 1999). The high concentration of mud present in the material is not allowed for surf-zone disposal according to EPA Region IX standards for grain-size (Foss, 1999). The concern is that the fine-grained material may be retained in the beach and nearshore benthic habitats and change the existing natural environment that was present before the experimental dredging event.

The primary goal of the monitoring period was to determine if sedimentary changes occurred in the beach and nearshore benthic marine habitats near the Santa Cruz Harbor due to the retention of fine-grained mud that was released during the experimental dredging event. Sedimentary changes were anticipated that may include, but not limited to, the degradation of the quality of sand on the neighboring beaches, burial of the nearshore marine benthic habitats, and alteration of the natural transport of coastal sediment.

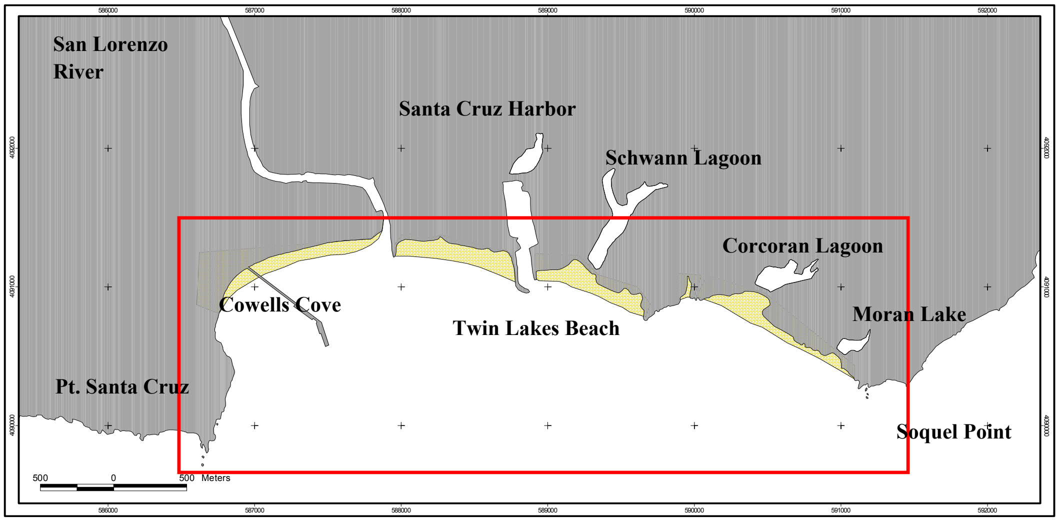
Our approach was to monitor the habitats that stand the greatest chance of being impacted by the experimental dredging event rather than focus on tracking the dispersal of the mixed sand and mud sediment as it enters the surf-zone. This study focuses on the sandy beaches from Point Santa Cruz eastward to Soquel Point and the nearshore benthic habitats between Point Santa Cruz and Soquel Point out to ~20 meters water depth. To ascertain whether habitats had changed over the course of the monitoring period, a clear baseline of information about the sedimentary grain size distribution of the beaches and offshore habitats within the study area was established before any upper harbor sediment was deposited into the surf-zone. This includes monitoring the natural processes in the study area

a.



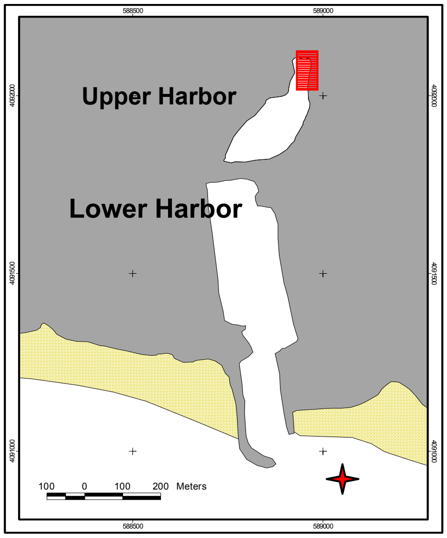
a. Red box denotes location of the study area within the Monterey Bay, California

b.



b. Red box indicates the approximate boundary of the beaches and offshore regions of the study area. Major geographic points, rivers, beaches, lagoons, and the Santa Cruz Harbor are shown. Yellow areas indicate approximate area of beaches.

c.



c. Area of upper harbor that was dredged (🟥) with location of dredge outfall (✦) offshore of Twin Lakes Beach.

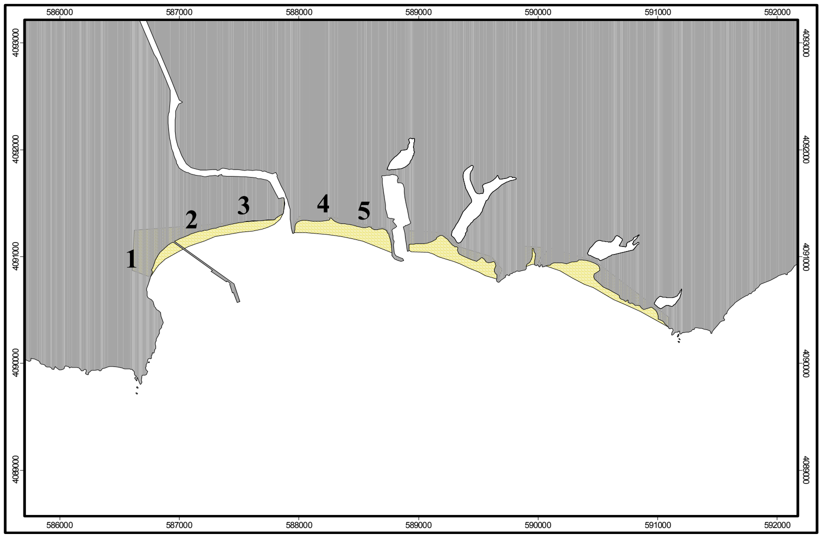
Figure 1. Location of mixed sediment dredging experiment in Santa Cruz, CA

such as sediment input from the San Lorenzo River and transport of sediment in littoral drift from wave action, as well as monitoring anthropogenic inputs such as the addition of sand from the dredging of the harbor entrance. This baseline information was then compared to data collected over the course of the monitoring period, both while the experimental dredging event was executed and after it had been completed.

2. Local Geologic and Climatic Setting

The Santa Cruz Small Craft Harbor is incised in the lowest of a series of erosional marine terraces that step up from the coast into the Santa Cruz Mountains. These wave-cut terraces formed in response to glacioeustatic fluctuations in sea level and tectonic uplift caused by the oblique convergence of the Pacific Plate with the North American Plate and movement along faults within the transform fault system, specifically the offshore San Gregorio Fault with the inland San Andreas Fault (Greene, 1990). The terraces are eroded into the marine and sedimentary rocks of the Pliocene Purisima Formation, a moderate to well-consolidated sandstone, siltstone, and mudstone, interspersed with beds of mollusk shell hash or coquina in the Santa Cruz area. The terraces are overlain by poorly consolidated marine and non-marine gravels, sands and silts ranging from 1.5 to 6 meters thick (Best and Griggs, 1991). The Purisima unconformably overlies the late Miocene Santa Cruz Mudstone, a medium to thick bedded, highly fractured, folded, and faulted siliceous mudstone which is visible in the cliffs to the north of the study area (Greene and Clark, 1979).

Beaches have formed between Point Santa Cruz and Soquel Point (Figure 2) in response to natural physical processes. The cross-shore width of these beaches (or in some cases the presence or absence of these beaches) varies depending upon proximity to sediment sources, coastal geology and exposure to swell. Beaches occur where a protruding cliff or jetty has created a littoral trap, allowing sand to accumulate over time (i.e. Seabright Beach). Some beaches are seasonal, accumulating sand throughout the calm summer months only to completely erode back to the bases of shoreline cliffs, sea walls, or protective revetments, in the winter (i.e. Cowells Cove, Beach and Boardwalk, and 26th Avenue). Others beaches have formed in low-lying areas where streams and rivers intersect the shoreline. In addition to the high surf and tides experienced at all beaches in the study area during winter months, heavy

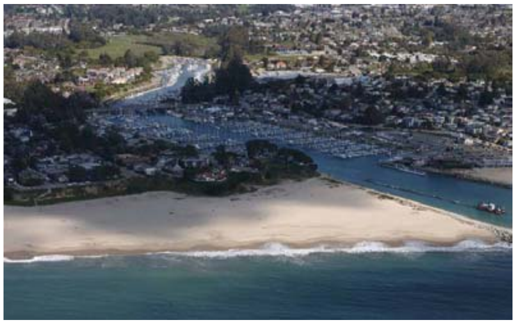


1. Cowells Beach

2. Beach and Boardwalk

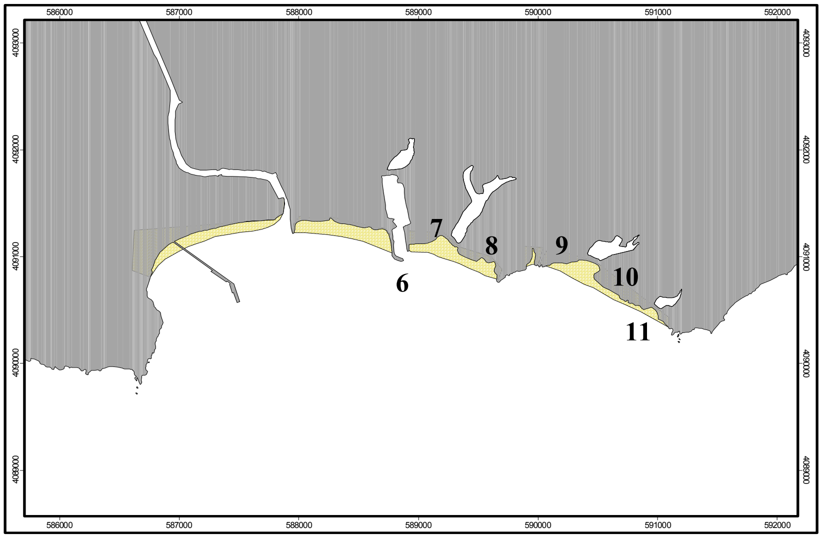
3. San Lorenzo River

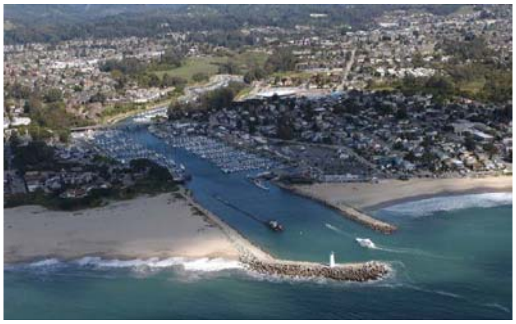
4. west Seabright Beach



5. east Seabright Beach

Figure 2a. West Santa Cruz beaches. Photos show west Santa Cruz beaches observed and sampled during the monitoring period. Copyright © 2002 Kenneth Adelman, California Coastal Records Project, www.californiacoastline.org.




6. Santa Cruz Harbor


7. Twin Lakes Beach


8. Blacks Point


9. Cocoran Lagoon


10. 26th Avenue


11. Moran Lake

Figure 2b. East Santa Cruz beaches. Photos show east Santa Cruz beaches observed and sampled during the monitoring period. Copyright © 2002 Kenneth Adelman, California Coastal Records Project, www.californiacoastline.org.

winter rainstorms cause episodic flooding from rivers, streams and creeks including the overflow of lakes and lagoons, which accelerates erosion of these beaches. This essentially makes these beaches prone to "attack" from both the seaward side and the landward side (i.e. Twin Lakes, Corcoran Lagoon, and Moran Lake).

Santa Cruz receives an annual mean rainfall of 40-70 cm on the coast and up to 150 cm in the mountains, most of which (90%) comes in the winter months from November to March (Best and Griggs, 1991). The summer months, July to October, are generally dry with occasional strong storms from the Southern Hemisphere, which rarely produce precipitation. Prevailing northwest winds are partially blocked by the Santa Cruz Mountains. Often times this creates a pocket of coastal sunshine in Santa Cruz, while the rest of the Monterey Bay is shrouded in fog (Best and Griggs, 1991).

3. Oceanographic Conditions

The waters of Monterey Bay are regionally part of the California Current System, which includes three seasonally influenced currents, the California Current, the California Undercurrent, and the Davidson Current. The California Current is strongest in the summer from July to August, flowing towards the equator at an average speed of 10 cm per second. The current velocity maximum is most often seaward of the continental shelf in most areas along the California, Oregon and Washington coasts. During the late fall, winter, and early spring, the California Current shifts offshore or is replaced by the poleward flowing Davidson Current on the continental shelf. The California Undercurrent, with its core staying at or above most of the continental slope, flows towards the equator with maximum flow velocity in the summer time. Interannual variations in the California Current have been linked to the El Nino/Southern Oscillation phenomena. During El Nino cycles, the equatorward flow of the California Current is abnormally weak and, conversely, abnormally strong during the anti-El Nino cycles (Chelton, 1984).

Breaker and Broenkow (1994) described currents in the Monterey Bay shelf region according to depth ranges. At 0-25 m depth, currents generally flow to the north, then shift to the south at intermediate depths of 25-150 m, and then shift north again at depths greater than

150 m. Nearshore (0-20 m depth) or littoral currents flow primarily to the south and are produced by ocean swells approaching from the west and northwest.

Tides are mixed semi-diurnal with maximum ranges of 2.4 to – 0.8 meters. Extreme low tides reveal tidal pools of exposed, flat bedrock while extreme high tides can completely submerge some winter beaches and inundate the bases of cliffs, sea walls or protective revetments.

The Santa Cruz coastline is open to ocean swells from three different sources, the Northern Hemisphere, the Southern Hemisphere, and locally generated wind swells. Northern Hemisphere swells develop in the north Pacific near Alaska and are common throughout the winter. Open ocean swell heights can top 8 meters. Southern Hemisphere swells develop off the coasts of New Zealand, and South America. Southern Hemisphere swells travel a great distance to reach the shores of northern Monterey Bay. As a result, the swells are less frequent, wave heights smaller, but the periods can be very long (over 20 seconds). Locally generated wind swells develop in response to low-pressure system movements off the California coast. They generally last only a day to a few days, developing and degrading quickly in the winter, spring and summer months. Wave heights are generally smaller and periods shorter than the average Northern Hemisphere swell and, therefore, less potent. The south facing beaches of Santa Cruz are subject to the full force of directly approaching Southern Hemisphere storms but are partially protected from the powerful North Pacific winter storm waves. West, and to a greater degree northwest swell, lose energy as they are refracted around Point Santa Cruz (Xu, 1999). However, most of the beaches, cliffs, coastal homes and roads between Point Santa Cruz and Soquel Point are protected in some way by seawall or revetment to prevent further wave-induced damage along the shoreline (Griggs & Savoy, 1985).

4. Santa Cruz Littoral Cell

Santa Cruz Harbor resides within the Santa Cruz Littoral Cell (Figure 3). The northern boundary of the cell is believed to be the Golden Gate Bridge in San Francisco and extends southward to Monterey submarine canyon. Many past and recent studies have been conducted to estimate a quantitative budget of sediment sources, sinks and transport mechanisms within

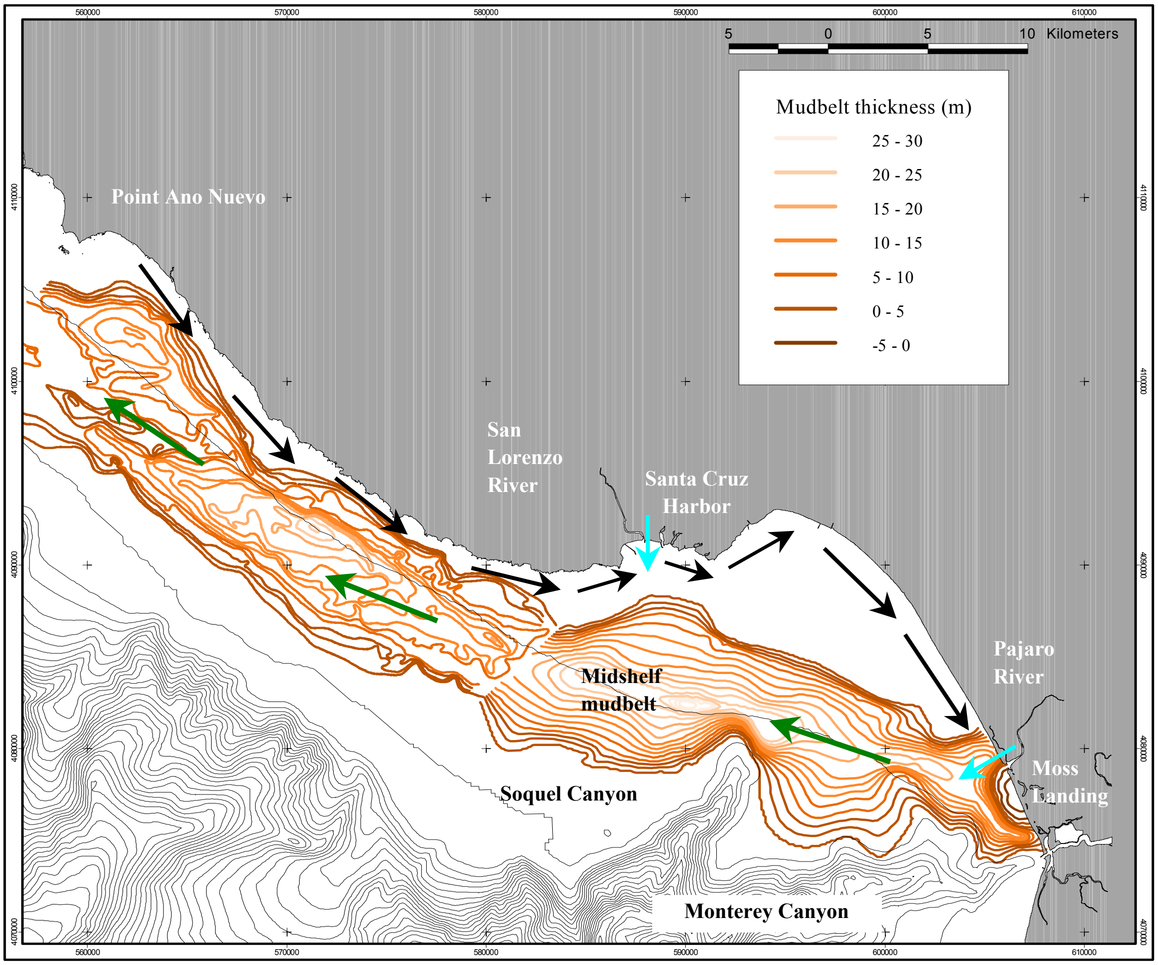


Figure 3. A modified conceptual model of sediment acumulation and transport for the northern Monterey Bay shelf from Point Ano Nuevo to Monterey Canyon by Eittreim et al. (2002b). Black lines are 50 meter bathymetry contours. Orange to brown lines represent the general outline and sediment isopachs (m) of the midshelf mudbelt. Green arrows indicate direction of silt and clay transport along the mudbelt. Blue arrows show discharge of sediment from the San Lorenzo and Pajaro Rivers. Black arrows point the direction of transport of littoral sediment. Arrows do not indicate transport rates or sediment discharge magnitudes. For details regarding transport rates and sediment discharge magnitudes, see Table 1. This figure was reproduced using GIS data from Wong and Eittreim (2002).

the cell (see Methods, *Scientific Literature Review*). Sediment sources include various rivers, small streams, and coastal cliff erosion. Sediment sinks include transport of sediment by wind to sand dunes and loss down the Monterey submarine canyon and the continental slope. Sediment previously deposited on the continental shelf, and sediment transported by littoral currents, may constitute either a source or a sink of sediment depending on location within the cell, season, wave and current conditions.

Past and current research by Arnal et al. (1973), Oradiwe (1986), Best and Griggs (1991), Eittreim et al. (2002b), and Edwards (2002) suggests that the majority of sediment enters the system during episodic flooding events of major rivers. Sediment of different grain size, density, and shape entering the coastal ocean are sorted into different depositional environments by the forces of waves and currents (Bascom, 1951). Best and Griggs (1991) determined the cut-off grain size diameter for transport in littoral drift to be 0.18 mm (2.45 phi) and larger in the Santa Cruz region. Littoral grain-sized sand of 0.18 mm and greater are transported to the southeast at an estimated rate of 200,000–250,000 m^3/year, based on annual Santa Cruz Harbor dredging records (Griggs, 1987).

Sediment smaller than 0.18 mm in size is believed to either bypass the inner shelf (less than 20 meters water depth) in a river flood plume, or are winnowed from the seafloor shortly after deposition by wave or current processes. The fine-grained silt and mud sediment is deposited in calmer deeper water on the midshelf between the depths of 30 to 90 m (Greene, 1977; Best and Griggs, 1991; Lewis et al., 2002; Eittreim et al. 2002a,b; Edwards, 2002). Northern Monterey Bay current meter (Xu et al., 2002) and seismic reflection profile data (Greene, 1977) suggest that silt and clay material is transported to the northwest at these depths along a midshelf mudbelt. The mudbelt extends from the southern Santa Cruz shelf region to north Half Moon Bay. The mudbelt is up to 30 meters thick and accumulates sediment at an average rate of 0.27 g/cm^2 per year (Lewis et al., 2002).

Table 1 is modified after Eittreim et al., (2002b). The table includes volume estimates of the sources, sinks and transport of sediment for the northern Monterey Bay shelf. Sediment volume estimates and transport rates of particular interest to us in this monitoring program are the input of sediment from the San Lorenzo River because of its close proximity to, and

SEDIMENT SOURCES	Source	Total	Littoral sand	Silt and clay
Pajaro River	Griggs and Hein (1980)	297,500	59,500	238,000
San Lorenzo River	Best and Griggs (1991)[1]	212,500	56,875	155,625
	Arnal et al. (1973)	37,472		
	Oradiwe (1986)	92,050	28,300	63,750
	Hicks and Inman (1987)	180,000	48,000	132,000
Santa Cruz Harbor	1965-2002 Harbor Dredge Logs[2]	124,048	114,124	9,924
Coastal cliff erosion	Best and Griggs (1991) average	26,695	8,996	17,699
	Oradiwe (1986)[3]	97,180	77,744	19,436
Gully erosion	Best and Griggs (1991) average	7,830	1,169	6,661
Stream erosion	Best and Griggs (1991) average	49,368	6,076	43,292
Erosion of submerged rock outcrops		unknown	unknown	unknown
Littoral sand from north		unknown	unknown	unknown

SEDIMENT SINKS

Monterey Canyon		unknown	unknown	unknown
Midshelf mudbelt	Lewis et al.., (2002)[4]	1,100,000	0	1,100,000

TRANSPORT RATES

Littoral sand transport	Best and Griggs (1991)[1]		200,000	
	Arnal et al. (1973) at Capitola		159,000	
Mudbelt silt and clay transport	Xu et al., (2002)			220,000

[1] Updated in Eittreim et al. (2002)

[2] Average of 37 years of entrance dredging records obtained from Ron Duncan, Maintenance Services, Santa Cruz Harbor Sediment composition is based on an estimated 92% sand 8% silt and clay from Sullivan and Krcik (2000)

[3] Point Santa Cruz to La Selva Beach based on an estimated composition of 80% sand 20% silt and clay

[4] Calculated over an area of 421 km^2

Table1. Volume estimates (m^3/year) of sediment sources, sinks, and transport in the Santa Cruz Littoral Cell (modified after Eittreim et al., 2002b)

upcoast direction from (~1 km) the harbor, and the accumulation of fine-grained sediment at the midshelf mudbelt. While the absolute values for sources and sinks of sediment are not fully understood, researchers agree (Arnal et al., 1973; Oradiwe, 1986; Best and Griggs, 1991; Eittreim et al., 2002b) that there is a net deficit of sand in the system.

5. Marine Biological Assessment

To closely examine the habitat and substrates associated with the Santa Cruz Harbor study area, four research dives were conducted by Moss Landing Marine Lab researchers and graduate students on January 4, 2001, prior to the experimental dredging event (see Appendix A). The intent of this study was to inventory the organisms associated with the various marine benthic habitats near the Santa Cruz Harbor through in situ observations to compare with potential marine biological studies that may take place in the future. The offshore habitats (including kelp forests) between the dredge outfall and Soquel Point (Appendix A, Figure 1) were considered to have the greatest risk of being impacted by the experimental dredge sediment, because of their position downcoast from the harbor. The experimental dredge material may travel southeastward (downcoast) with littoral drift, the predominant direction for sediment transport within the Santa Cruz Harbor vicinity (Wolf, 1970; Best and Griggs, 1991).

6. Methods

6.1 Scientific Literature Review

Marine research pertinent to this monitoring program has been produced in the Monterey Bay region by investigators at Moss Landing Marine Labs (MLML), U.C. Santa Cruz (UCSC), U.S. Geological Survey (USGS), Stanford University, the Naval Postgraduate School, and Monterey Bay Aquarium Research Institute. Detailed scientific information regarding the geology of the Monterey Bay region was obtained from Greene (1977, 1990) and Mullins et al. (1985). Research concerning coastal, river, and sedimentary processes by Wolf (1970), Arnal (1973), Griggs and Johnson (1976), Griggs and Hein (1980), Oradiwe (1986), Griggs (1987), and Best and Griggs (1991) were reviewed and included in this work. Coastal currents and other oceanographic information from Breaker & Broenkow (1994), Xu (1999) were reviewed and aided in the design of this monitoring period. McLaren's *Sediment Trend Analysis (STA®) of Santa Cruz Harbor* (2000) was particularly useful, as it pertains to the same experimental dredging event discussed in this report.

An extremely useful and timely source of scientific literature was obtained from Marine Geology Volume 181, March 2002 Special Issue: Seafloor Geology and Natural Environment of the Monterey Bay National Marine Sanctuary, edited by Stephen Eittreim and Marlene Noble. The issue contains the most recent work to date regarding coastal, geologic and sedimentary processes within the Monterey Bay National Marine Sanctuary. The issue contains several hard-copy maps and a CD containing GIS data for the Monterey Bay National Marine Sanctuary produced by Wong and Eittreim (2002). Six other articles were particularly useful for this monitoring program: Eittreim et al. (2002b) update of sediment budget estimates for the Santa Cruz shelf, Anima et al. (2002) and Eittreim et al. (2002a) with their descriptions of nearshore morphology and seafloor geology using side scan sonar and seismic reflection imagery. In addition, the discussion of accumulation rates on the northern Monterey Bay midshelf area by Lewis et al. (2002), suspended sediment transport rates near Davenport by Xu et al. (2002), and descriptions of variations in sediment texture on the Santa Cruz shelf by Edwards (2002) were extremely useful.

6.2 Monitoring Program

The monitoring program consisted of three phases: Pre-Experiment, Experiment and Post-Experiment (Figure 4). It was based on information gathered in a review of the scientific literature, a pilot field research project conducted by one of the authors of this report (Steve Watt) prior to the experimental dredging event, and a marine biological assessment of the habitats at risk due to the experimental dredging by Goldberg et al., 2000 (Appendix A) specific to this study. San Lorenzo River stream flow data were used to calculate sediment discharge estimates. Oceanographic swell information was downloaded to monitor wave conditions and to calculate littoral drift estimates. Over 300 sediment samples were collected and grain-size analyses performed. Over 300 water samples were collected to observe changes

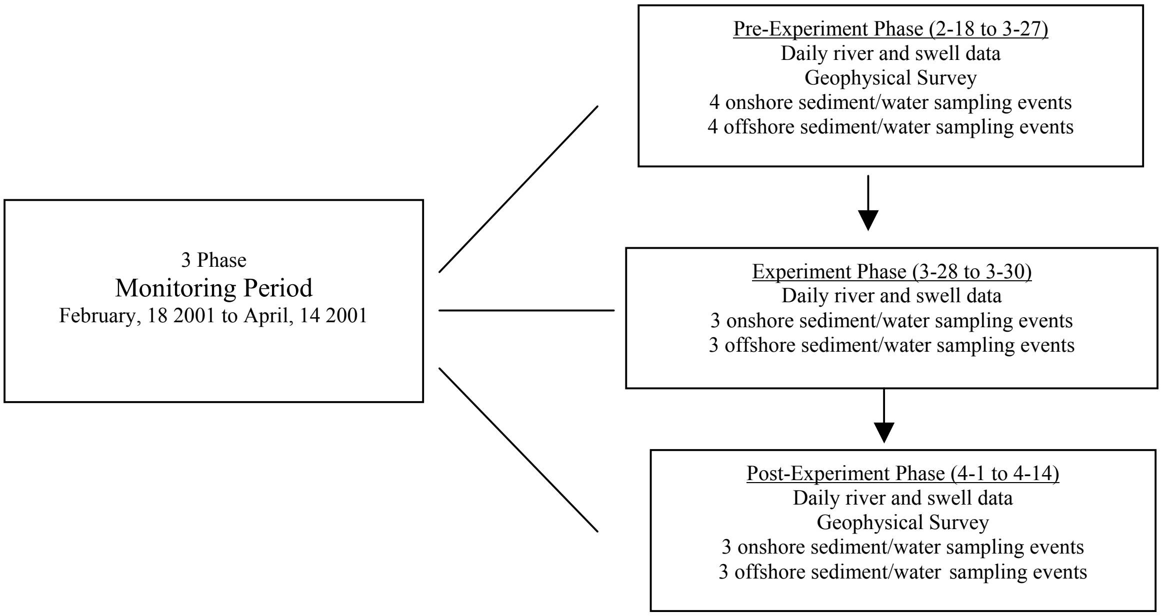


Figure 4. Chart showing the types of data collected and timeline adhered to throughout the monitoring period.

in turbidity over time. Two separate 7 km^2 geophysical surveys were also executed to describe and quantify benthic habitats and sedimentary changes that may have occurred during the monitoring period from February 18 to April 14, 2001.

6.3 San Lorenzo River

The mouth of the San Lorenzo River is located approximately 1 km west of the Santa Cruz Harbor (Figure 5). The USGS real-time stream flow gauges for the river measure the average daily stream flow in meters^3 at the Big Trees Station # 11160500 and at the Santa Cruz Station # 11161000. The Big Trees Station has recorded 64 years of non-consecutive historical stream flow data while the Santa Cruz Station has recorded 48 years of non-consecutive data.

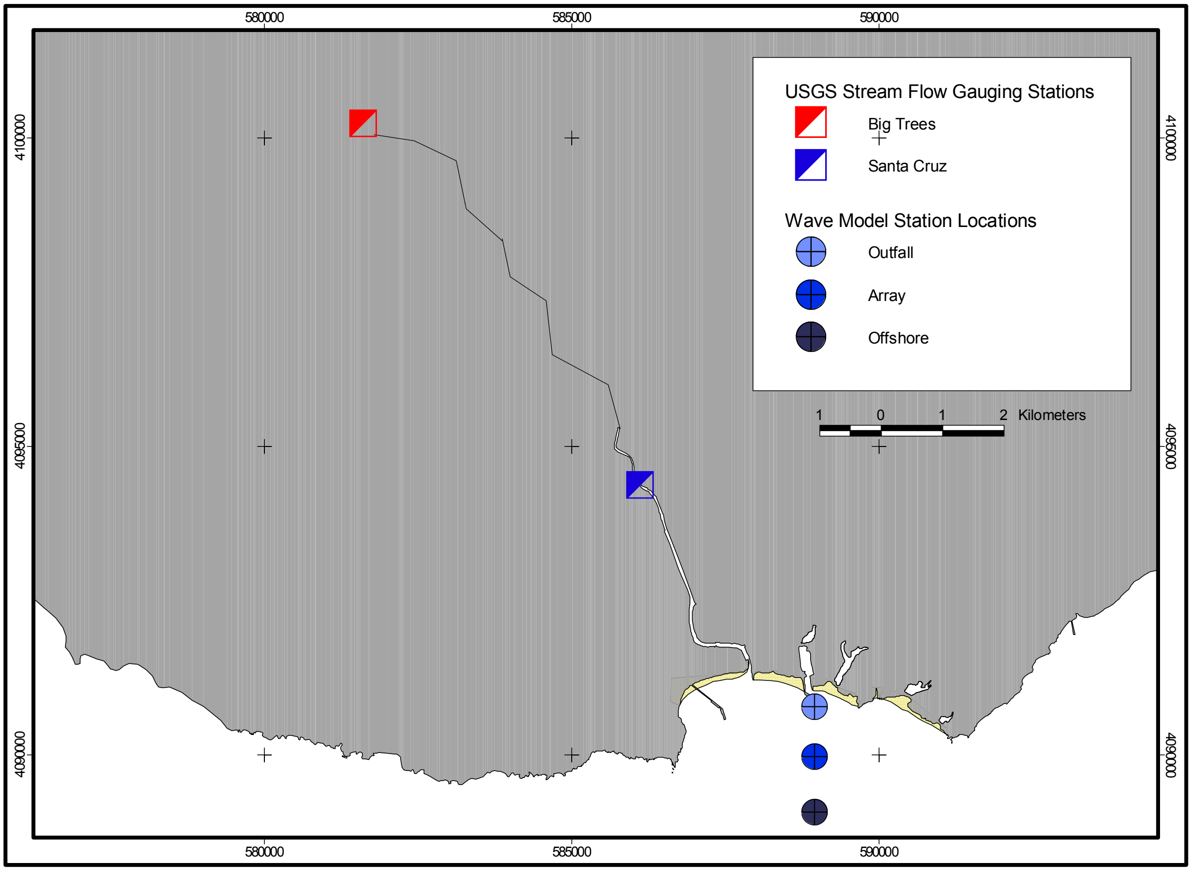


Figure 5. Locations of USGS stream flow gauging stations and spectral refraction wave model stations used in the monitoring period.

Daily stream flow (m^3/second) values for the Santa Cruz Station were downloaded over the duration of the monitoring period from the USGS Real-Time Water Data website http://waterdata.usgs.gov/ca/nwis/rt. Stream flow records were not available for the Big Trees Station during the monitoring period. Using stream flow data and suspended sediment measurements at the Big Trees Station, other researchers have created sediment-transport curves to calculate sediment discharge from a river based on its stream flow (Oradiwe, 1986; Best and Griggs, 1991). Sediment discharge estimates are based on the following relationship:

$$Qs = kQ^m$$

where Qs = total sediment discharge (m^3/day)

Q = mean daily water discharge (m^3/second)

m & k = constants that are solved as the slope and intercept of the least square linear fit to the plot of log (Q, Qs) (Oradiwe, 1986).

The log of the equation gives:

$$\log Qs = m \log Q + \log k$$

A total sediment discharge estimate was calculated by summing the results from two sediment-rating curves found in Best and Griggs (1991).

For total suspended sediment load:

$$Qs = 0.335Q^{2.22} \text{ (where } k = 0.335 \text{ and } m = 2.22\text{) } r^2 = 0.856$$

And for bed load:

$$Qs = 3.64Q^{1.23} \text{ (where } k = 3.64 \text{ and } m = 1.23\text{) } r^2 = 0.766$$

The total sediment load (suspended load plus bed load) that was released over the course of the monitoring period was divided into a littoral sand class and a silt and clay class using percentages of those respective classes from Eittreim et al. (2002b) San Lorenzo River sediment discharge estimate. Estimates for the sediment discharge from the San Lorenzo River in littoral sand, and silt and clay classes were computed for the total monitoring period as well as for each experimental phase.

Short-term sediment discharge estimates may be subject to errors of an order of magnitude or more. The monitoring period sediment discharge estimate for the river was calculated using Best and Griggs (1991) sediment transport curves that were based on sediment concentration and stream flow data from the Big Trees Station. Because stream flow data were only available for the Santa Cruz Station during the monitoring period, we applied its stream flow information to the Big Trees sediment transport curves. It is unknown whether this method causes sediment discharge to be over or under estimated. Other potential factors that lead to errors in sediment discharge estimates include accounting for either the build up or removal of sand by prior to extreme floods or drought along the river channel. The velocity and duration of the stream flow through the entire river channel (not only at gauging stations) plays a crucial role in determining sediment discharge (Brown, 1973). In addition, San Lorenzo River stream flow and sediment discharge is extremely episodic. While years of drought may not produce significant amounts of sediment, a winter fueled by the El Nino/Southern Oscillation or even a particularly large winter storm may deliver many years of “annual” sediment discharge in one winter or over the course of a few days (Best and Griggs, 1991; Hicks and Inman, 1986).

6.4 Santa Cruz Harbor

The Santa Cruz Harbor suffers from sediment accumulation not only in the upper harbor (the primary focus of this study) but in the entrance channel as well. Sediment accumulation from both of these sources create potential hazards to navigation. The entrance channel is closed to navigation many times throughout the winter because of the sand accumulation. As a result, the channel is dredged periodically. The origin of the accumulated harbor entrance sand is from the natural transport of the material downcoast, which then becomes trapped in the calmer, protected waters within the harbor mouth. The harbor acts as a temporary sediment sink.

In the past, the annual sediment volume dredged from the Santa Cruz Harbor entrance has been used to estimate the rate of longshore transport in the general area (Griggs, 1987). For the purposes of this study, the Santa Cruz Harbor entrance dredging records were used in two ways. First, as an estimated of source of sediment being returned to the study area from a temporary sink (the protected waters of the harbor), which could affect the local habitats, similar to a river, or the experimental dredging event. Secondly, the harbor dredging records will be used as an estimate of longshore sediment transport to compare with estimates produced using oceanographic swell data and a spectral wave refraction model.

The entrance dredging records for the past 37 years were obtained from the Santa Cruz Harbor and averaged into an annual sediment load. The annual entrance sediment accumulation supplied by littoral drift was separated into two different size classes, littoral sand, and silt and clay, based on sediment grain-size data analyses performed by RRM Inc. (Sullivan and Krcik, 2000) who found that the entrance sediment are composed of approximately 92% sand and 8% silt and clay (Table 1). For comparison, the upper harbor experimental dredge sediment are composed of approximately 40% sand, and 60% silt and clay (Sullivan and Krcik, 1999). In addition to the upper harbor experimental dredging, harbor entrance dredging contributions to the beaches and offshore benthic habitats were accounted for throughout the study.

6.5 Oceanographic Data

Significant swell height (meters), period (seconds), and dominant swell direction degrees were obtained from the Coastal Data Information Page (CDIP) at http://seaboard.ndbc.noaa.gov/station_history.phtml?station=46042 for buoy #46042 outside of Monterey Bay and http://cdip.ucsd.edu/tmp/stream_frame14659.html for Array #00601 offshore of the Santa Cruz Harbor. Swell direction was not available for the Santa Cruz Harbor Array. These data were averaged into daily values to monitor and quantify the oceanographic conditions present over the course of the monitoring period. The swell data were also used to check the results from a spectral wave refraction model used to produce littoral drift volume estimates.

Wave data from the Point Reyes Buoy (#02901) were downloaded into a spectral wave refraction model (O’Reilly and Guza, 1993) by Dr. William O’Reilly of the Scripps Institution of Oceanography’s Center for Coastal Studies. The model used multibeam bathymetric data collected during the Pre-Experiment phase of the monitoring period (gridded to 30 meters) to provide estimates of littoral drift. For chosen points within a study area, the spectral wave refraction model produces values of significant wave height (meters), peak wave period (seconds), mean wave direction (degrees), radiation stress (S_{xy}), and an associated S_{xy} direction (degrees). S_{xy} is the longshore-directed (y-component) of radiation stress that is moving toward the shoreline (in the x-direction) and is defined by the following equation (Komar, 1998):

$$S_{xy} = En \sin \alpha \cos \alpha$$

Where E is the wave-energy density, n is the ratio of the wave group and phase velocities, and α is the angle the wave crests make with the shoreline. Twin Lakes Beach shoreline (which faces 200^{o}) was used as the location for approaching ocean waves. The value α is calculated by subtracting a given shoreline (200^{o}) from an approaching wave angle (for example 220^{o}), $\alpha = 220 - 200 = 20^{o}$. The smaller the angle between shoreline and the approaching swell, the less energy is available for the longshore current. When the angle between approaching wave crests and the shoreline equals zero (become parallel), there is no driving force for longshore currents.

S_{xy} radiation stress daily mean values were converted to P(l), which is referred to as the "longshore component of wave power" and is described by the following equation (Komar, 1998):

$$P(l) = (ECn) \sin \alpha \cos \alpha$$

which is reported in Newtons/second or equally Watts/meter.

P(l) is then used to calculate Q(l), the volume transport rate (m^3/day) according to the following equation (Komar, 1998):

$$Q(l) = 2.6P(l)$$

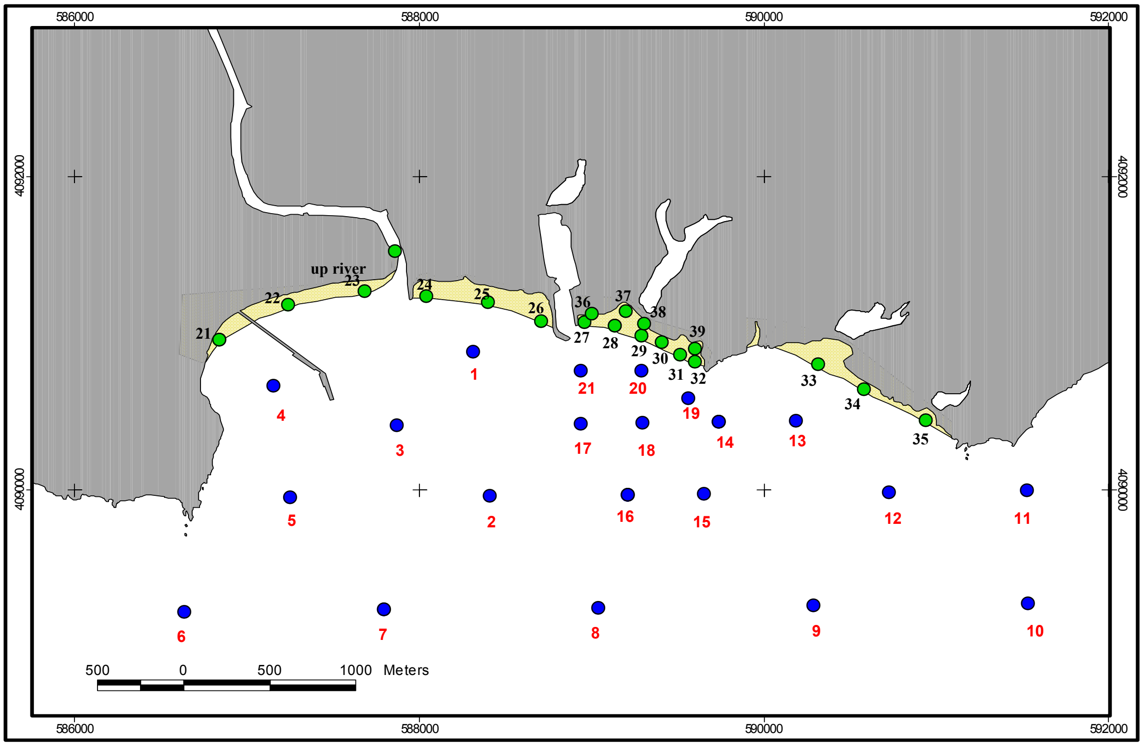
Using the spectral refraction wave model provided by for the Santa Cruz Harbor area by Dr. William O'Reilly (O'Reilly and Guza, 1993) and the above two equations from Komar (1998), littoral drift rates were calculated for three different study area locations. The first is the Outfall Station (~6 m deep) where the experimental dredge outfall was located. The second is the Array Location (13 m deep) where the Santa Cruz Harbor Array #00601 is located. The third is the Offshore Station (17 m deep) at the outer edges of the study area (Figure 5). Littoral drift transport volumes were calculated daily for each of the three stations throughout the entire monitoring period and for each experimental phase.

6.6 Sediment & Water Sampling

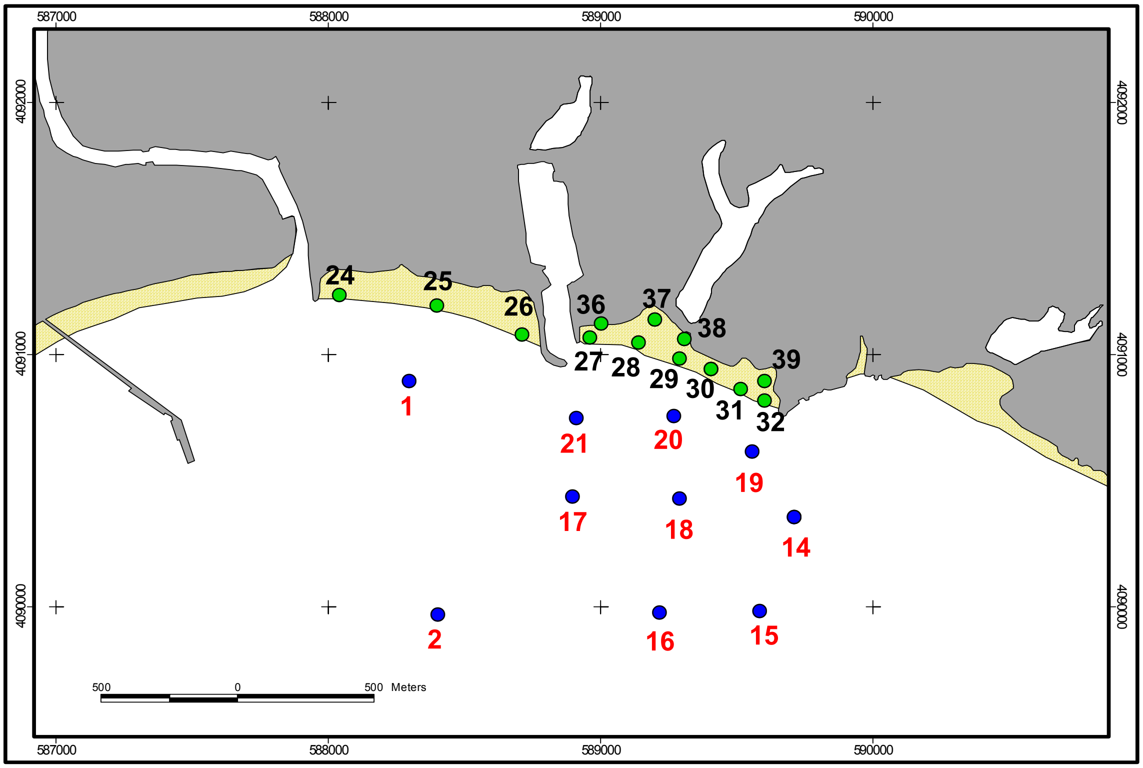
6.6.1 Onshore Sample Collection

Comprehensive sets of sediment samples were collected throughout all three phases of the monitoring period (Figures 4, 6 and Table 2). In the Pre- Experiment Phases, three sets of 20 onshore samples (Pre-Experiment 1, 2, and 3) and one set of 13 onshore samples (Pre-Experiment 4) were collected. Samples collected during Pre-Experiment 4 were originally planned to be collected on the first day of experimental dredging, which is why Pre-Experiment 4 has the same sample design and number of samples as those collected in the Experiment phases. The experimental dredging event was postponed for a day due to permitting issues. Therefore, Pre-Experiment 4 samples were collected 24 hours prior to the initiation of experimental dredging event, providing an excellent comparison to Experiment and Post-Experiment samples. In the Experiment phase, three sets of 13 daily onshore samples were collected. In the Post-Experiment phase, three sets of 20 samples were collected in the same manner as those collected in Pre-Experiment 1, 2, and 3. Onshore sediment samples were taken along, or slightly above, the high tide berms of beaches from Cowells Cove to Moran Lake. Sample sites were moved to the location of the high tide berm for each individual day of sampling, which shifted over time because of high surf, floods and seasonal changes throughout the monitoring period. Twin Lakes Beach received the greatest focus for sediment sampling, including four back beach samples, based on the beaches proximity to the dredge outfall and the presence of Schwann Lagoon backing the beach (Figure 2b).

Beach water samples were collected in the swash zone directly in front of pre-selected beach sediment sample locations, in the San Lorenzo River, and in locations where storm drains or lagoon run-off were reaching the ocean at the time sampling took place (Figure 7). Water samples were not taken from lagoons or storm drains that were not visibly connected to the ocean at the time of sampling for each event.



a. ID numbers and locations of Pre- and Post-Experiment sediment samples. The onshore sample ID's are black with green dots, and offshore are red with blue dots.

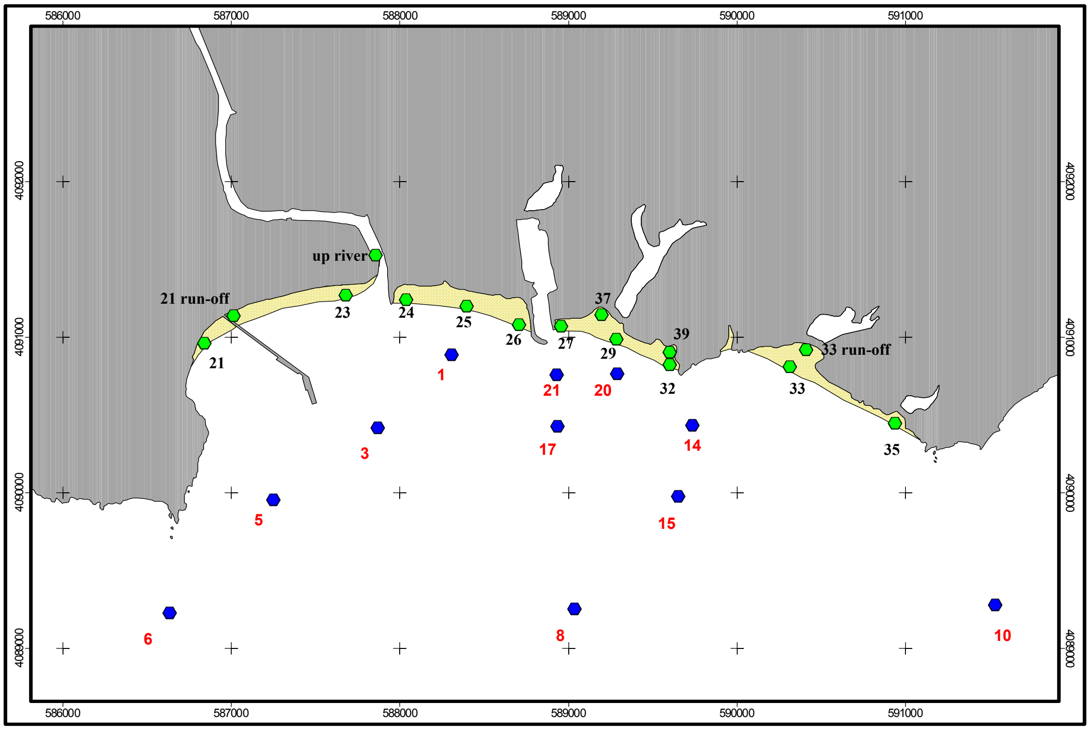


b. ID numbers and locations of Experiment sediment samples. The onshore sample ID's are black with green dots, and offshore are red with blue dots.

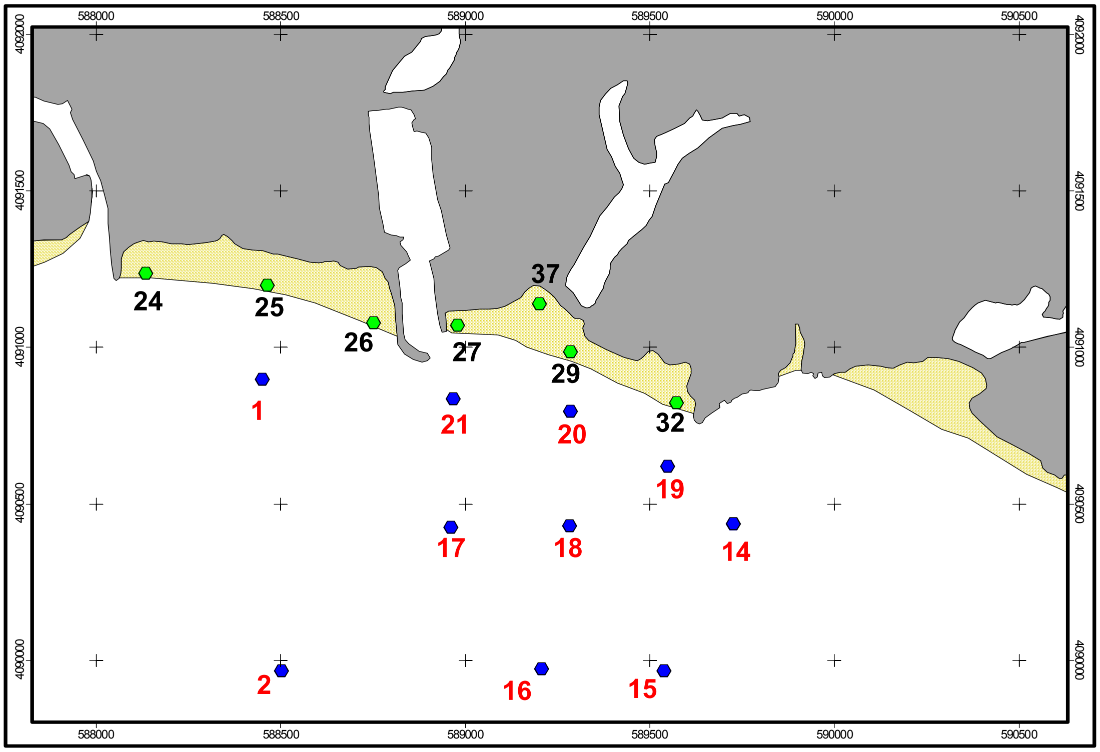
Figure 6. Locations for beach and offshore sediment samples

Monitoring Phase	Date in 2001	Event	Sediment Samples	Water Samples**
Pre-Experiment	2/18	Pre 1 Onshore	20	11
	2/21	Geophysical Survey	x	x
	2/28	Pre 1 Offshore	21	22
	3/1	Pre 2 Onshore	20	15
	3/3	Pre 2 Offshore	21	22
	3/07	Pre 3 Offshore	21	22
	3/10	Geophysical Survey	x	x
	3/13	Pre 3 Onshore	20	12
	3/27	Pre 4 Onshore*	13	6
	3/27	Pre 4 Offshore*	10	20
Experiment	3/28	Experiment 2 Onshore	13	6
	3/28	Experiment 2 Offshore	10	20
	3/29	Experiment 3 Onshore	13	7
	3/29	Experiment 3 Offshore	10	20
	3/30	Experiment 4 Onshore	13	6
	3/30	Experiment 4 Offshore	10	20
Post-Experiment	4/1	Post 1 Onshore	20	12
	4/2	Post 1 Offshore	21	22
	4/5	Post 2 Offshore	21	22
	4/8	Post 2 Onshore	20	11
	4/10	Geophysical Survey	x	x
	4/11	Geophysical Survey	x	x
	4/12	Post 3 Offshore	21	22
	4/14	Post 3 Onshore	20	11
Totals	56 days	24 Events	338	309

Table 2. Timeline of sampling events and geophysical surveys over the monitoring period. * Denotes sediment and water sample events collected for Pre-Experiment 4 on 3/27/01, which were collected the day before experimental dredging took place (beginning on March 28, 2001) and are of the same sample design as Experiment sampling events. ** Some beach water sampling events have a larger number of samples due to sampling at flooding storm drains or lagoons.



a. ID numbers and locations of Pre- and Post-Experiment water samples. The onshore sample ID's are black with green dots, and offshore are red with blue dots.



b. ID numbers and locations of Experiment water samples. The onshore sample ID's are black with green dots, and offshore are red with blue dots.

Figure 7. Locations for onshore and offshore water samples

6.6.2 Offshore Sample Collection

Three sets of 21 offshore samples were collected in Pre-Experiment 1, 2, and 3 and one set of 10 samples in Pre-Experiment 4 for reasons described in the previous section. Three sets of 10 daily offshore samples were collected in the Experiment phase (Figures 4, 6, and Table 2) In the Post-Experiment phase, three sets of 21 offshore samples were collected in the same manner as those collected in Pre-Experiment 1, 2, and 3. GPS was used to locate pre-determined offshore sample locations using the Port District Harbor Patrol vessels HP1 and HP2. A petite ponar grab sampler (borrowed from the U.S. Geological Survey) was deployed to obtain surface sediment samples. Water samples were collected concurrently at selected offshore sample locations (Figure 7) at the surface and at 2.5 meters water-depth using a Niskin bottle.

High-energy winter wave conditions experienced during the monitoring period made it difficult to collect sediment and water samples from intended targets offshore. In order to compensate for the impossibility of resampling an exact location on the seafloor, designated sample locations were occupied and position coordinates were recorded as soon as possible after the sediment grab sampler reached the seafloor. Samples obtained using this method were mapped using GIS and positional error was measured to be no greater than seventy five meters from the intended target. Other sample locations were moved intentionally at the time of survey because of either large breaking waves, a thick kelp canopy, or the close proximity of otters or harbor seals. The largest displacement of these intentional relocations was approximately 275 m to the southeast at offshore sample location 7 (see Figure 6), due to large breaking waves at Point Santa Cruz.

6.6.3 Sediment and Water Sample Processing

Sediment samples were processed at Moss Landing Marine Labs using dry sieve analysis described in Folk (1974). Percentages of each sieve weight for each sample were calculated and graphed on probability paper to obtain phi values needed to calculate mean grain size diameter (phi and mm), sorting (phi), and skewness for each individual sample. The following formulas from Folk (1974) were used in those calculations:

Graphic mean:

$$m_{\varnothing} = (\varnothing 16 + \varnothing 50 + \varnothing 84)/3$$

The graphic mean is an estimation of the mean grain diameter for an individual sediment sample, which is the most common way of displaying sediment information. The mean can be categorized into a Wentworth Size Class (Appendix B.) for a common verbal description of sediment size such as, “medium sand”.

Inclusive graphic standard deviation (sorting):

$$\sigma_{\varnothing} = (\varnothing 84 - \varnothing 16)/4 + (\varnothing 95 - \varnothing 5)/6.6$$

Inclusive graphic standard deviation (sorting) is a measure of how closely grouped around the graphic mean the remaining grain-size fractions are. For example, a sample that is poorly sorted indicates that there are significant percentages of other grain sizes in the sample, other than the graphic mean. The units from the equation are in phi values, which can be described verbally according to the sorting scale in Appendix B.

Inclusive graphic skewness:

$$\alpha_{\varnothing} = \frac{(\varnothing 16 + \varnothing 84) - 2(\varnothing 50)}{(\varnothing 84 - \varnothing 16)} + \frac{(\varnothing 5 + \varnothing 95) - 2(\varnothing 50)}{2(\varnothing 95 - \varnothing 5)}$$

The inclusive graphic skewness is a measure of the whether a sediment samples grain size distribution is symmetrical or asymmetrical with respect to a normal curve. If asymmetrical, the value indicates which side of the curve, the fine (+ number) or the coarse (- number), the sample favors. Skewness values can also be categorized verbally by the skewness scale in Appendix B.

The influx of mixed sand and mud sediment into the surf-zone could alter the sediment transport properties and the composition of beaches and nearshore benthic habitats around the Santa Cruz Harbor. According to McLaren (2000), when the mud content of sediment becomes greater than approximately 25%, the material may change from non-cohesive sediment to cohesive sediment that is more difficult to transport. The exact mud (silt and clay) content needed for sediment to behave in a cohesive nature depends upon the environment in which it is deposited, and may be much different from 25%. If the mud content reaches 50%, then sediment will always behave in a cohesive manner (McLaren, 2000).

If there were a lasting sedimentary change due to the addition of fine-grained sediment after the experimental dredging event, we would expect simultaneous changes in sediment samples over time such as:

1.) Increase in silt and clay percentages
2.) Decrease in the mean grain size
3.) Samples to become more poorly sorted
4.) A shift in skewness toward the fines

To ascertain if this is the case, sample analyses in the Pre-Experiment phase were compared to Experiment and Post-Experiment sediment sample analyses, paying close attention to samples in the 20% and greater silt and clay range.

Swash zone and offshore water samples were processed on the same day following collection using a Monitek Model 21PE portable nephelometer to measure turbidity. The manufacturer's instructions for this instrument were followed to measure the turbidity of the water column for each sample location in NTU's (nephelometric turbidity units). Turbidity is an optical property of water that causes light to be scattered and absorbed rather than pass in straight lines through a water sample. It is caused by the molecules of water itself, dissolved substances, and organic and inorganic suspended particles. Turbidity is not a measure of toxicity. According to Thackston et al., (1999), a nephelometer's NTU values may only be comparable to itself and perhaps only to samples collected on the same day. This is because an NTU value caused by a river plume could have the same NTU value caused by an algal bloom or other source of turbidity.

Data tables (Appendices C and D) were produced for each sampling event in the monitoring period. Table fields contain sample identification information, location in UTM Zone 10, date of collection, mean grain size (phi and mm), Wentworth Size Class (Appendix

B), percentages of sediment greater than sand, sand, silt and clay, sorting (phi), skewness and water turbidity (NTU). These sample tables were then imported to ArcView3.3® in order to display them geographically for comparison to other sampling events over time or to overlay on seafloor images produced from two geophysical surveys.

6.7 Geophysical Surveys

Two separate geophysical surveys were conducted in the study area (Figure 8) using the CSUMB Seafloor Mapping Lab's 32-foot R/V MacGinitie. The vessel is equipped with a pole mounted Reson 8101 SeaBat shallow water (1-300 meter) multibeam sonar system. The 240

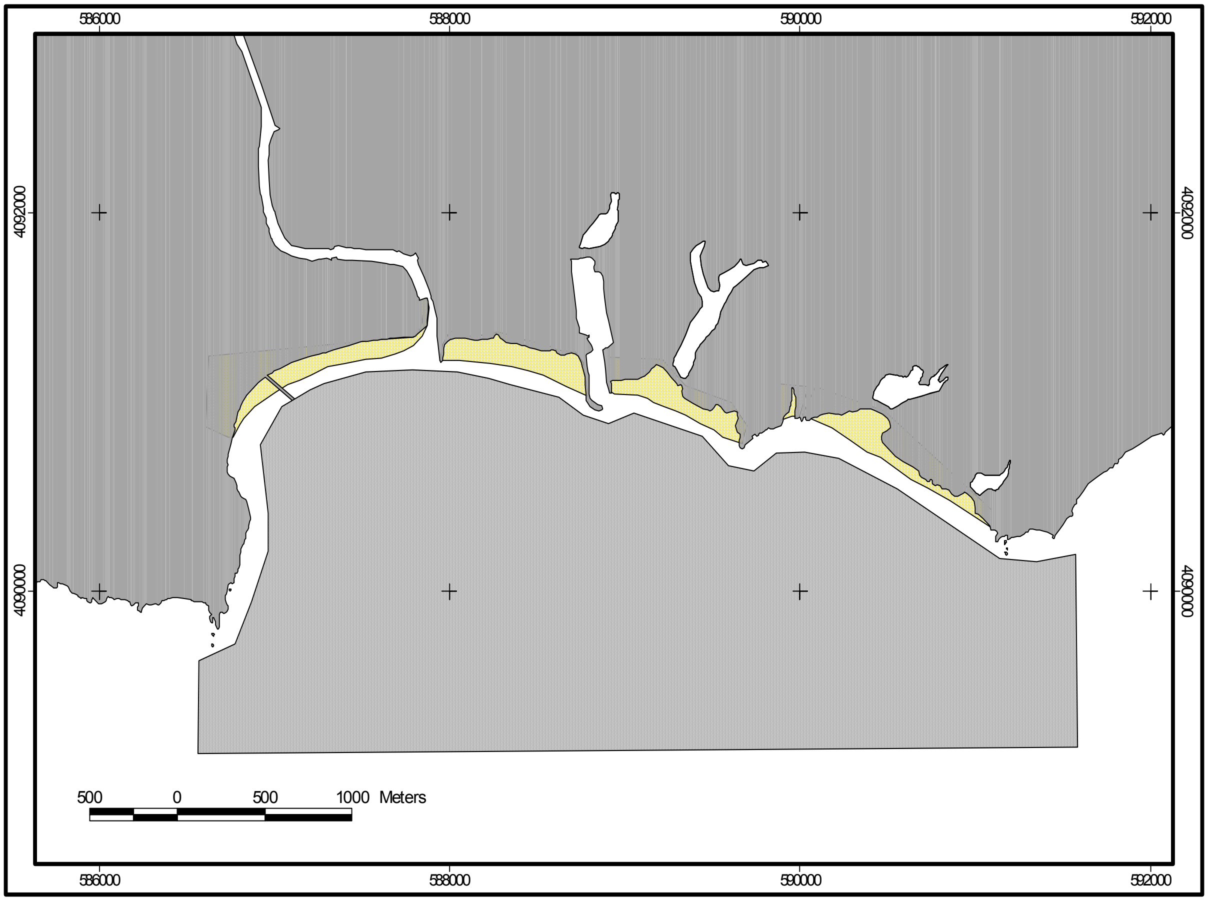


Figure 8. Outline of the ~7km^2 geophysical surveys conducted in the Pre- and Post-Experiment Phases.

KHz SeaBat 8101 multibeam measures discrete depths (accurate to 1.25 cm in ideal flat water conditions), enabling complex underwater features to be mapped with precision. Dense seafloor coverage is achieved utilizing up to 3,000 soundings per second. In addition to bathymetric data, the SeaBat provides backscatter imagery for the creation of mosaics that image the seafloor. Differential GPS (DGPS) vessel positioning for multibeam surveys was obtained by a Trimble 4700 GPS with differential corrections provided by a Trimble ProBeacon receiver. Heave, pitch, heading, and roll data were provided by a TSS HDMS heading and motion sensor (±0.02 degree accuracy). Coastal Oceanographics HyPack® software were used for survey design and execution. All raw data were logged using a Triton-Elics International Isis Sonar® data acquisition system. Water column sound velocity profiles were collected using an AML SV+ sound velocity profiler.

The two surveys covered the same ~7 km^2 from Point Santa Cruz to Soquel Point and took two full days per survey to complete. The bathymetric multibeam data were edited line-by-line using CarisHIPS® to produce UTM Zone 10 geo-referenced sun-shaded images and ASCII text files with northings, eastings, and depth values in meters for each sounding. The ASCII text files were gridded to 1-meter pixel size using Fleidermouse®. The 1 meter grids were imported into ArcView 3.3® to create bathymetric contours, sun-shaded images, and to produce maps for visual interpretation and presentation.

Backscatter survey lines were processed into separate geo-referenced gray-scale images at 0.20-meter pixel size, using Triton-Elics International Isis Sonar®. The separate backscatter lines were imported into TNTmips 6.7® for line editing and to create mosaiced images of the seafloor. The final geo-referenced seafloor mosaic (UTM Zone 10) was then exported to ArcView 3.3® to produce maps for visual interpretation and presentation.

Sun-shaded multibeam bathymetric imagery, mosaiced backscatter imagery, and physical quantitative sediment sample data were used to visually classify the seafloor into benthic habitats according to Greene, et al. (1999) Habitat Classification Scheme (Appendix E). Hand drawn habitat interpretations were made on clear mylar sheets overlain on hard-copy sun-shaded multibeam bathymetry and backscatter maps at a scale of 1: 2,500. The hard-copy interpretations were scanned into digital images after which they were geo-referenced and vectorized using TNTmips 6.7®. The visual interpretations were then edited and improved at a scale of 1:750 by displaying the geo-referenced interpretation vector directly over multibeam and backscatter imagery. Sediment samples were also displayed over the seafloor images to "ground truth" or provide physical quantitative evidence of seafloor substrate where it was collected geographically. The edited vectors (one for each survey) were exported to ArcView3.3® to produce shapefiles and attribute polygons into their respective benthic habitat types. Once attributed, an area analysis (in km^2 and m^2) was performed for each habitat type.

Habitat interpretations of Pre- and Post-Experiment geophysical surveys were compared to evaluate shifts in sediment (erosion, deposition, or no habitat change) that occurred between the time of two surveys using the Spatial Analyst extension in ArcView3.3®. The two habitat interpretation shapefiles were intersected to create a single shapefile containing the attributed polygons from both surveys and creating new ones where habitats cross into one another. Where a habitat polygon from the Pre-Experiment survey intersects with the same habitat type polygon in the Post-Experiment survey, it produces a polygon where the habitats have not changed over the course of the monitoring period. Conversely, if a habitat polygon from the Pre-Experiment survey crosses into a different habitat type polygon in the Post-Experiment survey, it produces a polygon where change has occurred over the course of the monitoring period. Depending on the shift in habitat types, erosion or deposition may be inferred. For example, if a rocky habitat in the Pre-Experiment survey shifted to a sandy habitat in the Post-Experiment survey, it is assumed that sand was deposited over the exposed bedrock during the time between the two surveys. In this manner, a sediment shift map was produced and an area analysis (in m^2) was executed to quantify the amount of erosion, or deposition of sediment that occurred between the two geophysical surveys.

7. Results and Discussion

7.1 Sediment input over the monitoring period

Approximately 9,000 m^3 of new sediment (sediment which has not previously been deposited into the beach or nearshore benthic habitats in the study area) is estimated to have entered the study area over the monitoring period from the combined sediment totals of the San

Lorenzo River discharge (~6,700 m^3) and the experimental dredging event (~2,300 m^3) (Table 3). Approximately 30,000 m^3 of sediment was returned to the study area from the dredging of the Santa Cruz Harbor entrance. A combined 39,000 m^3 of new and returned sediment was released into the study area over the monitoring period. Of that total, 78% is estimated to be sand and 22% is estimated to be silt and clay. The total amount of silt and clay released to the study area over the 56-day monitoring period was approximately 8,700 m^3. Sixty percent of the

Pre-Experiment (38 days)

Sediment sources (m^3)	Littoral Sand	Silt and Clay	Total	% of phase	% of overall total
San Lorenzo River	1,755	4,746	6,501	52	16.7
Harbor Entrance	5,627	489	6,116	48	15.7
Experiment Dredge	0	0	0	0	0
Phase Sediment Total	7,382	5,235	12,618	100	32.4
% of Phase Sediment Total	59	41			

Experiment (3 days)

Sediment sources (m^3)	Littoral Sand	Silt and Clay	Total	% of phase	% of overall total
San Lorenzo River	10	26	36	1	0.1
Harbor Entrance	4,403	383	4,786	67	12.3
Experiment Dredge	917	1,376	2,294	32	5.9
Phase Sediment Total	5,330	1,785	7,116	100	18.3
% of Phase Sediment Total	75	25			

Post-Experiment (15 days)

Sediment sources	Littoral Sand	Silt and Clay	Total	% of phase	% of overall total
San Lorenzo River	40	108	148	1	0.4
Harbor Entrance	17,613	1,532	19,144	99	49.1
Experiment Dredge	0	0	0	0	0.0
Phase Sediment Total	17,653	1,639	19,292	100	49.5
% of Phase Sediment Total	92	8			

Monitoring Period Total (56 days)

Sediment sources (m^3)	Littoral Sand	Silt and Clay	Total	% of total
San Lorenzo River	1,805	4,880	6,685	17
Harbor Entrance	27,643	2,404	30,047	77
Experiment Dredge	917	1,376	2,294	6
Sediment Total	30,366	8,660	39,025	
% of Sediment Total	78	22		

Table 3. Summary of sediment input (m^3) for each experimental phase and for the entire monitoring period.

silt and clay was delivered in the Pre-Experiment phase, primarily by the San Lorenzo River (4,746 m^3) and to a lesser extent by Santa Cruz Harbor entrance dredging (489 m^3). The experimental dredging event accounts for ~6% of the total sediment input to the study area and ~16% of the total silt and clay over the monitoring period.

7.2 San Lorenzo River

Figure 9 plots stream flow in meters^3/second at the Santa Cruz Station throughout the monitoring period in relation to the 48-year average for the Santa Cruz Station and the 64-year average for the Big Trees Station between the dates of February 18- April 14, 2001 (see Figure 5). In general, the stream flow during the monitoring period was below both stations' historical averages with the exception of two stream flow spikes, which occurred on February 18-26 and March 4-7, prior to the experimental dredging event (Figure 10). These two occasions mark the times of the heaviest rainfall, contributing nearly 84% of the total San Lorenzo River sediment discharge during the monitoring period. The river released 56% of the overall total silt and clay to the study area, most of which (97%) occurred during the Pre-Experiment phase. Sediment discharge dropped substantially after early March (Figure 11). Only 184 m^3 was released by the San Lorenzo River to the study area over the Experiment and Post-Experiment phases.

7.3 Santa Cruz Harbor

The Santa Cruz Harbor entrance was dredged eleven times, returning ~30,000 m^3 of temporarily trapped sand sediment back to the surf-zone during the monitoring period. The majority of the entrance sediment was released in the Post-Experiment phase (19,145 m^3). The three-day upper harbor experimental dredging event took place in the evenings of March 28, 29, and 30th, releasing 2,294 m^3 of silt and clay rich sediment. The event was stopped on the third evening due to mechanical problems with the dredging equipment. The experimental dredging event released about the same amount of silt and clay (1,376 m^3) as was returned to the surf-zone in Post-Experiment harbor entrance dredging (1,532 m^3) over April 1-4, 2001. This equals three days of upper harbor dredging with a one-day break followed by four days

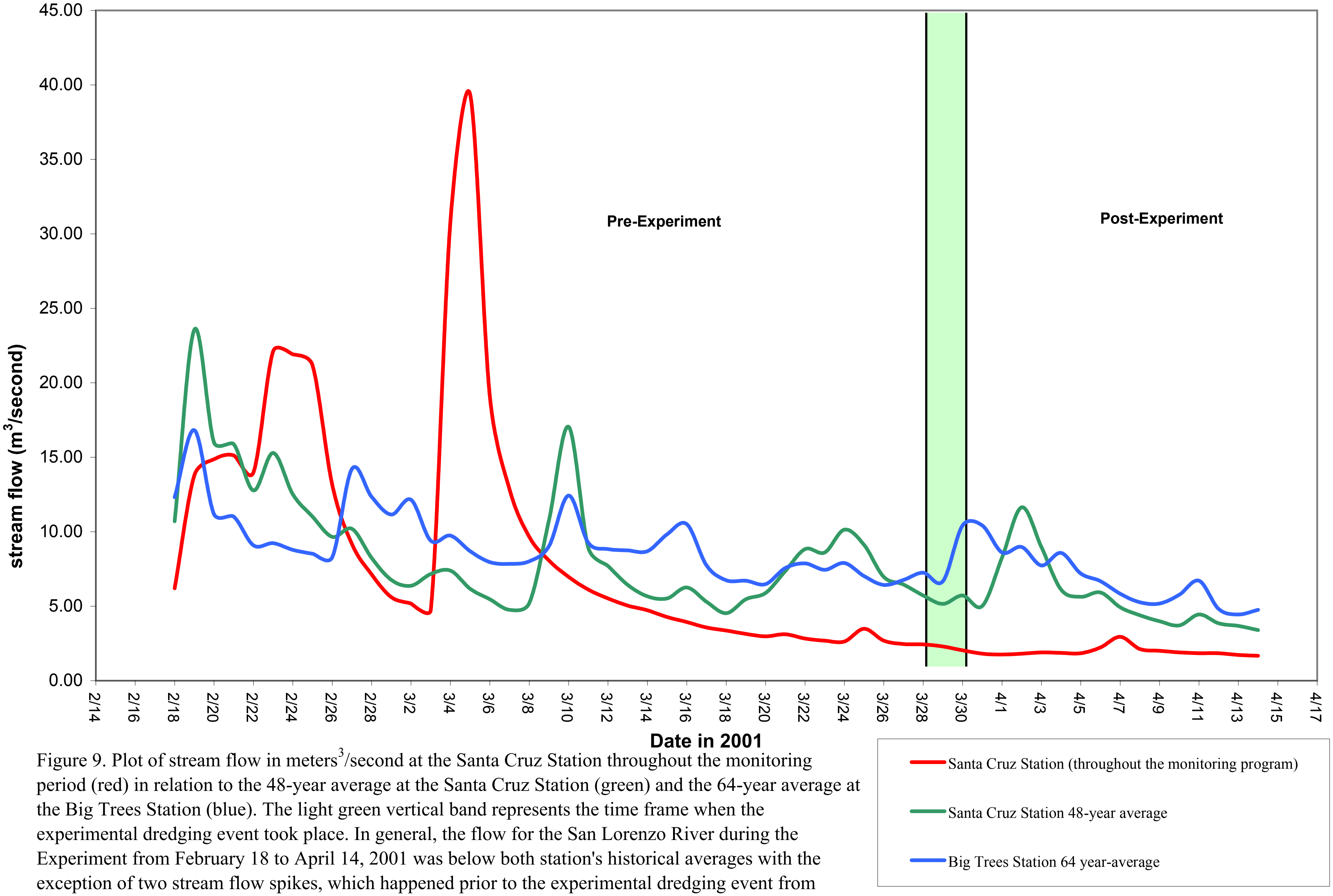


Figure 9. Plot of stream flow in meters^3/second at the Santa Cruz Station throughout the monitoring period (red) in relation to the 48-year average at the Santa Cruz Station (green) and the 64-year average at the Big Trees Station (blue). The light green vertical band represents the time frame when the experimental dredging event took place. In general, the flow for the San Lorenzo River during the Experiment from February 18 to April 14, 2001 was below both station's historical averages with the exception of two stream flow spikes, which happened prior to the experimental dredging event from February 22-27 and March 3-9.

Figure 10. Photo of the mouth of the San Lorenzo River was taken February 20, 2001 looking westward towards the Beach and Boardwalk. This flood represents one of the largest stream flow events observed during the Pre- Experiment phase and the entire monitoring period.

Figure 11. Photo of the San Lorenzo River mouth, looking southward toward the ocean, in the Post-Experiment phase on April 8, 2001. Water flow at this particular time alternated between landward tidal flow and weak seaward river flow.

of entrance dredging. A total of 21,438 m^3 sediment, of which ~2,900 m^3 was silt and clay (~14%), was delivered or returned to the study are over this period. This eight-day period marks the greatest combined new and returned sediment influx to the study area over the entire monitoring period (~55%), coming at a time of relatively low wave energy.

A few other sources that may have contributed sediment to the study area over the monitoring period have not been considered or accounted for in this study. Transport of sediment in longshore drift from the north or south, erosion of submerged bedrock outcrops, and cliff erosion (not observed within the study area beaches) are sources of sediment that may have entered the study area at some point during the monitoring period. Previously deposited deeper water shelf sediment returning to the nearshore could also have contributed sediment to the system.

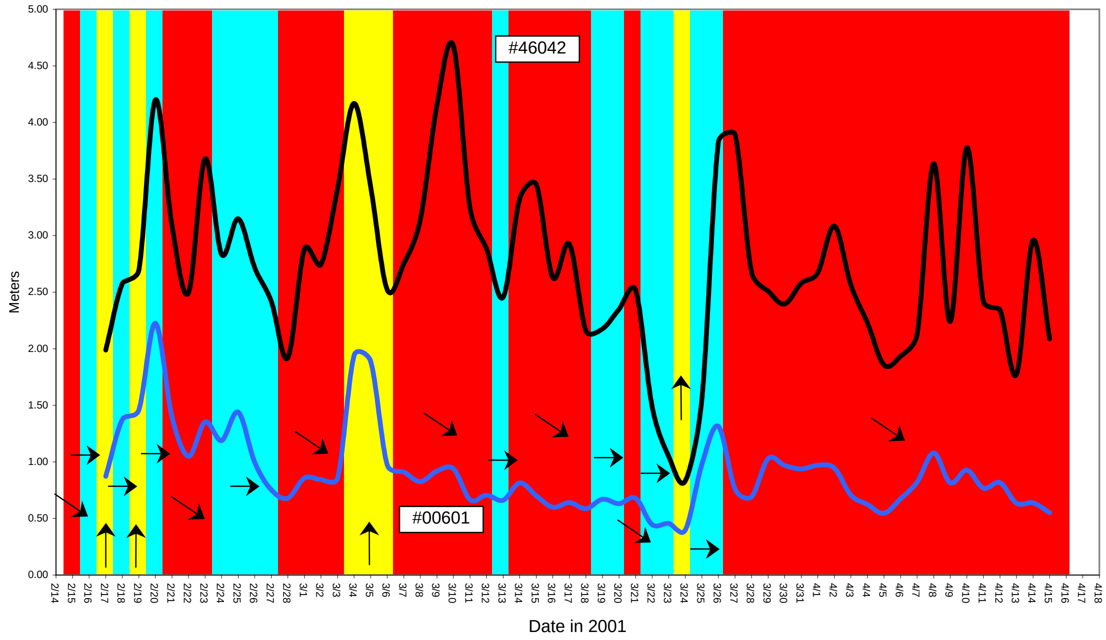
7.4 Marine Biological Assessment

Habitats between the Santa Cruz Harbor and Soquel Point were surveyed on January 4, 2001. Visibility was less than 1 m at the four sites surveyed (Appendix A, Figure 1): dredge outfall buoy, Black's Point, Corcoran Lagoon, and West Moran Lake. The diversity of marine organisms observed at these locations are most likely an underestimation due to the surge and limited visibility occurring at the times of the dives. At the dredge outfall station 7.6 m deep the seafloor had low-relief (<0.5 m) siltstone riddled with holes and locally covered with silty-sand. Siltstone outcrops (up to 1 m tall), and stretches of silty-sand were observed at Black's Point, at 9.7 m water depth. The substratum at Corcoran Lagoon site, 10.7 m deep, was sandy and covered by a flocculent layer that limited visibility to 0.6 m. West Moran Lake site, 7.6 m deep, was similar to Black's Point with siltstone outcrops and sand channels. For a complete list of marine organisms observed at theses locations, see Appendix A, Tables 1 and 2.

7.5 Oceanographic Conditions and Littoral Drift

Figure 12 is a plot of wave height and period for buoy #46042 offshore of Monterey Bay and the Santa Cruz Harbor Array #00601 just south of the Santa Cruz Harbor displayed over categorized directional wave data (in degrees) obtained from buoy #46042. Swell directions were bundled into three categories, northwest (290-325^{o}), west (245-290^{o}), and

Dominant wave height (meters) for buoy #46042 and array #00601



Average Daily Wave Period for buoys #46042 and array #00601

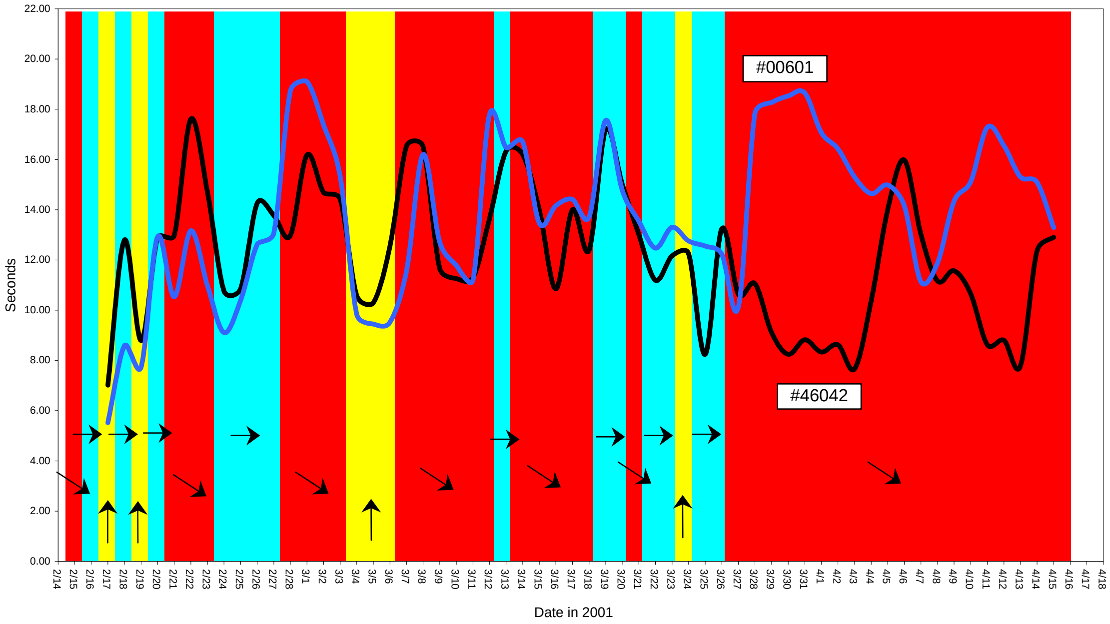


Figure 12. Wave height (meters) and period (seconds) from Monterey Bay buoy #46042 (black line) and Santa Cruz Harbor Array #00601(blue line) are shown seperately superimposed over categorized swell direction according to buoy #46042. Directional wave data (in degrees) were grouped into three colored categories, swell approaching the northwest is red (290-325), from the west is blue (245-290), and from the southwest is yellow (190-245) as indicated by arrows. For example, the arrows pointing straight up indicate that swells are approaching from the south or southwest. The swell direction was primarily northwest (73% of the time), while west (20%) and southwest (7%) were much less frequent. Directional swell data were only available for buoy #46042.

southwest (190-245^{o}). Directional data for the Santa Cruz Harbor Array #00601 were not available. Waves during the Pre-Experiment phase were primarily from the northwest with a few significant storms from the south and west. The Experiment and Post-Experiment phases were subject to primarily short period wind swells from the northwest. Figure 12 highlights the decreases seen in wave heights in the offshore Monterey Bay buoy (#46042) and the nearshore Santa Cruz Harbor Array (#00601). Note that the directly approaching south swells decrease less in wave height than northwest and west swells refracted around Point Santa Cruz. To get an idea of how much refraction is taking place before waves reached the harbor shoreline the mean daily wave direction from Monterey Bay buoy #46042 was subtracted from the daily wave direction predictions produced by the spectral wave refraction model Outfall Station (see Figure 5). The average wave refraction around Point Santa Cruz was 85^{o} and the range of wave refractions was from 12^{o} to 122^{o} over the monitoring period.

Littoral drift estimates from entrance dredging records and three spectral refraction wave model locations are shown in Table 4 (Figure 5). The model estimates suggest that longshore currents are very weak in the middle section between Point Santa Cruz and Soquel Point in the depth range of 6 to 18 meters because approaching waves are refracted to become nearly parallel to the coastline. The model predicts a small component of energy that is directed to the southeast (207^{o} -219^{o}). As a group of waves from the same direction approaches the shoreline, they become increasingly more parallel to the shoreline the closer they travel to it. This means the component of wave energy directed in the longshore direction, S($_{xy}$), becomes decreasingly closer to zero as the waves approach the shoreline.

Experimental Phase	Outfall Station Q(l)	Direction	Array Station Q(l)	Direction	Offshore Station Q(l)	Direction	Harbor Entrance	Direction
Pre-Experiment total	1.90		2.99		4.35		6,116	Assumed
38 day average	0.05	207	0.08	215	0.11	219	161	southeast
Experiment total	0.06		0.09		0.16		4,786	Assumed
3 day average	0.02	214	0.03	223	0.05	229	1,595	southeast
Post-Experiment total	0.23		0.31		0.69		19,144	Assumed
15 day average	0.02	214	0.02	223	0.05	231	1,276	southeast
Monitoring Period total	2.19		3.39		5.20		30,047	Assumed
56 day average	0.04	209	0.06	217	0.09	223	537	southeast

Table 4. Comparison of entrance dredging events and littoral drift estimates.

This is why littoral drift estimates predicted by the spectral wave refraction model are higher in the deeper water Array (13 m) and Offshore Stations (18 m) than the inshore Outfall Station (7 m). This does not imply that there is not enough energy to resuspend and transport sand size sediment, just that it is not directed in a overwhelming southeast littoral current at the model locations, according to the spectral wave refraction model.

Wave heights recorded at the Santa Cruz Harbor Array #00601 agree reasonably well with the wave heights predicted by the spectral wave refraction model for the same location (Array Station), building confidence in the models S_{xy} calculations (Figure 13). The 56-day average difference in wave height between the recorded Santa Cruz Array (#00601) wave height and the spectral wave model predictions Array Station wave height predictions is ±16 centimeters.

Estimates of longshore transport at the three model stations do not agree with the Santa Cruz Harbor entrance dredging records. Model results indicate that there has been very little transport of sediment downcoast during the monitoring period at the model locations, suggesting that transport is most likely cross-shore than along shore. In addition to the results of the spectral wave refraction model, McLaren's (2000) Sediment Trend Analysis® of sediment samples collected in the late summer of 1999, also indicate that there is little littoral drift occurring in the harbor region. McLaren's *net sediment transport pathways* are west and east towards the harbor entrance at the shorelines on either sides of the jetties, directed shoreward towards the harbor in the waters between Point Santa Cruz and Soquel Point, and to the southeast downcoast in the waters outside of the monitoring period study area.

The observation that the west jetty at the Santa Cruz Harbor has accumulated more sediment than the east jetty (Figure 14), producing a wide beach at Seabright, and the fact that the harbor entrance was dredged eleven times over the course of the monitoring period, indicates that there is significant transport of sediment to the southeast in littoral drift.

One explanation for the differences between model results and the entrance dredging records may be that the spectral wave refraction model locations were located in waters too deep to accurately predict littoral drift. Littoral drift is at its peak near the breaker zone (Komar, 1998), which was inshore of the shallowest model station (Outfall Station, 7 m) for

most of the monitoring period. It is possible that increased littoral drift is occurring inshore of the model stations, but it is unlikely due to the nearly parallel approach of waves to the shoreline at the wave model Outfall Station. Another possible explanation is that littoral drift rates at Point Santa Cruz, just west of the harbor are likely to be significantly higher than near the harbor due to the increased difference between angles of approaching waves and the shoreline. Waves at Point Santa Cruz break nearly perpendicular to the shoreline. Perhaps this angle produces a littoral drift momentum that the spectral wave refraction model has not accounted for, coupled with the abundance of transportable littoral sediment available by the Santa Cruz Wharf and the San Lorenzo River mouth. Another possibility is that McLaren's (2000) STA® may have recorded a summer sediment transport signature (his sediment samples were collected in late summer of 1999), while the accumulation of sediment in the harbor entrance occurs primarily in winter. It is also possible that sand sediment near the harbor entrance is simply resuspended during winter storms and pushed into the harbor entrance with wave surge or with the rising tide. Once in the protected harbor waters, the sand settles, eventually clogging the harbor entrance.

The approach of highly refracted wave angles to the diverse orientations of coastlines within the study area creates a complex range of possibilities for sediment transport not completely understood in the study area. Sediment transport in the study area might have a greater cross-shore component than longshore. Littoral drift may be greatest during strong winter storms in the deeper waters where there is a greater component of wave energy directed downcoast. The spring/summer transport regime is most likely inshore, rebuilding beaches from sand previously stored in offshore winter bars, with little contribution downcoast. Local geologic and coastal structure likely plays a significant role in sediment transport within the study area. Sediment transport may be blocked or diverted by rock outcrops elevated above the seabed or sediment may become trapped in low lying scours and fractures of bedrock similar to the situation described by Storlazzi & Field (2000) on the Monterey Peninsula. Overall, we believe there is a net littoral drift of sediment to the southeast, but the rate is probably less than harbor dredging records indicate and may be greater than model results suggest.

7.6 Onshore Sediment Samples

Averages and ranges of mean grain diameter, sorting and skewness for each beach sampling event are displayed on Table 5. Beach samples collected from Cowells Cove to Moran Lake range from fine to coarse sand and are generally moderately sorted, and range from strongly coarse- to fine-skewed. Beach samples collected during the monitoring period contained virtually no silt or clay, having percentages of 99.5% sand class size or larger.

Beaches at the start of the Pre-Experiment survey were in “winter profile”, meaning there were no well-developed berms or large, back beaches at most locations (Figure 15). In most cases, there was evidence that the beaches had been periodically completely submerged to their landward extent, leaving narrow, compacted, flat winter beach profiles. In other areas, parts of beaches had eroded to nearly sea level (primarily the beaches west and east of Moran Lake), with seawater regularly reaching protective revetments. Beaches backed by lagoons or lakes (Figure 16) had been severely eroded by flooding water, creating sea level trenches to the ocean that were further excavated by high tides and large surf. Twin Lakes Beach was eroded enough to reveal wooden pilings protruding out of the low tide beach (Figure 17). Seabright beach just west of the harbor was the exception, maintaining the majority of its width throughout the monitoring period. Mean grain size values from analyses of beach samples collected during the monitoring period are graphically displayed in Figures 18, 19 and 20.

The experimental dredging event took place in calm wave conditions and during excellent weather. Onshore sediment samples were collected at night while dredging was taking place to observe any abnormal beach deposit or odor. Neither was observed. Offshore samples were collected in the morning the following day. Beaches during the Experiment phase were observed to be in the early stages of rebuilding. At Seabright beach, large cusps were cut into the soft rebuilding beach by high tides (Figure 21). During the high tide at Twin Lakes Beach, the ocean would breach the high tide berm in the evening causing a pool to form on the back beach, recharging the exchange of water between Schwann Lagoon and the ocean for the majority of the monitoring period (Figure 22).

Pre-Experiment 1	Average	Average class	Range	Range classes
mean diameter (mm)	0.29	medium sand	0.20 to 0.53	fine to coarse sand
mean phi size	1.77	medium sand	2.32 to 0.92	fine to coarse sand
sorting (phi)	0.46	well sorted	0.39 to 0.64	well to moderately well sorted
skewness (phi)	0.04	near symmetrical	-0.10 to 0.11	near symmetrical to fine skewed
Pre-Experiment 2				
mean diameter (mm)	0.29	medium sand	0.17 to 0.70	fine to coarse sand
mean phi size	1.77	medium sand	2.56 to 0.52	fine to coarse sand
sorting (phi)	0.53	moderately well	0.34 to 1.37	very well to poorly sorted
skewness (phi)	-0.03	near symmetrical	-0.52 to 0.28	strongly coarse to fine skewed
Pre-Experiment 3				
mean diameter (mm)	0.27	medium sand	0.16 to 0.55	fine to coarse sand
mean phi size	1.89	medium sand	3.11 to 0.86	fine to coarse sand
sorting (phi)	0.50	well sorted	0.34 to 0.82	very well to moderately sorted
skewness (phi)	-0.02	near symmetrical	-0.27 to 0.16	coarse to fine skewed
Pre-Experiment 4				
mean diameter (mm)	0.31	medium sand	0.19 to 0.63	fine to coarse sand
mean phi size	1.69	medium sand	2.39 to 0.67	fine to coarse sand
sorting (phi)	0.52	moderately well	0.39 to 0.97	well to moderately sorted
skewness (phi)	0.02	near symmetrical	-0.21 to 0.11	coarse to fine skewed
Experiment 1				
mean diameter (mm)	0.29	medium sand	0.19 to 0.56	fine to coarse sand
mean phi size	1.77	medium sand	2.39 to 0.84	fine to coarse sand
sorting (phi)	0.59	moderately well	0.41 to 1.62	well to very poorly sorted
skewness (phi)	-0.04	near symmetrical	-0.49 to 0.08	strongly coarse to near symmetrical
Experiment 2				
mean diameter (mm)	0.29	medium sand	0.19 to 0.50	fine to coarse sand
mean phi size	1.77	medium sand	2.39 to 1.00	fine to coarse sand
sorting (phi)	0.51	moderately well	0.37 to 0.64	well to moderately well sorted
skewness (phi)	-0.01	near symmetrical	-0.12 to 0.19	coarse to fine skewed
Experiment 3				
mean diameter (mm)	0.32	medium sand	0.20 to 0.53	fine to coarse sand
mean phi size	1.65	medium sand	2.32 to 0.92	fine to coarse sand
sorting (phi)	0.56	moderately well	0.40 to 0.83	well to moderately sorted
Post-Experiment 1				
mean diameter (mm)	0.35	medium sand	0.21 to 0.83	fine to coarse sand
mean phi size	1.52	medium sand	2.25 to 0.27	fine to coarse sand
sorting (phi)	0.65	moderately well	0.39 to 1.49	well to poorly sorted
skewness (phi)	-0.06	near symmetrical	-0.54 to 0.08	strongly coarse to near symmetrically skewed
Post-Experiment 2				
mean diameter (mm)	0.33	medium sand	0.20 to 0.55	fine to coarse sand
mean phi size	1.60	medium sand	2.18 to 0.86	fine to coarse sand
sorting (phi)	0.52	moderately well	0.40 to 0.72	well to moderately sorted
skewness (phi)	0.00	near symmetrical	-0.23 to 0.14	coarse to fine skewed
Post-Experiment 3				
mean diameter (mm)	0.27	medium sand	0.19 to 0.42	fine to medium sand
mean phi size	1.89	medium sand	2.39 to 1.25	fine to medium sand
sorting (phi)	0.56	moderately well	0.37 to 0.91	well to moderately sorted
skewness (phi)	-0.09	near symmetrical	-0.22 to 0.09	coarse to near symmetrically skewed

Table 5. Averages and ranges of descriptive statistics for beach sediment sample events throughout the monitoring period. Samples are at or above the Best and Griggs (1991) cut-off diameter (0.18mm) for littoral sediment.

Figure 15. Photo taken March 1, 2001 from Blacks Point looking west to the east harbor jetty in the Pre-Experiment phase showing the flat, eroded winter beach at low tide.

Beach sediment sample descriptive statistics remained very consistent over the course of the monitoring period from February 18, 2001 to April 14, 2001. No sample had a silt and clay percentage of over 0.5%, suggesting that fine-grained material released in the experimental dredging event was not deposited or retained on the beaches from Cowells Cove to Moran Lake during the monitoring period. Redeposition of sand to the beaches in the seasonal rebuilding process did not widely change the descriptive statistical parameters recorded in the experimental phases. This suggests that the exchange of sediment between beaches and offshore was of sediment having the same relative statistical parameters. Notice that the mean and ranges of beach sediment samples on Table 5 are close to or above Best and Griggs (1991) cut-off diameter (0.18mm) for littoral sediment.

7.7 Offshore Sediment Samples

Table 6 categorizes the averages and ranges of mean grain size diameters, silt and clay percentages, sorting and skewness for offshore sampling events during the monitoring period.

Pre-Experiment 1	Average	Average class	Range	Range classes
% silt & clay	3.63	sand	0 to 14.42	rock to silty sand
mean diameter (mm)	0.21	fine sand	0.08 to 0.35	very fine to medium sand
mean phi size	2.25	fine sand	3.64 to 1.51	very fine to medium sand
sorting (phi)	0.84	moderately sorted	0.49 to 1.36	well to poorly sorted
skewness (phi)	-0.09	near symmetrical	-0.32 to 0.12	strongly coarse to fine skewed
Pre-Experiment 2				
% silt & clay	6.35	sand	0 to 18.65	rock to silty sand
mean diameter (mm)	0.27	medium sand	0.09 to 1.09	very fine to very coarse sand
mean phi size	1.89	medium sand	3.48 to -0.12	very fine to very coarse sand
sorting (phi)	0.93	moderately sorted	0.57 to 1.42	moderately well to very poorly sorted
skewness (phi)	-0.08	near symmetrical	-0.61 to 0.23	strongly coarse to fine skewed
Pre-Experiment 3				
% silt & clay	3.74	sand	0 to 25.65	rock to silty sand
mean diameter (mm)	0.09	very fine sand	0.08 to 1.08	very fine to very coarse sand
mean phi size	3.48	very fine sand	3.64 to -0.11	very fine to very coarse sand
sorting (phi)	0.43	well sorted	0.52 to 1.24	moderately well to very poorly sorted
skewness (phi)	0.00	near symmetrical	-0.35 to 0.32	strongly coarse to strongly fine skewed
Pre-Experiment 4				
% silt & clay	7.72	sand	0 to 23.15	rock to silty sand
mean diameter (mm)	0.14	fine sand	0.08 to 0.23	very fine to fine sand
mean phi size	2.84	fine sand	3.64 to 2.12	very fine to fine sand
sorting	0.75	moderately well sorted	0.62 to 1.21	moderately well to poorly sorted
skewness	-0.13	coarse skewed	-0.32 to 0.13	strongly coarse to fine skewed
Experiment 1				
% silt & clay	7.35	sand	0 to 24.93	rock to silty sand
mean diameter (mm)	0.16	fine sand	0.07 to 0.26	very fine to medium sand
mean phi size	2.64	fine sand	3.84 to 1.94	very fine to medium sand
sorting (phi)	0.76	moderately sorted	0.38 to 1.14	well to poorly sorted
skewness (phi)	0.06	near symmetrical	-0.22 to 0.32	coarse to strongly fine skewed
Experiment 2				
% silt & clay	8.04	sand	1.72 to 19.49	sand to silty sand
mean diameter (mm)	0.13	fine sand	0.09 to 0.22	very fine to medium sand
mean phi size	2.94	fine sand	3.48 to 2.18	very fine to medium sand
sorting (phi)	0.76	moderately sorted	0.57 to 1.20	moderately well to poorly sorted
skewness (phi)	0.02	near symmetrical	-0.45 to 0.35	strongly coarse to strongly fine skewed
Experiment 3				
% silt & clay	7.69	sand	0 to 14.04	rock to silty sand
mean diameter (mm)	0.13	fine sand	0.10 to 0.24	very fine sand to medium sand
mean phi size	2.94	fine sand	3.32 to 2.06	very fine sand to medium sand
sorting (phi)	0.85	moderately sorted	0.61 to 1.10	moderate well to poorly sorted
skewness (phi)	-0.13	coarse skewed	-0.39 to 0.34	strongly coarse to strongly fine

Table 6. Averages and ranges of offshore sediment sample descriptive statistics for sampling events throughout the monitoring period.

Post-Experiment 1	Average	Average class	Range	Range classes
% silt & clay	7.14	sand	0 to 26.33	rock to silty sand
mean diameter (mm)	0.21	fine sand	0.09 to 0.54	very fine to coarse sand
mean phi size	2.26	fine sand	3.48 to 0.89	very fine to coarse sand
sorting (phi)	0.88	moderately sorted	0.51 to 1.38	moderately well to poorly sorted
skewness (phi)	-0.06	near symmetrical	-0.39 to 0.38	strongly coarse to strongly fine skewed
Post-Experiment 2				
% silt & clay	6.14	sand	0 to 22.54	rock to silty sand
mean diameter (mm)	0.19	fine sand	0.09 to 0.54	very fine to coarse sand
mean phi size	2.39	fine sand	3.48 to 0.89	very fine to coarse sand
sorting (phi)	0.85	moderately sorted	0.55 to 1.18	moderately well to poorly sorted
skewness (phi)	-0.04	near symmetrical	-0.33 to 0.37	strongly coarse to strongly fine skewed
Post-Experiment 3				
% silt & clay	8.60	sand	0 to 25.49	rock to silty sand
mean diameter (mm)	0.15	fine sand	0.07 to 0.33	very fine to medium sand
mean phi size	2.74	fine sand	3.84 to 1.60	very fine to medium sand
sorting (phi)	0.81	moderately sorted	0.36 to 1.40	well to poorly sorted
skewness (phi)	-0.02	near symmetrical	-0.65 to 0.35	strongly coarse to strongly fine skewed

Table 6. Continued from previous page.

In general, offshore sediment samples range from very fine sand to medium sand with rock outcrop, shell fragments, pebbles or no return observed in similar areas near Point Santa Cruz, Soquel Point and Blacks Point in the nearshore. Offshore sediment samples have a much greater variety of mean grain sizes, silt and clay percentages, sorting and skewness values than beach samples. Diverse descriptive statistical ranges are found at nearly all sample locations over time, which can be explained by positional shifts in offshore sample collection (see Methods), and the deposition and erosion of sediment common in an active high-energy environment such as the study area. Many of the sediment samples collected were bimodal, indicating that sediment could come from different sources.

Figures 23, 24, and 25 graphically depict the locations and the color-coded mean grain-size diameters for samples in each of the experimental phases collected over the monitoring period. Samples that were greater than sand-size such as shell hash, pebbles, or exposed rock outcrop, and samples in areas where sediment could not be recovered after repeated attempts (no return), were grouped into one category expressed by a red circle.

Figures 26, 27 and 28 display the locations and percent composition of sediment samples in pie charts with three categories: percent greater than sand, percent sand, and percent silt and clay. Samples that were composed of shells, pebbles, rock outcrop, or where sediment

could not be recovered after multiple attempts (no return) were given a value of 100% greater than sand and displayed as full blue circles. The pie charts illustrate that most samples contain a majority of sand size sediment with other samples that either contain larger than sand fractions (shell fragments or pebbles), rock outcrop or no return.

Individual percentages of silt and clay obtained from grain-size analyses of samples collected during the monitoring period are illustrated in Figures 29, 30, and 31. Percentages of silt and clay are broken into six classes from 0 to 25% and greater. Sediment samples that were composed of shell fragments, pebbles, or rock chunks, or where a sample could not be recovered after multiple attempts (no return), received a value of 0% silt and clay and are displayed as gray circles in the figures. The greatest percentage of silt and clay found within any sample over the monitoring period was 26.5% at sample location 7 collected during the Post-Experiment 1 sample event on April 4, 2001. The highest percentage of silt and clay in samples collected in the Pre-Experiment phase was 25.7% for sample location 14 obtained during sampling event Pre-Experiment 3 on March 7, 2001. The highest percent silt and clay found in the Experiment phase was sample location 16 (24.9%) collected during the Experiment 1 sampling event on March 28, 2001.

No sediment sample collected in the study area over the monitoring period had a silt and clay concentration higher than 26.3%. Offshore sediment samples containing over 20% silt and clay in the study area were rare, representing only six of 166 total offshore sediment samples collected (<4%). Sample location 16 had the highest number of samples collected with a silt and clay percentage over 20%, occurring three times over the course of the monitoring period.

Three offshore sediment samples (<2%) had silt and clay percentages over 25%. One of the three over 25% silt and clay samples was collected at sample location 14, prior to the experimental dredging event during sampling event Pre-Experiment 3 on March 7, 2001 (Figure 32). The other two over 25% silt and clay samples were collected in Post-Experiment phases. One sample was located at sample location 7 collected during Post-Experiment 1 on April 2, 2001, which contained the highest concentration of silt and clay of any monitoring period sample (26.3%). The second sample was collected at sample location 16 during sampling event Post-Experiment 3 on March 12, 2001.

It is difficult to know whether higher concentration of mud in samples is a result of the experimental dredging sediment input, from another source, or is a natural sediment size for the area. Samples collected during the Pre-Experiment phase of the study that show relatively equal silt and clay percentages suggest that sediment containing nearly 25% mud are normal for the study area. McLaren (2000) found similar grain size distributions in samples he collected in the late summer of 1999, including areas he described as "muddy sand" near locations where we found over 20% concentrations of silt and clay in samples 16 and 7. The variability of grain size parameters found at most sediment sample locations and evidence that sediment transport has occurred (i.e. sediment build up in the harbor entrance, our sediment shifts map, and changing beach profiles) over the monitoring period, suggests that the mud rich experimental dredge sediment introduced to the study area was not retained in the nearshore environments or caused the sediment to become cohesive and alter sediment transport properties.

To better understand grain size distribution and habitat change in the study area it would be necessary to monitor the depositional environment at least over the course of a year so that the changes between the intense dynamic winter season and the calmer summer season can be observed. A good comparison to our winter/spring study would be a similar study conducted in late summer, when the rivers and streams have slowed or stopped flowing, when wave action is less intense, when the harbor entrance does not need to be dredged, and after the beaches have completely rebuilt. A more complete picture of the study area could be described following an El Nino/Southern Oscillation event when environmental conditions are extreme; when San Lorenzo Rover sediment discharge is at its peak and when coastal erosion is most likely to occur, widely impacting the beach and nearshore habitats.

7.8 Onshore Water Samples

Averages and ranges in turbidity (NTU) of swash-zone, San Lorenzo River, storm drain, and lagoon flood water samples collected throughout the monitoring period are listed in Table 7. Turbidity measurements of water samples collected over the monitoring period are geographically displayed in Figures 33, 34 and 35. Water samples were only collected at river,

	NTU average	NTU range
Pre-Experiment 1		
swash zone	3.8	1.1 to 9.8
river, storm drain, lagoon	7.8	4.5 to 11.0
Pre-Experiment 2		
swash zone	3.6	1.2 to 7.6
river, storm drain, lagoon	21.8	9.8 to 49.0
Pre-Experiment 3		
swash zone	1.2	0.8 to 2.9
river, storm drain, lagoon	6.5	1.6 to 15.0
Pre-Experiment 4		
swash zone	2.9	1.5 to 4.5
river, storm drain, lagoon	9.8	9.8
Experiment 1		
swash zone	2.8	1.2 to 4.1
river, storm drain, lagoon	6.5	6.5
Experiment 2		
swash zone	3.0	2.0 to 5.5
river, storm drain, lagoon	5.5	5.5
Experiment 3		
swash zone	3.6	1.7 to 6.5
river, storm drain, lagoon	6.6	6.6
Post-Experiment 1		
swash zone	1.4	1.1 to 2.0
river, storm drain, lagoon	2.0	0.7 to 3.1
Post-Experiment 2		
swash zone	1.3	0.5 to 1.7
river, storm drain, lagoon	2.4	0.7 to 4.1
Post-Experiment 3		
swash zone	1.4	0.7 to 1.9
river, storm drain, lagoon	0.8	0.8

Table 7. Averages and ranges in NTU for swash-zone, river, storm drain, and lagoon flood water samples over the monitoring period.

storm drain, or lagoon locations when they were visibly connected to the ocean, which changed throughout the monitoring period and is why some sampling events contain more water samples than another. Pre-Experiment river, storm drain, and lagoon flood samples recorded the highest turbidity values (NTU) throughout the monitoring period. These high turbidity water samples were in response to intense rainstorms causing flooding of the San Lorenzo River and lagoons where standing water existed during the dry months. The most turbid of all water samples collected in the monitoring period came from the first seasonal overflow of the Corcoran lagoon (onshore water sample location 33) of 49.0 NTU. Later on, following the intense rainstorms of late February and early March, NTU at all water sample locations drop

considerably. At this point, relatively high NTU values were then located near the areas where run-off continued to occur by the mouth of the San Lorenzo River and Schwann Lagoon. A strong turbidity signature was not identified in the swash-zone water samples during the experimental dredging event, nor was any odor or discoloration observed.

7.9 Offshore Water Samples

Table 8 lists the averages and ranges of turbidity (NTU) measurements of surface waters and water column samples at 2.5-meter water depth for each water sample

	NTU average	NTU range
Pre-Experiment 1		
surface	0.8	0.2 to 2.0
2.5 m deep	0.5	0.3 to 0.5
Pre-Experiment 2		
surface	0.5	0.2 to 1.1
2.5 m deep	0.3	0.2 to 0.5
Pre-Experiment 3		
surface	0.4	0.1 to 0.5
2.5 m deep	0.2	0.1 to 0.3
Pre-Experiment 4		
surface	0.6	0.5 to 0.9
2.5 m deep	0.4	0.3 to 0.7
Experiment 1		
surface	0.6	0.5 to 1.0
2.5 m deep	0.7	0.4 to 0.9
Experiment 2		
surface	0.8	0.6 to 1.2
2.5 m deep	0.5	0.2 to 1.0
Experiment 3		
surface	0.8	0.3 to 1.7
2.5 m deep	0.4	0.2 to 0.6
Post-Experiment 1		
surface	0.6	0.1 to 2.1
2.5 m deep	0.3	0.2 to 0.7
Post-Experiment 2		
surface	0.2	0.2 to 0.6
2.5 m deep	0.3	0.2 to 0.4
Post-Experiment 3		
surface	0.7	0.3 to 1.9
2.5 m deep	0.3	0.2 to 0.5

Table 8. Averages and ranges of turbidity measurements (NTU) for water samples collected at sea surface and at 2.5 meters water depth for each experimental phase throughout the monitoring period.

collected during the monitoring period. Figures 36, 37, and 38 geographically display the individual NTU value for each water sample collected in the monitoring period. Turbidity values of offshore samples are diluted by the ocean and therefore have lower NTU values than those collected in the swash-zone, river, storm drain, or flooding lagoons. The values are noticeably higher in the Pre-Experiment sampling events than the other experimental phases because of the intense rainstorms, which occurred during the Pre-Experiment time. Surface water NTU values are generally higher than those recovered from 2.5 meters water depth. This was expected because freshwater flow generally stays on the surface of denser seawater. River plumes are often concentrated on the sea surface with little vertical expression in the water column. Other causes of increased turbidity may come from the resuspension of sediment by waves, experimental dredging, or entrance dredging.

Surface NTU values determined from samples collected during the Post-Experiment phase were similar to surface NTU values collected during the Pre-Experiment phases. High surface NTU values collected in the Pre-Experiment phase are probably caused by sediment discharge from the San Lorenzo River during flooding. High surface NTU values from the Post-Experiment water samples may have been caused by experimental dredging, harbor entrance dredging, or resuspension of sediment by wave action. The experimental dredge sediment was piped underwater into the surf-zone mixed with upper harbor seawater. If increases in turbidity were caused by the experimental dredging event, we would expect increases in both 2.5-meter water depth sample and the surface sample. This was not the case in the Experiment and Post-Experiment phases.

7.10 Geophysical Surveys

The experimental dredging event was planned for the winter months to insure that the fine-grained sediment released to the surf-zone would have the best chance of being quickly dispersed by high-energy winter wave conditions. While good for dispersing sediment, high-energy winter wave conditions are not conducive to the collection of geophysical survey data. The Pre-Experiment survey began in rough weather on February 21, 2001, but had to be terminated a third of the way through due to deteriorating weather conditions. The survey had

to be rescheduled and was completed in better conditions on March 10, 2001. As a result, there is a certain degree of vertical error in the bottom depth (roughly ±50 cm) associated with the data due to rough seas. In addition, in the Pre-Experiment survey data, a latency shift error in the acquisition software Isis Sonar® caused a significant roll error to appear in the sonar data. Triton-Elics greatly improved the quality of the data by supplying a software patch that was applied to the data after the survey. Seafloor features such as rock outcrops, boulders, sandy substrate and sediment waves are still easily distinguished in the sonar images.

Figures 39 and 40 display the processed multibeam bathymetry and backscatter imagery used in conjunction with the Pre-Experiment sediment sample data to create seafloor habitat interpretations. Four different benthic habitat types were identified and classified according to the Greene et al. (1999) classification system (Appendix E) over the ~6 km^2 area. Figure 41 displays multibeam bathymetry and backscatter imagery examples of the four benthic habitat types identified in the images, written descriptions of the benthic habitats, and the attribute codes used. Features such as scour depressions filled with course sediment waves had been previously identified in side-scan sonar records by Anima et al. (2002) and Eittreim et al. (2002a). The Pre-Experiment habitat interpretations along with the survey area analysis (in km^2 and m^2) are displayed in Plate 1. The seafloor is composed of approximately 50% sand in the very fine to medium size class (shown as Ssf_b/u) that are deposited into large expanses and in what may be ancient eroded river channels from times of lower sea level (Anima et al., 2002). Mixed sediment in filled scour depressions or fractures (shown as Smw_b/f/s) comprise about 5% of the study area seafloor, with patchy sediment covered rock outcrops (shown as Sm_b/u) accounting for 25% of the survey area and exposed rock outcrops (shown as Sh(b)/e_f) accounting for the remaining 17%. There was no bathymetric expression of a sedimentary mound or river flume sediment deposit on the seafloor near the San Lorenzo River in our Pre-Experiment processed geophysical images like that imaged by Hicks and Inman (1987) after intense flooding of the San Lorenzo River.

Post-Experiment processed multibeam bathymetry and backscatter images are displayed in Figures 42 and 43. The Post-Experiment survey was conducted on April 10 and 11, 2001 almost exactly a month after the Pre-Experiment survey was completed and covered ~7km^2. The Post-Experiment survey was executed in better weather, which allowed us to map

closer to the shoreline, which accounts for the difference between Pre- (~6 km^2) and Post-Experiment (~7 km^2) survey coverage. These images were used in conjunction with geographically located sediment sample data to identify habitats like those discovered in the Pre-Experiment geophysical survey (see Figure 41 for habitat types). The Post-Experiment seafloor habitat interpretation including area analysis (in km^2 and m^2) is presented in Plate 1.

There was no bathymetric expression of a sedimentary mound or river sediment plume deposit near the San Lorenzo River or a bathymetric expression of sediment mound imaged near the experimental dredge outfall in our Post-Experiment processed geophysical images. It is possible that sedimentary mounds may have been produced by the San Lorenzo River and the experimental dredging sediment that were under our geophysical detection limits (i.e. ± 50 cm). Another possibility is that sedimentary mounds that may have been produced by the San Lorenzo River or the experimental dredging event were quickly dispersed by waves between the times of the two geophysical surveys. In either case, no change in wave shoaling patterns (for example, a peculiar shoal in the study area not observed prior to dredging) was observed near the experimental dredge outfall or the San Lorenzo River.

The Post-Experiment seafloor interpretation is very similar to the Pre-Experiment interpretation. Areas of rock outcrop, sediment covered rock outcrop, sand flats and channels, and scour depressions or fractures filled with mixed sediment were identified in the same general areas and with similar seafloor percentages as those identified in the Pre-Experiment interpretations. Using the Spatial Analyst extension in ArcView3.2®, the interpretations of the two surveys were intersected and analyzed to produce a sediment shift map (Plate 1). The Sediment Shifts Explanation table in Plate 1 describes the types of shifts that were identified, area of shifts (in m^2) and maps percentages of the total shifts in sediment. Shifts in habitat type were categorized as erosion, deposition, or no habitat change. Over the 32-day period between the two surveys, a combined seafloor area of 160,000 m^3 experienced sediment deposition. Estimates of sediment volumes eroded or deposited were based on the arbitrary assumption that the sediment had an average thickness of 10 cm. Using the 10cm thickness, the total net depositional volume equals approximately 16,000 m^3 over the time between the two surveys. We acknowledge it is not possible from our data to account for the shifts in sediment that are undoubtedly taking place on some of the areas categorized as “no habitat change”. The methods we have used cannot resolve vertical changes in sandy or mixed sediment areas under roughly ±50 cm due to the vertical roll error previously described in the Pre-Experiment geophysical survey data.

It is not possible to conclude from the sediment shifts map the dominant direction of sediment transport, nor is it possible to know the sediment source. It does appear that deposition and/or erosion have occurred in every benthic habitat type identified throughout the study area seafloor. The majority of erosion is occurring on the eastern inshore areas of the survey area and deposition has occurred most often in the southern middle section, in the deeper study area waters. While the majority of the seafloor is described as “no habitat change” (~86%), a net deposition of sediment was calculated over the study area seafloor. The offshore sediment sample analyses indicate that seafloor surface sediment mean grain sizes, silt and clay percentages, sorting and skewness did not change substantially change over the course of the monitoring period when compared with Pre-Experiment sediment analyses. This suggests that the ~160,000 m^2 of sediment that has been deposited in the study area over the monitoring period was primarily sand sized or larger.

5. Conclusions

The results of the 56-day monitoring period represent a snapshot of a seasonal transition from late winter to early spring of 2001. Except for the harsh weather experienced in the first half of the Pre-Experiment phase in late February and early March, the experiment was conducted in mostly calm spring and summer like conditions. The study area in winter is subjected to intense rainstorms, flooding rivers and lagoons, eroding beaches, and strong winter waves. The winter is when river sediment discharge peaks, when transport of sediment is greatest, and when coastal erosion is most likely to occur. These conditions are replaced by drier, calmer spring and summer weather, mild to non-existent river or lagoon flows, rebuilding of beaches, and a wave pattern dominated by local wind swell with shorter periods, heights and durations than experienced during winter conditions.

We would expect the change from winter to spring conditions to affect grain size distribution on the beaches and in the nearshore benthic marine habitats of the study area.

Spring and summer conditions may provide calmer environments for the deposition of fine-grained suspended sediment or sediment entering the system from a source other than the San Lorenzo River, such as littoral drift from the north or harbor dredging. In this respect, there could be a natural decrease in mean grain diameters and an increase in silt and clay percentages as sediment settles on the seafloor in calm conditions.

. The integration and analysis of all the data types that were collected over the monitoring period from February 18, 2001 to April 14, 2001 leads us to the conclusion that the fine-grained silt and clay released during the experimental dredging event (in addition to sediment input from other study area sources), have not substantially changed the beaches or altered the sedimentary characteristics of offshore benthic habitats. Beach grain size and compositional parameters changed little over the course of the monitoring period, even while the beaches were in a rebuilding stage. Pre-Experiment natural, or baseline, conditions reveal a seafloor of widely differing substrate types and sediment grain sizes that change over time. Descriptive statistical grain size diversity, evidence of sediment deposition, and erosion were identified offshore over the course of the monitoring period to remain within the same ranges as baseline or natural conditions data collected in the Pre-Experiment phase. In addition, the geophysical surveys indicate that the same basic geometric shape, diversity, and distribution of benthic habitats established in the Pre-Experiment phase persisted throughout the monitoring program.

The San Lorenzo River, just a kilometer west of the harbor, has released an estimated average of 212,500 m^3 of multi-grain sized sediment on an annual basis to the Santa Cruz shelf and has done so over periods of decades and possibly centuries. Even with this amount of multi-grained sediment discharge, a high percentage of silt or clay was not found within the study area during the monitoring period and has not been reported in previous sedimentological studies on the Santa Cruz inner shelf by other investigators (Wolf, 1970; Arnal, 1973; Best and Griggs, 1991; McLaren, 2000; Edwards, 2002). The high-energy nature of this coastline (especially in the winter months, from November to April) must be of sufficient magnitude to suspend the majority of silt and clay sediment delivered to the study area by any source, including harbor dredging. The silt and clay is most likely transported to deeper waters offshore, outside of the study area (30 m and greater water-depths) and deposited on the midshelf mudbelt. Past and present research has identified the midshelf mudbelt to be the largest sink of silt and clay sediment on the northern Monterey Bay shelf and that deposition of mud sediment there continues to occur (Greene, 1977; Edwards, 2002; Lewis et al. 2002; Eittreim et al. 2002).

Acknowledgments

This research was made possible by funding from the California Department of Boating and Waterways and the Santa Cruz Port District. The authors would like to thank the Santa Cruz Port District staff and the Harbor Patrol staff for their help and patience with this project, specifically Port Director Brian Foss, Operations Manager Kimbra Eldridge, Ron Duncan (Maintenance Services), Harbormaster Larry White, and Don, Chuck, Mike and many others for their help sampling offshore. We would also like to thank Kevin O'Toole of the USGS for the use of their petite ponar grab sampler on such short notice, John Haskins for the use of his Niskin bottle and nephelometer, and Dr. William O'Reilly for generously running his wave model for us. Conversations, suggestions and comments regarding this study by Dr. Tracy Vallier greatly improved the quality of this work. Many thanks to Janet Tilden for her help in the field and in the laboratory.

Literature cited

Anima, R., Eittreim, S.L., Edwards, B.D., Stevenson, A.J. (2002). Nearshore morphology and late Quaternary geologic framework of the northern Monterey Bay Marine Sanctuary, California. Mar. Geol. Vol. 181, pp. 35-54.

Arnal, R.E., Dittmer, E., Shumaker, E., 1973. Sand transport studies in Monterey Bay, California. Moss Landing Marine Labs Technical Publication 73-5, 71pp.

Bascom, W.N., 1951, The Relationship Between Sand-Size and Beach-Face Slope, Transactions American Geophysical Union, 32: 866-874.

Best, T. and Griggs, G.B., 1991, A sediment budget for the Santa Cruz littoral cell, California. Shoreline to Abyss S.E.P.M. Special Publication No. 46.

Breaker, L.C., Broenkow, W.W., 1994. The Circulation of Monterey Bay and related processes. Ocean Mar. Biol. Annu. Rev 32, 1-64.

Brown, W.M., 1973. Erosion processes, fluvial-sediment transport, and reservoir sedimentation in part of Newell and Zayante Creek basins, Santa Cruz County, California: U.S. Geological Survey Open-File Report, 31 p.

Chelton, D.B., 1984. Seasonal variability of alongshore geostrophic velocity central California. J. Geophys. Res., vol. 89, pp. 3473-3486.

Folk, R.L., 1974, Petrology of Sedimentary Rocks, Hemphill Pub. Co., Austin Texas, 182pp.

Foss, B, 1999, Impact of Santa Cruz Harbor Dredging Disposal Sediment on Kelp Forest at Twin Lakes Beach, Santa Cruz Port District Report to CDF&G, MBNMS, U.S. Army Corp of Engineers, CARWQCB, and California Coastal Commission.

Edwards, B.D. (2002). Variations in sediment texture on the northern Monterey Bay National Marine Sanctuary continental shelf. Mar. Geol. vol. 181, pp. 83-100.

Eittreim, S.L., Anima, R.J., Stevenson, A.J.,(2002a). Seafloor geology of the Monterey Bay area continental shelf. Mar. Geol. Vol. 181, pp. 3-34.

Eittreim, S.L., Xu, J.P., Noble, M., Edwards, B.D., (2002b). Towards a sediment budget for the northern Monterey Bay continental shelf. Mar. Geol. vol.181, pp. 235-248.

Goldberg, N., Foster, M. and Watt, S.G., (2000). Expected dredge material transport and habitats at risk within the vicinity of The Santa Cruz Small Craft Harbor**.** Prepared for Mr. Brian Foss, Port Director of the Santa Cruz Small Craft: In response to the California Coastal Commission request

Greene, H.G., 1977. Geology of the Monterey Bay region. US Geological Survey Open-File Report OF 77-718, 347 pp.

Greene, H.G., 1990. Regional tectonics and structural evolution of the Monterey Bay region, Central California. In: Garrison, R.E., Greene,, H.G., Hicks, K.R., Weber, G.E., Wright, T.L., (Eds.), Geology and Tectonics of the Central California Coastal Region, San Francisco to Monterey. Pacific Section of the American Association of Petroleum Geologists Guidebook vol. 67, pp. 31-56.

Greene, H.G. and Clark, J.C., 1979. Neogene Paleogeography of the Monterey Bay Area, California. IN: Cole, M.R., Ter-Best, H., Armentrout, J. (Eds.), Cenozoic Paleogeography of the Western United States. Pacific Section SEPM, Pacific Coast Paleogeography Symposium vol. 3, pp. 277-296.

Greene, H.G., M.M. Yoklavich, R.M. Starr, V.M. O'Connell, W.W. Wakefield, D.E. Sullivan, J.E. McRea Jr., and G.M. Cailliet, 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta. Vol 22: 6. pp. 663-678

Griggs, G.B., 1987, Littoral cells and harbor dredging along the California coast, Environmental Geology and Water Sciences, v. 10, n. 1, p. 7-20.

Griggs, G.B., Hein, J.R., 1980, Sources, dispersal, and clay mineral composition of fine-grained sediment off central and Northern California, Journal of Geology, v. 88 p. 541-566.

Griggs, G.B., Johnson, R.E., 1976, Effects of Santa Cruz Harbor on coastal processes of northern Monterey Bay, California, Environmental Geology and Water Sciences v. 1 n. 5, p. 299-312.

Griggs, G. and Savoy, L., 1985, Living with the California Coast, Duke University Press, Durham, North Carolina, 394 pp.

Hicks, D.M., Inman, D.L., 1987, Sand dispersion from an ephemeral river delta on the central California coast, Marine Geology, v. 77, p. 305-318.

Komar, P.D., 1998, Beach Processes and Sedimentation, Second Edition: Prentice Hall Inc. Simon & Schuster/ A Viacom Company, Upper Saddle River, New Jersey, 544pg.

Lewis, R.C., Coale, K.H., Edwards, B.D., Marot, M., Douglas, J.N., Burton, E.J., 2002. Accumulation rate and mixing of shelf sediments in the Monterey Bay National Marine Sanctuary. Mar Geol. vol. 181, pp. 157-169.

McLaren, P. 2000. A Sediment Trend Analysis (STA®) of Santa Cruz Harbor and its Vicinity: Implications to Dredge Disposal Operations. Prepared fort the Santa Cruz Harbor and The California Department of Boating and Waterway by GeoSea Consulting (Canada) Ltd. 789 Saunders Lane, Brentwood Bay, B.C. V8M 1C5, Canada

Mullins, H.T., Nagel, D.K., Dominguez, L.L., 1985. Tectonic and eustatic controls of late Quaternary shelf sedimentation along the central California (Santa Cruz) continental margin: high-resolution seismic stratigraphic evidence. Sed. Geol. 44, 327-347.

Oradiwe, E.N., 1986, Sediment Budget for Monterey Bay. M.S. thesis, U.S. Naval Post Graduate School, Monterey California, 101 pp.

O'Reilly, W.C. and Guza, R. (1993). A Comparison of two spectral wave models in the Southern California Bight, Coastal Engineering, 1993, v19, p263-282.

Storlazzi, C.D., Field, M.E., 2000, Sediment Distribution and transport along a rocky, embayed coast: Monterey Peninsula and Carmel Bay, California. Mar. Geol. vol. 170, pp. 289-316.

Sullivan, M., Krcik, S.E., 1999, Sediment Sampling and Analysis Report for North Harbor Sediments, RRM Engineering and Contracting Firm, prepared for the Santa Cruz Port District.

Sullivan, M., Krcik, S.E., 2000, Sediment Sampling and Analysis Report for Entrance Sediments, RRM Engineering and Contracting Firm, prepared for the Santa Cruz Port District.

Thackston, E.L., Palermo, M.R., 1999, Improved methods for correlating turbidity and suspended solids for monitoring. *DOER Technical Notes Collection* (ERDC TN-DOER-E8), U.S. Army Engineer Search and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

Wolf, S.C.1970, Coastal currents and mass transport of surface sediments over the shelf regions of the Monterey Bay, California, Marine Geology, v. 8, n. 5, p.321-336.

Wong, F.L. and Eittreim, S.L., (2002) Continental shelf GIS for the Monterey Bay National Marine Sanctuary. Mar. Geol. vol. 181, pp. 317-321.

Xu, J.P. 1999. Local wave climate and long-term bed shear stress characteristics in Monterey Bay, CA. Mar. Geol. vol. 159, pp. 341-343.

Xu, J.P., Noble, M., Eittreim, S.L., (2002). Suspended sediment transport on the continental shelf near Davenport, California. Mar. Geol. vol. 181, pp. 171-193.

Appendix A.

Expected dredge material transport and habitats at risk within the vicinity of

The Santa Cruz Small Craft Harbor

Nisse Goldberg, Dr. Mike Foster, and Steve Watt
Moss Landing Marine Laboratories

Expected dredge material transport and habitats at risk within the vicinity of The Santa Cruz Small Craft Harbor

Prepared for Mr. Brian Foss, Port Director of the Santa Cruz Small Craft
In response to the California Coastal Commission request

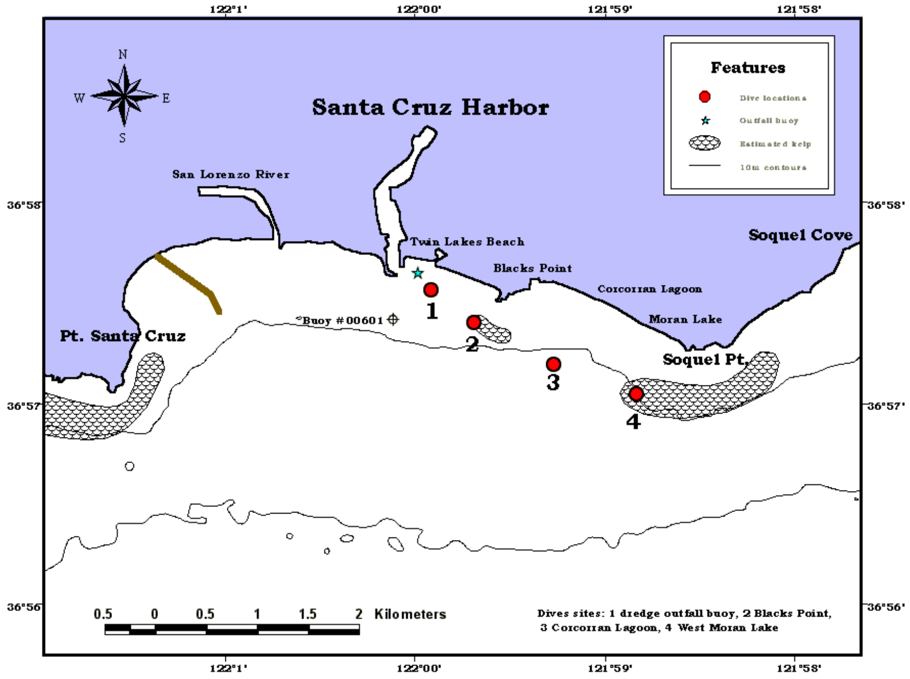
Prepared by Nisse Goldberg, Dr. Mike Foster, and Steve Watt
Moss Landing Marine Laboratories

To properly understand the sedimentary and ecological environment offshore of the Santa Cruz Small Craft Harbor, previous scientific literature regarding the marine benthic habitats, coastal processes, and oceanography of the northern part of Monterey Bay were reviewed. A pilot study of grain size distribution was conducted using sediment samples collected onshore and nearshore from Cowells Cove to Soquel Point. Offshore grain size data was evaluated from a report Sediment Trend Analysis of the Santa Cruz Harbor McClaren, (1999). Side-scan sonar maps of Northern Monterey Bay produced by the United States Geological Survey (available on the web) in 1993 were also interpreted and incorporated into the pilot study to gain an understanding of the offshore sedimentary patterns near the Santa Cruz Small Craft Harbor and to help design a monitoring program.

The purpose of this study is to inventory organisms associated with the various marine benthic habitats in the vicinity of where the Santa Cruz Harbor Port District will undertake a demonstration dredging event. The intent of this work is to determine through in situ observations the diversity and relationship of those organisms for the purpose determining a cursory baseline to be compared during and after the dredging demonstration.

Northwest swells dominate the central California coast between the months of October to April. Littoral offshore currents transport sand and suspended sediment derived primarily from river flow and cliff erosion to the southeast in the Monterey Bay (Wolf, 1970; Best and Griggs, 1991). This suggests that the offshore areas (including the kelp forests) between the dredge outfall and Soquel Point have the highest probability of being impacted by dredge materials due to their location downcoast of the Santa Cruz Harbor (Figure 1). Four research dives were conducted on January 4, 2001 to closely examine the habitat and substrates associated with this location.

Figure 1. Study Area



Material entering the surf zone, whether it is by dredge or river, undergoes a sorting process controlled by factors such as grain density, grain diameter, currents, wave height and direction (Bascom, 1951). Xu (1999) analyzed five and one half years of wave measurements from buoy # 00601, 150m southwest of the Santa Cruz Harbor north jetty, 13m above the seafloor (Figure 1). He found sediment resident times of 140 days for fine sand (0.125 –

0.25mm) and over 5,000 days for coarse sand (0.5 – 1.00mm), suggesting slow sediment transport for these size classes at 13 m depth. Resuspension and transport of sediments increases as depth decreases shoreward assuming constant wave energy. In a steady state environment, some minimum grain size should exist below which particles in any appreciable quantity will not remain within the active zone of littoral transport. Best and Griggs (1991) determined the cut-off diameter of grain size for transport in littoral drift to be 0.18mm and above. Upper harbor dredge material is composed of 41.8% sand (0.0625-2.00mm), 28.7% silt (0.0039-0.0625mm) and 29.5% clay (< 0.0039mm). Any sediment with diameters smaller than 0.18 mm are sorted out by wave action, stay in suspension and move offshore to be deposited onto the inner shelf. Larger clasts are transported in the longshore current to the southeast to be deposited either onshore by waves, wind or lost at the end of the littoral cell into the Monterey canyon (Griggs & Hein, 1980; Best and Griggs, 1991). Material entering the nearshore from a surf zone dredge at the Santa Cruz Small Craft Harbor should be subject to the same natural coastal processes as material entering from the San Lorenzo River to the west.

Physical Environment as Related to Benthic Habitats

The subtidal environment off the Santa Cruz Harbor is affected by seasonal swells, sediment transport and deposition, substrate characteristics, and turbidity. During winter months, the site is protected from northwesterly waves by the Santa Cruz headlands; southerly and southwesterly swells dominate during summer months. The San Lorenzo River and local streams deposit sand and silt offshore during winter rains (Thompson 1982). The benthic habitats at Soquel Point are composed of submerged shelf bedrock outcrops and sand channels. These outcrops expose friable sand and siltstone of the Pliocene Purisima Formation. The seafloor in Soquel Cove is underlain by the Purisima Formation that is covered with 30-40 cm of silty sand (Thompson, 1982). At Point Santa Cruz, rocks and boulders eroded from the Purisima Formation, Santa Cruz mudstone and are interspersed between sand channels (Breda, 1982). Turbidity at these sites increases with river run-off and when water motion suspends sediment in the water column. When thermoclines have developed during calm periods, phytoplankton blooms develop. Visibility can range between 0 and 3 m; visibility is greatest in winter and spring (Breda, 1982, Thompson, 1982).

Habitats between Point Santa Cruz and Soquel Point were surveyed on 4 Jan 2001. Visibility was less than 1 m at the four sites surveyed: dredge outfall buoy (1 on Figure 1), Black's Point (2 on Figure 1), Corcoran Lagoon (3 on Figure 1), and West Moran Lake (4 on Figure 1). The diversity observed is most likely an underestimation due to the surge and limited visibility. At the dredge outfall station 7.6 m deep the seafloor had low-relief (<0.5 m) siltstone riddled with holes and locally covered with silty-sand. Siltstone outcrops (up to 1 m tall), and stretches of silty-sand were observed at Black's Point, 9.7 m deep. The substratum at Corcoran Lagoon site, 10.7 m deep, was sandy and covered by a flocculent layer that limited visibility to 0.6 m. West Moran Lake site, 7.6 m deep, was similar to Black's Point with siltstone outcrops and sand channels.

Algae

The Point Santa Cruz kelp forest is affected by seasonal deposition of sediment. The kelp forest consists of a *Macrocystis pyrifera* and *Cystoseira osmundacae* surface canopy in summer and fall, a patchy subsurface kelp canopy of *Pterygophora californica* that is present year-round, and a year-round ground cover of red algae (perennial and annual species) and *Desmarestia* spp. (present only in spring and summer; Mattison, 1977; Rose 1979) Species are listed in Tables 1 and 2. These inventories (not associated with the January 2001 dives) were compiled in 1984. A present day inventory could show a difference. Aerial photographs (taken before 1977 shows that the extent of the kelp canopy has remained the same at Point Santa Cruz (Mattison et al*.,* 1977). *Macrocystis pyrifera* surface canopy was greatest May through August 1980, and absent after November storms removed fronds (Breda 1982). Perennial algae include *Chondracanthus corymbifera* and *Rhodymenia* spp. Annual species are most abundant in spring and summer: *Cryptopleura farlowianum*, *C. violacea*, *Nienburgia andersoniana*, *Phycodrys setchellii*, and *Polyneura latissima*. As percentage cover of sand increases due to sand transport during winter storms and summer swells, red algal biomass decreases. In October, the seafloor sampled at Point Santa Cruz increased from ten to sixty percent, sand and red algal biomass was reduced to 5 g/ 0.25 m^2 or less. Sand scour and fragmentation of the substrate opened up bare space available for spore settlement. Perennial species persist during fall and winter. By spring, recruits are abundant (up to 10 g algal biomass/ 0.25 m in 1980; Breda 1982).

At Soquel Point, the algal assemblage had similar seasonal trends with annuals most abundant in spring and summer, and perennial persisting through winter months. In August 1979, adult *M. pyrifera* density was 8 plants/10 m^2. Thompson (1982) cleared a 10 m radius of *Macrocystis pyrifera*; a year later, the clearings were still visible from the surface. *Pterygophora californica* had no recruits during 1979 to 1980. Over 500 recruits of *M. pyrifera* were observed during the same period. Storms removed smaller plants (less than 60 fronds per plant). Most mortalities of adult plants were due to the gradual thinning of fronds. As in Point Santa Cruz site, bare space in winter increased from 5 to13 percentage cover (Thompson 1982).

Algal diversity on siltstone outcrops was greater at Black's Point than at West Moran Lake; no algae was observed at the dredge outfall buoy and Corcoran Lagoon sites. Adult (fronds reaching surface) and juvenile *M. pyrifera* plants were observed at Black's Point and West Moran Lake. Six red algae species were observed at Black's Point and one species at West Moran Lake (Table 2).

Invertebrates

Macro-invertebrates are more abundant on mudstone outcrops than in sand channels. Hydroids, colonial tunicates, bryazoans, sponges, cup corals, and barnacles were common at Point Santa Cruz, in 10- 14 m depth (Rose 1979). Mattison et al. (1977) observed greater densities of *Strongylocentrotus fransicanus* at the borders (less than 1 urchin/ m^2) than within the Point Santa Cruz kelp forest (up to 55 urchins/10 m^2): sea stars were also common (approximately 30 sea stars/ m^2 inside the forest and over 40 stars/ m^2 at the border of the forest). At depths less than 10 m in Soquel Cove, *Diopatra ornata*, *Urechis caupo*, barnacles, sea stars, encrusting tunicates, and anemones are common (Table 1 for compiled species list). At Point Soquel, the piddock clam *Parapholas californica* can be abundant (26 clams/ m^2 in 1982), in addition to *Anthopleura atemisia*, and *Asterina miniata* (Thompson 1982).

Invertebrate diversity was greatest at Black's Point and West Moran Lake sites. At the outfall site, *Dendraster excentricus* was observed in the sediment and *Dermasterias imbricata* and *Diopatra ornata* were found on mudstone. At Black's Point and West Moran Lake sites, sea stars, hydroids, solitary and colonial tunicates, polychaetes, crabs, and anemones were observed. No invertebrates were seen at the Corcoran Lagoon site.

Fish

At Soquel Cove, Solonsky (1983) studied fish diversity at two artificial cement reefs (one marked with a surface buoy and the other left unmarked) and surrounding sandy-bottom habitats during 1982 to1983. Fish traveled more than 1.6 km from nearest reef or kelp forest to colonize the artificial reefs. The most common fishes (86% of fish observed) were *Sebastes mystinus*, *S. serranoides*, *Phanerodon furcatus*, *Embiotica jacksoni*, and *Hysurus caryi*. Fish abundances peaked in summer (7 fish/m^2) and declined in fall and winter to 3 fish/ m^2. Smaller fish (length less than 6 cm) were present summer and fall, and larger fish (greater that 12 cm in length) were more abundant in fall and winter. Fish in surrounding sandy habitats consisted of white croaker and speckled sand dab (70% of catch in otter trawl) in fall, spring, and summer. In fall and summer, white, walleye, and spotfin surfperch, and starry flounder made up 20% of otter trawl catch. Night smelt made up 15% of otter trawl catch in spring. Sport fishermen fished 'heavily' at the marked reef in Soquel Cove (Solonosky 1983).

Only one species of fish was observed during the diver survey: *Oxylebius pictus*, seen at Black's Point and West Moran Lake sites.

Impacts Due to the Introduction of Dredge Sediments

Deposition of sediment (no matter what the source) on rocky substrate and bedrock exposures can alter the habitat and decrease species richness, evenness, and density of reef communities (Burdette, 1992). How often sediment is added to the system, residence time of sediment, thickness of sediment layer, coarseness of sediment (i.e. scour potential), and suspension rates into the water column will affect the viability of a benthic community (Devinny and Volse, 1978). Sediment can smother invertebrates, prevent larval attachment, and scour soft-bodied organisms. Suspended sediment can clog feeding and respiratory mechanisms of filter feeders (Lilly *et al*. 1953, Devinny and Volse, 1978, Foster and Schiel, 1985 and Burdett, 1992). Sediment can prevent algal spore settlement on rocky substrates, decrease light by direct burial or increase turbidity in the water column, scour spores, and alter microclimates (Devinny and Volse, 1978). In a laboratory experiment, the addition of 8 mg/cm^2 fine sediment reduced the survival of *M. pyrifera* spores by 90%. Those spores completely buried, did not survive (Devinny and Volse, 1978). However, some algae can tolerate burial. *Zonaria farlowii* persisted in 50-100 mm sediment layer, despite damage to apical cells, and acclimated to sunlight after sediment was removed (Dahl, 1971). The distribution of algae is impacted by the introduction of sediment: during spring and summer at Point Santa Cruz, algae were observed on available rocky substrate, but in fall and winter, when sand deposition is greatest, algae were only visible on tops of rocks, suggesting that algae may be buried under the sand or removed by water motion (Breda, 1992). The diversity of fish in a bedrock exposure covered with sand may resemble a sandy bottom habitat: fewer rockfish and more flatfish (Solonsky, 1983). If sediment residence time is long, thus preventing spore and larval settlement and decreasing the survival of juvenile stages, the kelp forest may become patchy or nonexistent, and those animals associated with kelp forests (i.e. sea otters and harbor seals) may not inhabit the site. Potential toxic chemicals in dredge sediments may negatively impact organisms in a kelp forest; however, it is our understanding that sediment to be dredged by the Santa Cruz Harbor are toxin free.

Literature Cited

Bascom, W.N., 1951, The Relationship Between Sand-Size and Beach_Face Slope, Transactions American Geophysical Union, 32: 866-874.

Best, Tim and Griggs, G.B., 1991, A sediment budget for the Santa Cruz littoral cell, California. Shoreline to Abyss S.E.P.M. Special Publication No. 46.

Breda, V.A.1982. Composition, abundance, and phenology of foliose red algae associated with two *Macrocystis pyrifera* forests in Monterey Bay, California. San Jose State University. Masters' thesis. 67 pp.

Burdette, K.S. 1992. Rose of sand scour in structuring rocky subridal communities. California State University, Hayward. Masters' thesis. 70 pp.

Dahl, A.L. 1971. Develpment, form and environment in the brown alga Zonaria farlowii (Dictyotales). Botanica Marina. 14: 76-112.

Devinny, J.S. and Volse, L.A. 1978. Effects of sediments on the development of *Macrocystis pyrifera* gametophytes. Marine Biology.48: 343-348.

Foster, M.S. and Schiel, D.R. 1985. The ecology of giant kelp forests in California: A community profile. United States Fish and Wildlife Service Biological Report 85, 152 pp.

Griggs, G.B., Hein, J.R., 1980, Sources, dispersal, and clay mineral composition of fine grained sediment off central and Northern California, Journal of Geology, v. 88 p. 541-566.

Lilly, J.S., Sloane, J.F., Bassingdale, R., Ebling, F.J., and Kitching, J.A. 1953. The ecology of the Lough Ine rapids with special reference to water currents. Journal of Animal Ecology. 22: 87-122.

McCLaren, Patrick, 1999, A Sediment Trend Analysis (STA) of Santa Cruz Harbor and its Vicinity: Implications to Dredge Disposal Operations, GeoSea Consulting Ltd., Brentwood Bay, BC Canada.

Mattison J.E., Trent, J.D., Shanks, A.L., Akin, T.B., and Pearse J.S. Movement and feeding activity of red sea urchins (*Strongylocentrotus franciscanus*) adjacent to a kelp forest. Marine Biology. 39: 25-30.

Rose, D.K. 1979. The understory algal associations in six central California kelp forests. California State University, Hayward. Masters' thesis. 117 pp.

Solonsky, A.C. 1983. Fish colonization and the effect of fishing activities on two artificial reefs in Monterey Bay, California. California State University, San Francisco. Masters' thesis. 55 pp.

Thompson, J.P. 1982. Benthic illumination within a *Macrocystis* bed at Pt. Soquel, Santa Cruz, California, and its influence upon *Macrocystis* population structure and the abundance of benthic red algae. University of California, Santa Cruz. Masters' thesis. 110 pp.

Wolf, S.C.1970, Coastal currents and mass transport of surface sediments over the shelf regions of the Monterey Bay, California, Marine Geology, v. 8, n. 5, p.321-336.

Xu, J.P. 1999. Local wave climate and long-term bed shear stress characteristics in Monterey Bay, CA. Marine Geology. 159: 341-343.

Table 1. Species List from Soquel Cove (SQ), Point Santa Cruz (SC), and Point Soquel (S) (compiled from Mattison et al. 1977, Rose 1980, Thompson, 1982, and Solonsky 1983) These inventories (not associated with the January 2001 dives) were compiled in 1984. A present day inventory could show a difference.

Macroalgae

Phaeophyta

- *Cystoseira osmundacae* (SC, S)
- *Desmarestia ligulata* var. *ligulata* (SC, S)
- *Laminaria dentigera* (SC, S)
- *L. ephemera* (S)
- *L. sinclairii* (S)
- *Macrocystis pyrifera* (SC, S)
- *Nereocystis luetkeana* (SC)
- *Pterygophora californica* (SC, S)

Rhodophyta

- *Bosiella orbigniana* (S)
- *Calliarthron* sp. (SC)
- *Callophyllis* sp. (SC)
- *Ceramium* sp. (SC)
- *Cryptopleura farlowianum* var. *anomalum* (SC, S)
- *Chondracanthus* sp. (SQ, SC)
- *Gracilaria andersonii* (S)
- *Halymenia californica* (SC, S)
- *Hymenema* sp. (S)
- *Mazzaella* sp. (SC)
- *Sarcodiotheca gaudichaudii* (SC)
- *Neoptilota densa* (SC, S)
- *N. californica* (S)
- *Nienburgia andersonii* (S)
- *Opuntiella californica* (SC)
- *Phycodrys setchellii* (SC, S)
- *Pikea* sp. (SC)
- *Plocamium cartilagineum* (SC)
- *Polyneura latissima* (SC, S)
- *Polysiphonia* sp. (SC)
- *Pterosiphonia* sp. (SC)
- *Rhodymenia* sp. (SQ, SC, S)
- *Tiffaniella snyderae* (SC)
- Encrusting coralline algae (SC, S)

Table 1. Species List from Soquel Cove (SQ), Point Santa Cruz (SC), and Point Soquel (S).

Invertebrates

- Demospongia
  - *Acarnus erithacus* (S)
  - *Polymastia pachymastia* (S)
  - *Suberites* sp. (S)
- Calcarea
  - *Leucilla nuttingi* (S)
- Anthozoa
  - *Allophora porphyra* (SQ)
  - *Anthopleura artemesia* (S)
  - *A. elegantissima* (S)
  - *Balanophyllia elegans* (S)
  - *Cactosoma arenaria* (SQ)
  - *Clavularia* sp. (S)
  - *Corynactis californica* (SQ, S)
  - *Epiactis prolifera* (S)
  - *Metridium senile* (SQ)
  - *Obelia* (SQ)
  - *Paracyathus stearnsi* (S)
  - *Tealia lofotensis* (S)
- Hydrozoa
  - *Agalophenia struthoinides* (S)
  - *Plumularia* sp. (S)
  - *Sertularia* sp. (S)
  - *Sertularella* sp. (S)
- Polychaeta
  - *Cirripedia* sp. (SQ)
  - *Diopatra ornata* (S)
  - *Eudistyla polymorpha* (S)
  - *Phragmatopoma californica* (S)
  - *Salmacinia tribanchiata (*S)
  - *Semibalanus cariosus* (SQ)
  - *Serpula vermicularis* (S)
  - *Spirorbis* sp. (SQ, S)
- Crustacea
  - *Balanus nubilis* (SQ, S)
  - *B. crenatus* (SQ, S)
  - *Cancer antennarius* (SQ, S)
  - *Idotea* sp. (S)
  - *Loxyrhynchus crispatus* (SQ, S)
  - *Pugettia producta* (S)
  - *Scyra acutifrons* (S)

Table 1. Species List from Soquel Cove (SQ), Point Santa Cruz (SC), and Point Soquel (S).

Invertebrates

- Cheilostomata
    - *Dendrobeania laxa* (SQ)
    - *Eurystomella bilabiata* (SQ)
    - *Hippodiplosia* (SQ)
    - *Membranipora* sp. (S)
    - *Schizoporella unicornia* (SQ)
  - Bivalvia
    - *Chaceia ovidea* (S)
    - *Hiatella arctica* (S)
    - *Hinnites giganteus* (S)
    - *Parapholas californica* (S)
  - Cephalopoda
    - *Octopus* sp. (S)
  - Gastropoda
    - *Archidoris montereyensis* (S)
    - *A. odhneri* (S)
    - *Anisodoris nobilis* (S)
    - *Calliostoma annulatum* (S)
    - *C. canaliculatum* (S)
    - *C. ligatum* (S)
    - *Ceratostoma foliatum* (S)
    - *Haliotis rufescens* (S)
    - *Hermissenda crassicornis* (S)
    - *H. pugnax* (S)
    - *Pseudomelatoma torosa* (S)
    - *Triopha catalinae* (S)
  - Asteroidea
    - *Asterina miniata* (SQ, SC, S)
    - *Dermasterias imbricata* (SQ, S)
    - *Henricia levisculosa* (S)
    - *Leptosterias hexactis* (S)
    - *Pisaster brevispinus* (SQ, SC, S)
    - *P. giganteus* (SC, S)
    - *P.ochraceus* (SC, S)
    - *Pycnopodia helioanthoides* (SQ, S)
  - Echinoidea
    - *Strongylocentrotus franciscanus* (SC)
    - *S. purpuratus* (S)
  - Holothuroidea
    - *Cucumaria miniata* (S)

Table 1. Species List from Soquel Cove (SQ), Point Santa Cruz (SC), and Point Soquel (S).

Invertebrates

Ophiuroidea
- *Ophioplocus esmarki* (S)
- *Ophiothrix spiculata* (S)

Urochordata
- *Archidistoma molle* (SQ, S)
- *A.psamnion* (S)
- *Ascidia ceratodes* (SQ)
- *Clavelina huntsmani* (S)
- *Cystodytes* sp. (S)
- *Didemnun carnulentum* (SQ, S)
- *Euherdmania claviformis* (S)
- *Polyclinum planum* (S)
- *Pycnoclavella stanleyi* (S)
- *Pyura haustor* (S)
- *Styela montereyensis* (SQ, S)
- *S. plicata* (SQ)

Fish
- *Anarrichthys ocellatus* (S)
- *Cirrichthys stigmaeus* (SQ)
- *Cymatogaster aggregata* (SQ, S)
- *Damalichthus vacca* (SQ, S)
- *Embiotica jacksoni* (SQ)
- *Genyonemus lineatus* (SQ)
- *Heterostichus rostratus* (S)
- *Hexagrammos decagrammus* (SQ, S)
- *Hyperprosopon argenteum* (SQ)
- *H. anale* (SQ)
- *Hypsurus caryi* (SQ, S)
- *H. argentum* (SQ)
- *Myliobatis californica* (S)
- *Ophidion elongatus* (SQ, S)
- *Oxyjulis californica* (S)
- *Oxylebius pictus* (S)
- *Paralabrax clathratus* (S)
- *Parophrys vetulus* (SQ)
- *Phanerodon furcatus* (SQ)
- *Platichthys stellatus* (SQ)
- *Pleuronichthys decurrens* (SQ)
- *P. verticalis* (SQ)
- *Raja binoculata* (S)
- *Scorpaenichthus marmoratus* (S)

Table 1. Species List from Soquel Cove (SQ), Point Santa Cruz (SC), and Point Soquel (S).

Fish

- *Sebastes atrovirens* (SQ, S)
- *S. auriculatus* (SQ)
- *S. carnatus* (SQ)
- *S. caurinus* (SQ)
- *S. chrysomelas* (SQ, S)
- *S. melanops* (SQ)
- *S. mystinus* (SQ, S)
- *S. nebulosus* (S)
- *S. paucispinus* (SQ)
- *S. pinniger* (SQ)
- *S. serranoides* (SQ, S)
- *Spirinchus starksi* (SQ)
- *Torpedo californica* (S)
- *Triakus semifasciata* (S)

Mammals

- Cetacea
  - *Eschrichtius robustus* (S)
- Carnivora
  - *Enhydra lutris* (S)
- Pinnipedia
  - *Zalophus californianus* (S)
- Phocidae
  - *Phoca vitulina* (S)

Table 2. Species list from the sites outfall (O), Black's Point (BP), and West Moran Lake (WML).

Macroalgae

Phaeophyta
- *Macrocystis pyrifera*- adults with reproductive structures and juveniles (BP, WML)

Rhodophyta
- *Callophyllis flabellulata*- thallus covered with bryazoans (BP)
  - *C. violacea* (BP)
- *Chondracanthus* sp. (BP)
- *Halymenia californica*- thallus covered with hydroids and bryazoans (BP)
- *H. schizymeniodes* (BP)
- *Rhodymenia* sp. (WML)
- *Ptilota filiciana* (BP)

Invertebrates

Demospongia
- *Acarnus erithacus* (WML)

Anthozoa
- *Anthopleura* sp. (BP, WML)
- *Telia* sp. (BP)

Hydrozoa
- *Agalophenia struthoinides* (BP, WML)

Polychaeta
- *Diopatra ornate* (O, BP, WML)

Crustacea
- *Loxorhynchus crispatus* (BP)

Cheilostomata
- *Membranipora* sp. (BP)

Bivalvia
- Unidentified clam shells (O, BP, WML)

Gastropoda
- *Calliostoma annulatum* (BP, WML)

C. ligatum (WML)

- *Tegula funebralis* (BP, WML)

Table 2 (cont.). Species list from the sites outfall (O), Black's Point (BP), and West Moran Lake (WML).

Asteroidea
- *Asterina miniata* (BP)
- *Dermasterias inbricata* (O)
- *Pisaster brevispinus* (BP, WML)
- *P. giganteus* (BP, WML)
- *P. ochraceus* (BP)

Echinoidea
- *Dendraster exentricus* (O)

Urochordata
- *Cystodytes lobata* (WML)
- *Polyclinum planum* (BP, WML)
- *Styela montereyensis* (BP, WML)

Fish

- *Oxylebius pictus* (BP, WML)

Mammal

- *Enhydra lutris*- with pups, in kelp canopy at surface (BP, WML)
- *Phoca vitulina*- in kelp canopy at surface (BP)
- *Zalophus californianus* (O)

Appendix B.

Wentworth grain size and other classifications

Wentworth Size Class

Phi	mm	Class	Sediment Type
< -8.0	> 256	boulder	gravel
-6.0 to -8.0	64 to 256	cobble	
-2.0 to -6.0	4.00 to 64	pebble	
-1.0 to -2.0	2.00 to 4.00	granule	
0.0 to -1.0	1.00 to 2.00	very coarse sand	sand
1.0 to 0.0	0.50 to 1.00	coarse sand	
2.0 to 1.0	0.25 to 0.50	medium sand	
3.0 to 2.0	0.125 to 0.25	fine sand*	
4.0 to 3.0	0.0625 to 0.125	very fine sand	
5.0 to 4.0	0.031 to 0.0625	coarse silt	mud
6.0 to 5.0	0.0156 to 0.031	medium silt	
7.0 to 8.0	0.0078 to 0.0156	fine silt	
8.0 to 7.0	0.0039 to 0.0078	very fine silt	
> 8.0	< 0.0039	clay	

*Best and Griggs (1991) 0.18 cut-off diameter for littoral drift.

Sorting Verbal Classification

Phi	Class
< 0.35	very well sorted
0.35-0.50	well sorted
0.50-0.71	moderately well sorted
0.71- 1.0	moderately sorted
1.0-2.0	poorly sorted
2.0-4.0	very poorly sorted
>4.0	extremely poorly sorted

Skewness Verbal Classification

Phi	Class
1.00 to 0.30	strongly fine skewed
0.30 to 0.10	fine-skewed
0.10 to -0.10	near symmetrical
-0.10 to -0.30	coarse skewed
-0.30 to -1.00	strongly coarse skewed

Appendix C.

Onshore sediment and water sample database tables

Pre Experiment onshore sediment and water samples

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	%SILT&CLAY	MODE(S)	MEAN	DESCRIPTION	NTU
pr1b 21	2/18/01	586841.9769	4090957.233	0.00	100.00	0.00	2.10	1.85	medium sand	1.9
pr1b 22	2/18/01	587240.3094	4091183.218	0.00	100.00	0.00	2.10	1.87	medium sand	n/a
pr1b 23	2/18/01	587684.6224	4091265.464	0.00	100.00	0.00	2.20	1.95	medium sand	2.5
pr1b up riv	2/18/01	587860.0239	4091522.462	0.00	99.88	0.12	2.90	2.20	fine sand	4.5
pr1b 24	2/18/01	588041.0575	4091235.872	0.00	100.00	0.00	2.00	1.58	medium sand	9.8
pr1b 25	2/18/01	588397.611	4091195.201	0.00	100.00	0.00	2.00	1.27	medium sand	n/a
pr1b 26	2/18/01	588710.4687	4091076.423	0.00	100.00	0.00	1.20	0.92	coarse sand	6.4
pr1b 27	2/18/01	588959.8539	4091067.94	0.00	100.00	0.00	2.60	2.11	fine sand	1.1
pr1b 28	2/18/01	589138.1364	4091047.621	0.00	100.00	0.00	2.20	1.94	medium sand	n/a
pr1b 29	2/18/01	589290.1795	4090982.651	0.00	100.00	0.00	2.10	1.79	medium sand	3
pr1b 30	2/18/01	589406.3806	4090939.495	0.00	100.00	0.00	2.10	1.79	medium sand	n/a
pr1b 31	2/18/01	589514.0315	4090862.966	0.00	100.00	0.00	2.10	1.74	medium sand	n/a
pr1b 32	2/18/01	589603.5271	4090819.531	0.00	100.00	0.00	2.90	2.09	fine sand	4.4
pr1b 33	2/18/01	590315.983	4090804.896	0.00	100.00	0.00	2.10	1.61	medium sand	1.9
pr1b 34	2/18/01	590584.8432	4090641.338	0.00	100.00	0.00	2.10	1.46	medium sand	n/a
pr1b 35	2/18/01	590943.1018	4090445.461	0.00	100.00	0.00	2.10	1.44	medium sand	2.9
pr1b 36	2/18/01	589003.7842	4091123.875	0.08	99.92	0.00	2.80	2.11	fine sand	n/a
pr1b 37	2/18/01	589199.5206	4091137.026	0.00	100.00	0.00	2.90	2.13	fine sand	11
pr1b 38	2/18/01	589307.167	4091060.494	0.00	100.00	0.00	2.80	2.10	fine sand	n/a
pr1b 39	2/18/01	589602.7069	4090897.187	0.00	100.00	0.00	2.90	2.29	fine sand	n/a
pr2b 21	3/1/01	586841.9769	4090957.233	0.00	100.00	0.00	2.30	1.96	medium sand	4.4, 9.8
pr2b 22	3/1/01	587240.3094	4091183.218	0.00	100.00	0.00	2.90	2.13	fine sand	n/a
pr2b 23	3/1/01	587684.6224	4091265.464	0.00	100.00	0.00	3.00	2.54	fine sand	3.4
pr2b up riv	3/1/01	587860.0239	4091522.462	0.00	99.93	0.07	2.90	2.17	fine sand	21
pr2b 24	3/1/01	588041.0575	4091235.872	0.00	100.00	0.00	2.00	1.65	medium sand	6.5
pr2b 25	3/1/01	588397.611	4091195.201	0.00	100.00	0.00	2.00	1.62	medium sand	15
pr2b 26	3/1/01	588710.4687	4091076.423	0.00	100.00	0.00	2.00	1.46	medium sand	1.9
pr2b 27	3/1/01	588959.8539	4091067.94	0.00	100.00	0.00	2.00	1.79	medium sand	7.6
pr2b 28	3/1/01	589138.1364	4091047.621	0.00	100.00	0.00	2.10	1.92	medium sand	n/a
pr2b 29	3/1/01	589290.1795	4090982.651	0.00	100.00	0.00	2.10	1.81	medium sand	2
pr2b 30	3/1/01	589406.3806	4090939.495	0.00	100.00	0.00	2.10	1.79	medium sand	n/a
pr2b 31	3/1/01	589514.0315	4090862.966	0.00	100.00	0.00	2.20	1.96	medium sand	n/a
pr2b 32	3/1/01	589603.5271	4090819.531	0.00	100.00	0.00	2.40	1.87	medium sand	2.4
pr2b 33	3/1/01	590315.983	4090804.896	0.00	100.00	0.00	2.00	1.59	medium sand	3, 49
pr2b 34	3/1/01	590584.8432	4090641.338	0.00	100.00	0.00	2.00	1.23	medium sand	n/a
pr2b 35	3/1/01	590943.1018	4090445.461	16.59	83.41	0.00	-1, 1.9	0.51	coarse sand	1.2
pr2b 36	3/1/01	589003.7842	4091123.875	1.18	98.51	0.31	2.50	1.91	medium sand	n/a
pr2b 37	3/1/01	589199.5206	4091137.026	0.00	99.90	0.10	3.00	2.30	fine sand	16
pr2b 38	3/1/01	589307.167	4091060.494	0.00	100.00	0.00	2.20	1.97	medium sand	n/a
pr2b 39	3/1/01	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.36	fine sand	20
pr3b 21	3/13/01	586841.9769	4090957.233	0.00	100.00	0.00	3.00	2.28	fine sand	0.8, 1.6
pr3b 22	3/13/01	587240.3094	4091183.218	0.00	100.00	0.00	3.00	2.18	fine sand	n/a
pr3b 23	3/13/01	587684.6224	4091265.464	0.00	100.00	0.00	2.90	2.16	fine sand	0.9
pr3b up riv	3/13/01	587860.0239	4091522.462	0.00	100.00	0.00	3.00	2.28	fine sand	2.9
pr3b 24	3/13/01	588041.0575	4091235.872	0.00	100.00	0.00	2.30	1.93	medium sand	1.4
pr3b 25	3/13/01	588397.611	4091195.201	0.00	100.00	0.00	2.00	1.48	medium sand	n/a
pr3b 26	3/13/01	588710.4687	4091076.423	0.21	99.79	0.00	2.10	1.55	medium sand	1.2
pr3b 27	3/13/01	588959.8539	4091067.94	0.00	99.55	0.45	3.00	2.61	fine sand	2.9
pr3b 28	3/13/01	589138.1364	4091047.621	0.00	100.00	0.00	3.00	2.43	fine sand	n/a
pr3b 29	3/13/01	589290.1795	4090982.651	0.00	100.00	0.00	2.60	2.12	fine sand	1
pr3b 30	3/13/01	589406.3806	4090939.495	0.00	100.00	0.00	2.50	1.96	medium sand	n/a
pr3b 31	3/13/01	589514.0315	4090862.966	0.00	100.00	0.00	3.00	2.39	fine sand	n/a
pr3b 32	3/13/01	589603.5271	4090819.531	0.00	100.00	0.00	2.80	2.08	fine sand	0.6
pr3b 33	3/13/01	590315.983	4090804.896	0.00	100.00	0.00	2.00	1.36	medium sand	1.1
pr3b 34	3/13/01	590584.8432	4090641.338	0.07	99.93	0.00	2.00	1.61	medium sand	n/a
pr3b 35	3/13/01	590943.1018	4090445.461	5.07	94.93	0.00	1.70	0.86	coarse sand	1.3
pr3b 36	3/13/01	589003.7842	4091123.875	0.00	100.00	0.00	3.00	2.26	fine sand	n/a
pr3b 37	3/13/01	589199.5206	4091137.026	0.00	100.00	0.00	3.00	2.14	fine sand	15

Pre Experiment onshore sediment and water samples (continued)

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	%SILT&CLAY	MODE(S)	MEAN	DESCRIPTION	NTU
pr3b 38	3/13/01	589307.167	4091060.494	0.00	100.00	0.00	2.50	2.04	fine sand	n/a
pr3b 39	3/13/01	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.36	fine sand	n/a
pr4b 24	3/27/01	588041.0575	4091235.872	0.00	100.00	0.00	2.00	1.62	medium sand	4.5
pr4b 25	3/27/01	588397.611	4091195.201	0.64	99.36	0.00	1.60	0.98	coarse sand	n/a
pr4b 26	3/27/01	588710.4687	4091076.423	1.73	98.27	0.00	0.2, 1.7	0.66	coarse sand	4.2
pr4b 27	3/27/01	588959.8539	4091067.94	0.00	100.00	0.00	3.00	2.43	fine sand	1.5
pr4b 28	3/27/01	589138.1364	4091047.621	0.00	100.00	0.00	2.10	1.81	medium sand	n/a
pr4b 29	3/27/01	589290.1795	4090982.651	0.00	100.00	0.00	2.10	1.68	medium sand	3.0
pr4b 30	3/27/01	589406.3806	4090939.495	0.00	100.00	0.00	2.20	2.00	medium sand	n/a
pr4b 31	3/27/01	589514.0315	4090862.966	0.00	100.00	0.00	3.00	2.30	fine sand	n/a
pr4b 32	3/27/01	589603.5271	4090819.531	0.00	100.00	0.00	2.60	2.00	medium sand	1.5
pr4b 36	3/27/01	589003.7842	4091123.875	0.00	100.00	0.00	2.70	2.06	fine sand	n/a
pr4b 37	3/27/01	589199.5206	4091137.026	0.00	100.00	0.00	1.90	1.31	medium sand	9.8
pr4b 38	3/27/01	589307.167	4091060.494	0.00	100.00	0.00	2.50	2.00	medium sand	n/a
pr4b 39	3/27/01	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.22	fine sand	n/a
pr4b 24	3/28/01	588041.0575	4091235.872	0.25	99.75	0.00	2.10	1.67	medium sand	4.0
pr4b 25	3/28/01	588397.611	4091195.201	0.16	99.84	0.00	2.00	1.40	medium sand	n/a
pr4b 26	3/28/01	588710.4687	4091076.423	16.28	83.72	0.00	-1, 2.1	0.84	coarse sand	2.6

Experiment onshore sediment and water samples

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	%SILT&CLAY	MODE(S)	MEAN	DESCRIPTION	NTU
d1b 27	3/28/01	588959.8539	4091067.94	0.00	100.00	0.00	3.00	2.28	fine sand	4.1
d1b 28	3/28/01	589138.1364	4091047.621	0.00	100.00	0.00	2.10	1.67	medium sand	n/a
d1b 29	3/28/01	589290.1795	4090982.651	0.00	100.00	0.00	2.00	1.60	medium sand	1.9
d1b 30	3/28/01	589406.3806	4090939.495	0.00	100.00	0.00	2.30	1.97	medium sand	n/a
d1b 31	3/28/01	589514.0315	4090862.966	0.00	100.00	0.00	3.00	2.21	fine sand	n/a
d1b 32	3/28/01	589603.5271	4090819.531	0.00	100.00	0.00	2.90	2.10	fine sand	1.2
d1b 36	3/28/01	589003.7842	4091123.875	0.00	99.73	0.27	2.90	2.13	fine sand	n/a
d1b 37	3/28/01	589199.5206	4091137.026	0.00	100.00	0.00	3.00	2.35	medium sand	6.5
d1b 38	3/28/01	589307.167	4091060.494	0.00	100.00	0.00	2.20	1.98	medium sand	n/a
d1b 39	3/28/01	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.42	fine sand	n/a
d2b 24	3/29/01	588041.0575	4091235.872	0.00	100.00	0.00	2.00	1.68	medium sand	5.5
d2b 25	3/29/01	588397.611	4091195.201	0.00	100.00	0.00	2.00	1.53	medium sand	2.6
d2b 26	3/29/01	588710.4687	4091076.423	0.34	99.66	0.00	1.50	1.00	coarse sand	2.0
d2b 27	3/29/01	588959.8539	4091067.94	0.00	100.00	0.00	3.00	2.39	fine sand	n/a
d2b 28	3/29/01	589138.1364	4091047.621	0.00	100.00	0.00	2.00	1.42	medium sand	n/a
d2b 29	3/29/01	589290.1795	4090982.651	0.00	100.00	0.00	2.00	1.44	medium sand	2.2
d2b 30	3/29/01	589406.3806	4090939.495	0.00	100.00	0.00	2.20	1.86	medium sand	n/a
d2b 31	3/29/01	589514.0315	4090862.966	0.00	100.00	0.00	2.10	1.90	medium sand	n/a
d2b 32	3/29/01	589603.5271	4090819.531	0.00	100.00	0.00	2.90	2.11	fine sand	2.7
d2b 36	3/29/01	589003.7842	4091123.875	0.00	100.00	0.00	2.90	2.13	fine sand	n/a
d2b 37	3/29/01	589199.5206	4091137.026	0.00	100.00	0.00	3.00	2.18	fine sand	5.5
d2b 38	3/29/01	589307.167	4091060.494	0.00	100.00	0.00	2.20	1.98	medium sand	n/a
d2b 39	3/29/01	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.36	fine sand	n/a
d3b 24	3/30/01	588041.0575	4091235.872	0.00	100.00	0.00	2.00	1.59	medium sand	6.5
d3b 25	3/30/01	588397.611	4091195.201	0.72	99.28	0.00	1.60	0.91	coarse sand	n/a
d3b 26	3/30/01	588710.4687	4091076.423	0.18	99.82	0.00	1.90	1.21	medium sand	4.5
d3b 27	3/30/01	588959.8539	4091067.94	0.00	100.00	0.00	2.90	2.10	fine sand	2.4
d3b 28	3/30/01	589138.1364	4091047.621	0.00	100.00	0.00	2.00	1.72	medium sand	n/a
d3b 29	3/30/01	589290.1795	4090982.651	0.00	100.00	0.00	2.00	1.75	medium sand	1.7
d3b 30	3/30/01	589406.3806	4090939.495	0.00	100.00	0.00	2.90	2.21	fine sand	n/a
d3b 36	3/30/01	589003.7842	4091123.875	0.00	100.00	0.00	2.90	2.17	fine sand	n/a
d3b 37	3/30/01	589199.5206	4091137.026	0.00	99.93	0.07	2.90	2.19	fine sand	6.6
d3b 38	3/30/01	589307.167	4091060.494	0.00	100.00	0.00	2.3	2	medium sand	n/a

Post Experiment onshore sediment and water samples

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	%SILT&CLAY	MODE(S)	MEAN	DESCRIPTION	NTU
pt1b 21	4/1/01	586841.9769	4090957.233	0.00	100.00	0.00	2.00	1.66	medium sand	2, 2.1
pt1b 22	4/1/01	587240.3094	4091183.218	0.00	100.00	0.00	2.90	2.09	fine sand	n/a
pt1b 23	4/1/01	587684.6224	4091265.464	0.00	100.00	0.00	2.00	1.85	medium sand	1
pt1b up riv	4/1/01	587860.0239	4091522.462	0.00	100.00	0.00	2.90	2.19	fine sand	0.73
pt1b 24	4/1/01	588041.0575	4091235.872	0.00	100.00	0.00	2.10	1.79	medium sand	1
pt1b 25	4/1/01	588397.611	4091195.201	20.58	79.42	0.00	0, 1.9	0.27	coarse sand	n/a
pt1b 26	4/1/01	588710.4687	4091076.423	0.57	99.43	0.00	1.80	1.03	medium sand	1.9
pt1b 27	4/1/01	588959.8539	4091067.94	0.00	100.00	0.00	2.20	1.91	medium sand	1.5
pt1b 28	4/1/01	589138.1364	4091047.621	0.00	100.00	0.00	2.00	1.51	medium sand	n/a
pt1b 29	4/1/01	589290.1795	4090982.651	0.00	100.00	0.00	2.10	1.64	medium sand	1.6
pt1b 30	4/1/01	589406.3806	4090939.495	0.00	100.00	0.00	2.10	1.62	medium sand	n/a
pt1b 31	4/1/01	589514.0315	4090862.966	0.00	100.00	0.00	2.00	1.67	medium sand	n/a
pt1b 32	4/1/01	589603.5271	4090819.531	0.00	100.00	0.00	2.10	1.67	medium sand	1.4
pt1b 33	4/1/01	590315.983	4090804.896	0.00	100.00	0.00	2.00	1.54	medium sand	1.1
pt1b 34	4/1/01	590584.8432	4090641.338	11.69	88.31	0.00	-1, 2.1	0.82	coarse sand	n/a
pt1b 35	4/1/01	590943.1018	4090445.461	17.14	82.86	0.00	-1, 2	0.54	coarse sand	1.1
pt1b 36	4/1/01	589003.7842	4091123.875	0.00	100.00	0.00	2.20	1.94	medium sand	n/a
pt1b 37	4/1/01	589199.5206	4091137.026	0.00	100.00	0.00	2.90	2.24	fine sand	3.1
pt1b 38	4/1/01	589307.167	4091060.494	0.00	100.00	0.00	2.20	2.00	medium sand	n/a
pt1b 39	4/1/01	589602.7069	4090897.187	0.00	100.00	0.00	2.90	2.14	fine sand	n/a
pt2b 21	4/8/01	586841.9769	4090957.233	0.52	99.48	0.00	2.10	1.67	medium sand	1.7
pt2b 22	4/8/01	587240.3094	4091183.218	0.05	99.95	0.00	2.10	1.79	medium sand	n/a
pt2b 23	4/8/01	587684.6224	4091265.464	0.00	100.00	0.00	2.00	1.78	medium sand	0.65
pt2b up riv	4/8/01	587860.0239	4091522.462	0.06	99.94	0.00	2.00	1.23	medium sand	0.65
pt2b 24	4/8/01	588041.0575	4091235.872	0.00	100.00	0.00	2.00	1.82	medium sand	1.3
pt2b 25	4/8/01	588397.611	4091195.201	0.74	99.26	0.00	1.70	1.04	medium sand	n/a
pt2b 26	4/8/01	588710.4687	4091076.423	0.29	99.71	0.00	1.10	0.91	coarse sand	0.98
pt2b 27	4/8/01	588959.8539	4091067.94	0.00	100.00	0.00	2.60	1.97	medium sand	1.2
pt2b 28	4/8/01	589138.1364	4091047.621	0.00	100.00	0.00	2.10	1.97	medium sand	n/a
pt2b 29	4/8/01	589290.1795	4090982.651	0.00	100.00	0.00	2.00	1.57	medium sand	0.49
pt2b 30	4/8/01	589406.3806	4090939.495	0.00	100.00	0.00	2.00	1.52	medium sand	n/a
pt2b 31	4/8/01	589514.0315	4090862.966	0.00	100.00	0.00	2.00	1.57	medium sand	n/a
pt2b 32	4/8/01	589603.5271	4090819.531	0.00	100.00	0.00	2.00	1.52	medium sand	0.86
pt2b 33	4/8/01	590315.983	4090804.896	0.00	100.00	0.00	2.00	1.60	medium sand	3.2
pt2b 34	4/8/01	590584.8432	4090641.338	0.06	99.94	0.00	2.00	1.47	medium sand	n/a
pt2b 35	4/8/01	590943.1018	4090445.461	0.00	100.00	0.00	2.00	1.58	medium sand	0.95
pt2b 36	4/8/01	589003.7842	4091123.875	0.03	99.88	0.09	2.80	1.93	medium sand	n/a
pt2b 37	4/8/01	589199.5206	4091137.026	0.00	99.98	0.02	3.00	2.31	fine sand	4.1
pt2b 38	4/8/01	589307.167	4091060.494	0.00	99.99	0.01	2.20	1.96	medium sand	n/a
pt2b 39	4/8/01	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.10	fine sand	n/a
pt3b 21	104	586841.9769	4090957.233	0.05	99.95	0.00	2.90	2.02	fine sand	1.9
pt3b 22	104	587240.3094	4091183.218	0.00	100.00	0.00	2.90	2.13	fine sand	n/a
pt3b 23	104	587684.6224	4091265.464	0.58	99.42	0.00	2.10	1.86	medium sand	1.5
pt3b up riv	104	587860.0239	4091522.462	0.00	99.97	0.03	3.00	2.40	fine sand	0.8
pt3b 24	104	588041.0575	4091235.872	0.00	100.00	0.00	2.40	1.84	medium sand	1.5
pt3b 25	104	588397.611	4091195.201	0.20	99.80	0.00	2.60	1.48	medium sand	n/a
pt3b 26	104	588710.4687	4091076.423	2.39	97.61	0.00	2.00	1.26	medium sand	1.9
pt3b 27	104	588959.8539	4091067.94	0.00	100.00	0.00	2.90	2.10	fine sand	0.9
pt3b 28	104	589138.1364	4091047.621	0.00	100.00	0.00	2.80	2.05	fine sand	n/a
pt3b 29	104	589290.1795	4090982.651	0.00	100.00	0.00	2.40	1.87	medium sand	1.6
pt3b 30	104	589406.3806	4090939.495	0.00	100.00	0.00	2.50	1.89	medium sand	n/a
pt3b 31	104	589514.0315	4090862.966	0.00	100.00	0.00	2.40	1.85	medium sand	n/a
pt3b 32	104	589603.5271	4090819.531	0.00	100.00	0.00	2.00	1.65	medium sand	1.1
pt3b 33	104	590315.983	4090804.896	0.00	100.00	0.00	2.10	1.71	medium sand	1.6
pt3b 34	104	590584.8432	4090641.338	0.00	100.00	0.00	2.00	1.70	medium sand	n/a
pt3b 35	104	590943.1018	4090445.461	0.54	99.46	0.00	2.00	1.67	medium sand	n/a
pt3b 36	104	589003.7842	4091123.875	0.00	99.95	0.05	2.10	1.91	medium sand	0.7
pt3b 37	104	589199.5206	4091137.026	0.00	99.97	0.03	3.00	2.31	fine sand	n/a
pt3b 38	104	589307.167	4091060.494	0.00	100.00	0.00	2.10	1.97	medium sand	n/a
pt3b 39	104	589602.7069	4090897.187	0.00	100.00	0.00	3.00	2.32	fine sand	n/a

Appendix D.

Offshore sediment and water sample database tables

Pre Experiment offshore sediment and water sample database

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	%MUD	MODE(S)	MEAN	DESCRIPTION	NTU TOP	NTU 2.5
pr1off 1	2/28/01	588311.82179	4090883.64918	0.0	95.55	4.45	3.90	3.25	very fine sand	2.00	0.53
pr1off 2	2/28/01	588410.44324	4089963.79870	11.37	88.59	0.05	1.10	0.33	coarse sand	1.00	0.31
pr1off 3	2/28/01	587871.51554	4090413.09092	0.10	86.46	13.44	3	3.16	very fine sand	0.81	0.50
pr1off 4	2/28/01	587156.64352	4090660.89873	0.00	99.79	0.21	3	2.53	fine sand	n/a	n/a
pr1off 5	2/28/01	587252.97361	4089951.81743	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr1off 6	2/28/01	586637.08272	4089224.34242	0.16	96.95	2.89	3.9	3.07	very fine sand	0.50	0.50
pr1off 7	2/28/01	587794.65005	4089236.23788	0.58	91.26	8.16	3	2.68	fine sand	n/a	n/a
pr1off 8	2/28/01	589041.26245	4089249.22497	0.39	98.71	0.91	2	1.53	medium sand	0.20	0.47
pr1off 9	2/28/01	590287.87633	4089262.39523	n/a	n/a	n/a	n/a	n/a	no return	n/a	n/a
pr1off 10	2/28/01	591534.49173	4089275.74864	n/a	n/a	n/a	n/a	n/a	no return	0.50	0.32
pr1off 11	2/28/01	591526.71402	4089996.84099	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr1off 12	2/28/01	590725.38635	4089988.23506	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr1off 13	2/28/01	590186.33332	4090437.38250	0.05	99.51	0.44	2.30	2.12	fine sand	n/a	n/a
pr1off 14	2/28/01	589741.17566	4090432.66197	0.14	98.49	1.38	2.1, 3.9	2.52	fine sand	0.59	0.45
pr1off 15	2/28/01	589656.95043	4089976.87824	0.05	94.72	5.23	3.80	3.00	very fine sand	0.42	0.60
pr1off 16	2/28/01	589211.76912	4089972.18595	0.02	95.10	4.88	2.2, 3.8	2.43	fine sand	n/a	n/a
pr1off 17	2/28/01	588939.89234	4090424.22391	n/a	n/a	n/a	n/a	n/a	rocky	0.51	0.42
pr1off 18	2/28/01	589296.01818	4090427.96482	0.00	85.58	14.42	4.00	3.58	very fine sand	n/a	n/a
pr1off 19	2/28/01	589561.47300	4090586.09241	0.00	98.73	1.27	3.80	2.94	very fine sand	n/a	n/a
pr1off 20	2/28/01	589292.51507	4090760.77643	n/a	n/a	n/a	n/a	n/a	rocky	0.94	0.53
pr1off 21	2/28/01	588936.40320	4090757.03541	7.33	91.94	0.73	1.6, 3.5	1.29	medium sand	1.50	n/a
pr2off 1	3/3/01	588320.6968	4090894.947	0.05	84.70	15.26	4.10	3.53	very fine sand	1.1	0.23
pr2off 2	3/3/01	588374.921	4089971.672	0.00	82.93	17.07	4.00	3.24	very fine sand	n/a	n/a
pr2off 3	3/3/01	587871.5155	4090413.091	2.48	91.40	6.12	3.90	2.66	fine sand	0.41	0.21
pr2off 4	3/3/01	587127.1109	4090649.5	0.00	99.75	0.25	3.00	2.51	fine sand	n/a	n/a
pr2off 5	3/3/01	587372.9152	4089831.008	n/a	n/a	n/a	n/a	n/a	shell hash	n/a	n/a
pr2off 6	3/3/01	586752.8394	4089225.525	22.46	77.54	0.00	0.00	-0.07	shell hash/pebbles	0.2	0.3
pr2off 7	3/3/01	587619.349	4088964.488	31.80	67.28	0.91	-1, 2	-0.13	pebbly	n/a	n/a
pr2off 8	3/3/01	588952.1935	4089250.695	3.21	96.74	0.05	1.60	0.83	coarse sand	0.2	0.17
pr2off 9	3/3/01	590275.4221	4089261.142	13.37	74.36	12.27	-1, 2, 4	2.46	very fine sand	n/a	n/a
pr2off 10	3/3/01	591501.9939	4089275.101	n/a	n/a	n/a	n/a	n/a	rocky	0.3	0.22
pr2off 11	3/3/01	591572.9482	4089838.315	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr2off 12	3/3/01	590716.4856	4089987.874	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr2off 13	3/3/01	590195.2129	4090439.696	0.17	99.50	0.33	3.00	2.40	fine sand	n/a	n/a
pr2off 14	3/3/01	589750.1444	4090434.976	0.00	95.52	4.48	3.90	3.04	very fine sand	0.59	0.48
pr2off 15	3/3/01	589608.8556	4089977.813	0.04	99.60	0.36	2.00	1.67	medium sand	0.32	0.2
pr2off 16	3/3/01	589223.784	4089972.789	0.00	81.35	18.65	2, 4	3.01	very fine sand	n/a	n/a
pr2off 17	3/3/01	588954.6059	4090439.134	0.00	91.50	8.50	4.00	3.29	very fine sand	0.61	0.32
pr2off 18	3/3/01	589305.0935	4090432.853	0.00	89.89	10.11	3.90	3.25	very fine sand	n/a	n/a
pr2off 19	3/3/01	589543.6553	4090587.014	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr2off 20	3/3/01	589283.6356	4090758.464	0.05	88.20	11.75	3.90	3.28	very fine sand	0.54	0.23
pr2off 21	3/3/01	588927.4981	4090757.164	0.28	92.04	7.68	4.00	3.18	very fine sand	0.74	0.21
pr3off 1	3/7/01	588311.8218	4090883.649	0.00	87.51	12.49	4.00	3.47	very fine sand	0.35	0.21
pr3off 2	3/7/01	588410.4086	4089967.127	0.08	96.92	2.99	2.70	2.51	fine sand	n/a	n/a
pr3off 3	3/7/01	587916.2611	4090391.365	0.15	82.10	17.76	3.90	3.15	very fine sand	0.39	0.16
pr3off 4	3/7/01	587156.4612	4090678.649	1.28	98.24	0.48	3.00	2.51	fine sand	n/a	n/a
pr3off 5	3/7/01	587193.2396	4089958.97	0.13	99.70	0.17	2.90	2.16	fine sand	n/a	n/a
pr3off 6	3/7/01	586666.4722	4089224.143	14.81	85.07	0.12	0.20	-0.11	very coarse sand	0.48	0.2
pr3off 7	3/7/01	587735.1624	4089244.865	0.05	92.47	7.48	3.50	2.91	fine sand	n/a	n/a
pr3off 8	3/7/01	589050.0543	4089260.046	3.24	96.62	0.14	1.80	1.01	medium sand	0.15	0.25
pr3off 9	3/7/01	590289.3858	4089287.93	0.00	94.06	5.94	2.1, 3.9	2.83	fine sand	n/a	n/a
pr3off 10	3/7/01	591537.3484	4089285.843	n/a	n/a	n/a	n/a	n/a	rocky	0.48	0.13
pr3off 11	3/7/01	591556.3671	4089996.795	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pr3off 12	3/7/01	590814.7433	4089959.234	0.00	99.62	0.38	2.40	2.34	fine sand	n/a	n/a
pr3off 13	3/7/01	590185.9795	4090470.664	0.23	98.64	1.12	3.80	2.70	fine sand	n/a	n/a
pr3off 14	3/7/01	589844.723	4090467.043	0.08	74.27	25.65	4.00	3.73	very fine sand	0.1	0.21
pr3off 15	3/7/01	589659.0477	4089946.944	0.25	99.45	0.30	2.00	1.54	medium sand	0.25	0.11
pr3off 16	3/7/01	589181.6537	4090016.249	0.02	98.02	1.96	2.30	2.19	fine sand	n/a	n/a
pr3off 17	3/7/01	588948.8339	4090420.656	0.00	84.39	15.61	4.00	2.76	fine sand	1.4	0.1
pr3off 18	3/7/01	589355.4407	4090424.929	0.11	87.28	12.61	4.00	3.44	very fine sand	n/a	n/a
pr3off 19	3/7/01	589564.261	4090575.027	0.17	97.12	2.72	3.90	3.09	very fine sand	n/a	n/a
pr3off 20	3/7/01	589277.713	4090756.926	0.00	90.90	9.10	4.00	3.33	very fine sand	0.13	0.5

Pre Experiment offshore sediment and water sample database (continued)

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	%MUD	MODE(S)	MEAN	DESCRIPTION	NTU TOP	NTU 2.5

pr3off 21	3/7/01	588921.4076	4090771.634	0.20	95.94	3.85	3.00	2.68	fine sand	0.09	0.27
pr4off 1	3/27/01	588296.86559	4090894.58840	0.00	93.36	6.64	2.1, 3.7	2.12	fine sand	0.90	0.72
pr4off 2	3/27/01	588401.46254	4089971.10544	0.22	92.18	7.60	3.20	2.71	fine sand	0.41	0.30
pr4off 14	3/27/01	589712.32262	4090354.69208	0.06	97.50	2.45	3.90	3.06	very fine sand	0.66	0.45
pr4off 15	3/27/01	589585.64328	4089983.52541	0.71	99.23	0.06	2.10	2.09	fine sand	0.46	0.46
pr4off 16	3/27/01	589216.18209	4089975.92696	0.00	81.71	18.29	4.00	3.62	very fine sand	0.52	0.48
pr4off 17	3/27/01	588898.22512	4090434.88213	0.00	76.85	23.15	4.10	3.71	very fine sand	0.53	0.34
pr4off 18	3/27/01	589290.06028	4090429.75496	0.29	95.60	4.11	3.90	3.16	very fine sand	0.47	0.41
pr4off 19	3/27/01	589555.22237	4090615.61668	n/a	n/a	n/a	n/a	n/a	rocky	0.67	0.47
pr4off 20	3/27/01	589270.29695	4090756.84797	0.00	88.98	11.02	4.00	3.48	very fine sand	0.59	0.34
pr4off 21	3/27/01	588912.75631	4090747.54544	0.39	97.98	1.63	3.10	2.55	fine sand	0.83	0.35

Experiment offshore sediment and water sample database

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	% MUD	MODE(S)	MEAN	DESCRIPTION	NTU TOP	NTU 2.5
d1off 1	3/28/01	588384.4049	4090896.388	0.00	97.17	2.83	4.00	3.37	very fine sand	0.83	0.76
d1off 2	3/28/01	588440.0923	4089964.108	0.00	85.06	14.94	4.00	3.24	very fine sand	0.52	0.53
d1off 14	3/28/01	589770.8232	4090432.976	0.12	99.09	0.80	2.10	1.97	medium sand	0.61	0.87
d1off 15	3/28/01	589568.0313	4089964.844	0.04	93.84	6.12	2, 4	2.23	fine sand	0.66	0.79
d1off 16	3/28/01	589205.8037	4089972.123	0.00	75.07	24.93	4.10	3.76	very fine sand	0.46	0.44
d1off 17	3/28/01	588939.9156	4090422.005	0.37	86.61	13.02	4.00	3.48	very fine sand	0.5	0.56
d1off 18	3/28/01	589290.0531	4090427.902	0.00	93.96	6.04	3.90	3.08	very fine sand	0.52	0.69
d1off 19	3/28/01	589578.9471	4090617.709	n/a	n/a	n/a	n/a	n/a	rocky	0.54	0.72
d1off 20	3/28/01	589290.678	4090794.042	0.13	99.09	0.78	3.00	2.31	fine sand	0.46	0.81
d1off 21	3/28/01	588946.2921	4090832.918	0.11	96.53	3.36	3.10	2.85	fine sand	0.98	0.79
d2off 1	3/29/01	588298.2753	4090902.003	0.81	97.47	1.72	3.70	2.87	fine sand	0.76	0.55
d2off 2	3/29/01	588334.4934	4089988.859	0.03	87.28	12.68	3.90	3.21	very fine sand	1.2	0.26
d2off 14	3/29/01	589738.2109	4090432.631	0.00	90.63	9.37	4.00	3.23	very fine sand	0.56	0.49
d2off 15	3/29/01	589596.1119	4089976.236	0.03	97.94	2.03	2.1, 4.0	2.20	fine sand	0.91	0.3
d2off 16	3/29/01	589211.6525	4089983.28	0.00	80.51	19.49	2.0, 4.0	3.09	very fine sand	0.71	0.19
d2off 17	3/29/01	588938.8126	4090385.38	0.05	88.49	11.46	4.00	3.38	very fine sand	1.1	0.25
d2off 18	3/29/01	589306.5016	4090419.199	0.90	90.90	8.20	2.0, 4.0	2.89	fine sand	0.55	0.46
d2off 19	3/29/01	589577.7922	4090586.265	0.00	97.40	2.60	3.80	3.03	very fine sand	0.64	0.56
d2off 20	3/29/01	589280.811	4090747.672	0.00	85.59	14.41	4	3.53	very fine sand	0.81	0.74
d2off 21	3/29/01	588940.893	4090753.421	0.00	97.66	2.34	3.10	2.74	fine sand	0.94	0.98
d3off 1	3/30/01	588325.54194	4090848.62114	0.44	93.57	6.00	4.00	3.00	fine sand	1.70	0.61
d3off 2	3/30/01	588428.25857	4089963.20771	0.10	96.88	3.02	2.10	2.19	fine sand	0.38	0.25
d3off 14	3/30/01	589741.35168	4090416.02139	0.13	94.13	5.74	2, 4	2.97	fine sand	1.00	0.64
d3off 15	3/30/01	589641.97131	4089989.66779	0.00	91.60	8.40	2, 4	3.22	very fine sand	0.35	0.34
d3off 16	3/30/01	589220.59459	4089979.71235	0.00	99.40	0.60	2.50	2.05	fine sand	0.26	0.23
d3off 17	3/30/01	588940.18963	4090423.89418	2.69	84.01	13.30	4.00	3.26	very fine sand	0.85	0.36
d3offf 18	3/30/01	589290.05643	4090430.12106	0.13	88.38	11.49	4.00	3.21	very fine sand	0.74	0.35
d3off 19	3/30/01	589517.46494	4090537.58676	n/a	n/a	n/a	n/a	n/a	no return	0.74	0.30
d3off 20	3/30/01	589277.71299	4090756.92602	0.00	90.28	9.72	4.00	3.30	very fine sand	0.91	0.26
d3off 21	3/30/01	588929.21977	4090734.77023	0.66	93.82	5.52	3.70	2.93	fine sand	0.89	0.31

Post Experiment offshore sediment and water sample database

ID	DATE	EASTING	NORTHING	%>SAND	%SAND	% MUD	MODE(S)	MEAN	DESCRIPTION	NTU TOP	NTU 2.5
pt1off 1	4/2/01	588371.0753	4090896.471	0.00	88.69	11.31	3.90	3.39	very fine sand	n/a	n/a
pt1off 2	4/2/01	588347.8484	4089989.031	0.00	88.04	11.96	3.90	2.92	fine sand	0.45	0.28
pt1off 3	4/2/01	587864.0992	4090413.014	0.33	91.31	8.36	3.70	2.77	fine sand	n/a	n/a
pt1off 4	4/2/01	587154.9667	4090679.377	1.07	98.64	0.29	3.10	2.37	fine sand	n/a	n/a
pt1off 5	4/2/01	587218.8461	4089951.467	0.00	99.97	0.03	2.10	1.82	medium sand	n/a	n/a
pt1off 6	4/2/01	586628.235	4089218.705	21.32	78.36	0.32	0.90	-0.16	shell hash	0.51	0.41
pt1off 7	4/2/01	587742.7109	4089235.701	0.00	73.67	26.33	2.1, 4.1	3.54	silty sand	n/a	n/a
pt1off 8	4/2/01	589057.5842	4089249.396	0.08	97.29	2.63	2.10	2.13	fine sand	0.11	0.22
pt1off 9	4/2/01	590295.2937	4089262.474	0.00	93.95	6.05	3.90	3.35	very fine sand	n/a	n/a
pt1off 10	4/2/01	591516.6829	4089275.557	n/a	n/a	n/a	n/a	n/a	rocky	0.13	0.16
pt1off 11	4/2/01	591498.4767	4090000.198	0.02	99.81	0.17	2.50	2.09	fine sand	n/a	n/a
pt1off 12	4/2/01	590720.9345	4089988.187	0.00	98.04	1.96	3.90	3.09	very fine sand	n/a	n/a
pt1off 13	4/2/01	590184.8534	4090492.842	0.36	96.25	3.39	2.1, 3.9	2.77	fine sand	n/a	n/a
pt1off 14	4/2/01	589720.5632	4090419.973	0.10	91.79	8.11	2.1, 4.0	3.15	very fine sand	0.41	0.33
pt1off 15	4/2/01	589661.3436	4089982.472	6.50	93.26	0.24	1.9, 3.8	0.89	coarse sand	0.49	0.26
pt1off 16	4/2/01	589211.7691	4089972.186	0.17	87.49	12.34	2.0, 4.1	2.46	fine sand	n/a	n/a
pt1off 17	4/2/01	588913.1829	4090423.944	0.07	85.25	14.69	4.10	3.47	very fine sand	0.31	0.29
pt1off 18	4/2/01	589293.0558	4090427.712	0.00	87.34	12.66	4.00	3.57	very fine sand	n/a	n/a
pt1off 19	4/2/01	589567.4113	4090586.155	2.62	96.72	0.66	2.30	2.00	medium sand	n/a	n/a
pt1off 20	4/2/01	589285.1773	4090753.266	0.04	89.01	10.94	3.90	3.32	very fine sand	0.98	0.43
pt1off 21	4/2/01	588936.3838	4090758.888	1.44	94.85	3.71	3.60	2.61	fine sand	0.21	0.65
pt2off 1	4/5/01	588311.8992	4090876.216	0.09	91.41	8.50	4.00	3.44	very fine sand	0.35	0.31
pt2off 2	4/5/01	588344.9605	4089981.612	0.07	95.50	4.43	2, 3.9	1.98	medium sand	n/a	n/a
pt2off 3	4/5/01	587832.9535	4090411.216	0.11	90.40	9.49	3.20	2.81	fine sand	0.2	0.21
pt2off 4	4/5/01	587186.5751	4090633.469	0.00	99.14	0.86	3.00	2.49	fine sand	0.41	0.31
pt2off 5	4/5/01	587174.3474	4089949.123	0.13	99.54	0.33	3.00	2.28	fine sand	n/a	n/a
pt2off 6	4/5/01	586622.6547	4089183.477	0.11	98.88	1.01	2, 3.9	2.02	shell hash/sand	n/a	n/a
pt2off 7	4/5/01	587780.2463	4089193.562	3.81	95.80	0.39	1.80	0.90	coarse sand	0.15	0.35
pt2off 8	4/5/01	588981.7927	4089256.002	1.04	97.68	1.27	2.00	1.52	medium sand	0.25	0.21
pt2off 9	4/5/01	590264.2817	4089247.721	0.19	94.66	5.15	2, 4	2.25	fine sand	n/a	n/a
pt2off 10	4/5/01	591513.3589	4089308.806	n/a	n/a	n/a	n/a	n/a	no return	0.27	0.14
pt2off 11	4/5/01	591529.6511	4089999.458	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pt2off 12	4/5/01	590713.6781	4090000.603	0.00	99.28	0.72	3.50	2.54	fine sand	n/a	n/a
pt2off 13	4/5/01	590177.1157	4090466.875	0.30	97.59	2.11	3.80	2.89	fine sand	n/a	n/a
pt2off 14	4/5/01	589752.9282	4090443.693	0.31	91.19	8.50	2, 4	2.92	fine sand	0.36	0.19
pt2off 15	4/5/01	589609.1426	4090009.658	0.31	91.18	8.51	2, 4	2.50	fine sand	0.21	0.39
pt2off 16	4/5/01	589159.776	4089977.187	0.03	77.43	22.54	2, 4	3.45	very fine sand	n/a	n/a
pt2off 17	4/5/01	588929.2318	4090421.893	0.00	84.48	15.52	4.00	3.52	very fine sand	0.61	0.17
pt2off 18	4/5/01	589318.206	4090434.855	0.02	97.90	2.08	3.90	2.98	very fine sand	n/a	n/a
pt2of 19	4/5/01	589562.2862	4090621.239	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pt2off 20	4/5/01	589263.1804	4090730.844	0.16	90.49	9.35	4.00	3.32	very fine sand	0.39	0.35
pt2off 21	4/5/01	588924.2256	4090786.498	0.22	90.07	9.71	4.00	3.22	very fine sand	0.39	0.24
pt3off 1	4/12/01	588311.5139	4090913.225	0.00	96.68	3.32	4.00	3.34	very fine sand	0.98	0.44
pt3off 2	4/12/01	588425.2348	4089971.386	0.00	80.74	19.25	4.00	3.29	very fine sand	n/a	n/a
pt3off 3	4/12/01	587828.1613	4090444.074	0.06	86.61	13.33	3.10	3.42	very fine sand	0.46	0.27
pt3off 4	4/12/01	587156.6435	4090660.899	0.00	99.02	0.98	3.00	2.60	fine sand	n/a	n/a
pt3off 5	4/12/01	587240.0368	4089910.966	1.48	98.11	0.41	2.80	1.89	medium sand	n/a	n/a
pt3off 6	4/12/01	586629.4955	4089240.907	0.11	97.93	1.96	1.9, 3.9	1.76	medium sand	0.29	0.49
pt3off 7	4/12/01	587845.5015	4089201.627	0.00	85.08	14.92	2.1, 3.9	2.75	fine sand	n/a	n/a
pt3off 8	4/12/01	589043.0986	4089215.959	0.08	95.12	4.80	2, 3.9	2.24	medium sand	0.2	0.35
pt3off 8r	4/12/01	589043.0986	4089215.959	0.07	94.42	5.51	2, 4	2.34	fine sand	n/a	n/a
pt3off 9	4/12/01	590297.8492	4089262.501	0.00	96.33	3.67	2.1, 3.9	2.45	fine sand	n/a	n/a
pt3off 10	4/12/01	591547.9141	4089269.791	n/a	n/a	n/a	n/a	n/a	rocky	0.24	0.54
pt3off 11	4/12/01	591530.4169	4089928.458	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pt3off 12	4/12/01	590764.4013	4089947.934	0.00	94.09	5.91	4.00	3.36	very fine sand	n/a	n/a
pt3off 13	4/12/01	590211.576	4090435.765	0.00	97.34	2.66	4.00	3.18	very fine sand	n/a	n/a
pt3off 14	4/12/01	589728.6921	4090462.12	0.23	95.06	4.72	2, 4	2.75	fine sand	0.31	0.21
pt3off 15	4/12/01	589672.439	4089971.494	0.16	99.46	0.37	2.00	1.61	medium sand	1.9	0.22
pt3off 16	4/12/01	589192.3389	4089984.929	0.00	74.51	25.49	4.00	3.77	silty sand	n/a	n/a
pt3off 17	4/12/01	588939.8295	4090430.215	0.00	84.77	15.23	4.00	3.44	very fine sand	1.7	0.14
pt3off 18	4/12/01	589290.5857	4090379.833	0.00	86.73	13.27	4.00	3.55	very fine sand	n/a	n/a
pt3off 19	4/12/01	589540.9561	4090561.833	n/a	n/a	n/a	n/a	n/a	rocky	n/a	n/a
pt3off 20	4/12/01	589240.7406	4090745.442	0.00	88.84	11.16	4.00	3.46	very fine sand	0.26	0.29
pt3off 21	4/12/01	588924.6404	4090749.478	2.10	93.23	4.67	3.90	2.83	very fine sand	1.1	0.21

Appendix E.

Deep-Water Marine Benthic Habitat Classification Scheme

Explanation for Habitat Classification Code

(modified after Greene et al.., 1999)

Habitat Classification Code

A habitat classification code, based on the deep-water habitat characterization scheme developed by Greene et al.. (1999), was created to easily distinguish marine benthic habitats and to facilitate ease of use and queries within GIS (e.g., ArcView®, TNT Mips®, and ArcGIS®) and database (e.g., Microsoft Access® or Excel®) periods. The code is derived from several categories and can be subdivided based on the spatial scale of the data. The following categories apply directly to habitat interpretations determined from remote sensing imagery collected at the scale of 10s of kilometers to 1 meter: Megahabitat, Seafloor Induration, Meso/Macrohabitat, Modifier, Seafloor Slope, Seafloor Complexity, and Geologic Unit. Additional categories of Macro/Microhabitat, Seafloor Slope, and Seafloor Complexity apply to areas at the scale of 10 meters to centimeters and are determined from video, still photos, or direct observations. These two components can be used in conjunction to define a habitat across spatial scales or separately for comparisons between large and small-scale habitat types. Categories are explained in detail below. Not all categories may be required or possible given the study objectives, data availability, or data quality and in these cases categories may be omitted.

Explanation of Attribute Categories and their Use

Determined from Remote Sensing Imagery (for creation of large-scale habitat maps)

1) Megahabitat – This category is based on depth and general physiographic boundaries and is used to distinguish regions and features on a scale of 10s of kilometers to kilometers. Depth ranges listed for category attributes in the key are given as generalized examples. This category is listed first in the code and denoted with a capital letter.

2) Seafloor Induration – Seafloor induration refers to substrate hardness and is depicted by the second letter (a lower-case letter) in the code. Designations of hard, mixed, and soft substrate can be further subdivided into distinct sediment types, and are then listed immediately afterwards in parentheses either in alphabetical order or in order of relative abundance.

3) Meso/Macrohabitat – This distinction is related to the scale of the habitat and consists of seafloor features ranging from 1 kilometer to 1 meter. Meso/Macrohabitats are noted as the third letter (a lower-case letter) in the code. If necessary, several Meso/Macrohabitats can be included either alphabetically or in order of relative abundance and separated by a backslash.

4) Modifier – The fourth letter in the code, a modifier, is noted with a lower-case subscript letter or separated by an underline in some GIS periods (e.g., ArcView®). Modifiers describe

the texture or lithology of the seafloor. If necessary, several modifiers can be included alphabetically or in order of relative abundance and separated by a backslash.

5) Seafloor Slope – The fifth category, listed by a number following the modifier subscript, denotes slope. Slope is calculated for a survey area from x-y-z multibeam data and category values can be modified based on characteristics of the study region.

6) Seafloor Complexity – Complexity is denoted by the sixth letter and listed in caps. Complexity is calculated from slope data using neighborhood statistics and reported in standard deviation units. As with slope, category values can be modified based on characteristics of the study region.

7) Geologic Unit – When possible, the geologic unit is determined and listed subsequent to the habitat classification code, in parentheses.

Determined from video, still photos, or direct observation (for designation of small-scale habitat types)

8) Macro/Microhabitat –Macro/Microhabitats are noted by the eighth letter in the code (or first letter, if used separately) and preceded by an asterisk. This category is subdivided between geologic (surrounded by parentheses) and biologic (surrounded by brackets) attributes. Dynamic segmentation can be used to plot macroscale habitat patches on Mega/Mesoscale habitat interpretations (Nasby 2000).

9) Seafloor Slope – The ninth category (or second category, if used separately), listed by a number denotes slope. Unlike the previous slope designation (#5), the clarity of this estimate can be made at smaller scales and groundtruthed or compared with category #5. Category values can be modified based on characteristics of the study region.

10) Seafloor Complexity – The designations in this category, unlike those in category #6, are based on seafloor rugosity values calculated as the ratio of surface area to linear area along a measured transect or patch. Category letters are listed in caps and category values can be modified based on characteristics of the study region.

Literature Cited:

Greene, H.G., M.M. Yoklavich, R.M. Starr, V.M. O'Connell, W.W. Wakefield, D.E. Sullivan, J.E. McRea Jr., and G.M. Cailliet, 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta. Vol 22: 6. pp. 663-678.

Nasby, N.M. 2000. Integration of submersible transect data and high-resolution sonar imagery for a habitat-based groundfish assessment of Heceta Bank, Oregon. M.S. Thesis, **College of Oceanic and Atmospheric Science, Oregon State University.**

Deep-Water Marine Benthic Habitat Classification Scheme

Key to Habitat Classification Code for Mapping and use with GIS periods

(modified after Greene et al.., 1999)

Interpreted from remote sensing imagery for mapping purposes

Megahabitat – Use capital letters (based on depth and general physiographic boundaries; depth ranges approximate and specific to study area).

A = Aprons, continental rise, deep fans and bajadas (3000-5000 m)
B = Basin floors, Borderland types (floors at 1000-2500 m)
F = Flanks, continental slope, basin/island-atoll flanks (200-3000 m)
I = Inland seas, fiords (0-200 m)
P = Plains, abyssal (>5000 m)
R = Ridges, banks and seamounts (crests at 200-2500 m)
S = Shelf, continental and island shelves (0-200 m)

Seafloor Induration - Use lower-case letters (based on substrate hardness).

h = hard substrate, rock outcrop, relic beach rock or sediment pavement
m = mixed (hard & soft substrate)
s = soft substrate, sediment covered

Sediment types (for above indurations) - Use parentheses.
(b) = boulder
(c) = cobble
(g) = gravel
(h) = halimeda sediment, carbonate
(m) = mud, silt, clay
(p) = pebble
(s) = sand

Meso/Macrohabitat - Use lower-case letters (scale related).

a = atoll
b = beach, relic
c = canyon
d = deformed, tilted and folded bedrock
e = exposure, bedrock
f = flats
g = gully, channel
i = ice-formed feature or deposit, moraine, drop-stone depression
k = karst, solution pit, sink
l = landslide
m = mound, depression
n = enclosed waters, lagoon
o = overbank deposit (levee)
p = pinnacle
r = rill

s = scarp, cliff, fault or slump
t = terrace
w = sediment waves
y = delta, fan
$z_{\#}$ = zooxanthellae hosting structure, carbonate reef
  1 = barrier reef
  2 = fringing reef
  3 = head, bommie
  4 = patch reef

Modifier - Use lower-case subscript letters or underscore for GIS periods (textural and lithologic relationship).

$_{a}$ = anthropogenic (artificial reef/breakwall/shipwreck)
$_{b}$ = bimodal (conglomeratic, mixed [includes gravel, cobbles and pebbles])
$_{c}$ = consolidated sediment (includes claystone, mudstone, siltstone, sandstone, breccia, or conglomerate)
$_{d}$ = differentially eroded
$_{f}$ = fracture, joints-faulted
$_{g}$ = granite
$_{h}$ = hummocky, irregular relief
$_{i}$ = interface, lithologic contact
$_{k}$ = kelp
$_{l}$ = limestone or carbonate
$_{m}$ = massive
$_{o}$ = outwash
$_{p}$ = pavement
$_{r}$ = ripples
$_{s}$ = scour (current or ice, direction noted)
$_{u}$ = unconsolidated sediment
$_{v}$ = volcanic rock

Seafloor Slope - Use category numbers. Calculated for survey area from x-y-z multibeam data.

1	Flat (0-1º)
2	Sloping (1-30º)
3	Steeply Sloping (30-60º)
4	Vertical (60-90º)
5	Overhang (> 90º)

Seafloor Complexity - Use category letters (in caps). Calculated for survey area from x-y-z multibeam slope data using neighborhood statistics and reported in standard deviation units.

A	Very Low Complexity (-1 to 0)
B	Low Complexity (0 to 1)
C	Moderate Complexity (1 to 2)

D High Complexity (2 to 3)
E Very High Complexity (3+)

Geologic Unit – When possible, the associated geologic unit is identified for each habitat type and follows the habitat designation in parentheses.

Examples: Shp_{d}1D(Q/R) - Continental shelf megahabitat; flat, highly complex hard seafloor with pinnacles differentially eroded. Geologic unit = Quartenary/Recent.

Fhd_d2C (Tmm) - Continental slope megahabitat; sloping hard seafloor of deformed (tilted, faulted, folded), differentially eroded bedrock exposure forming overhangs and caves. Geologic unit = Tertiary Miocene Monterey Formation.

Determined from video, still photos, or direct observation.

Macro/Microhabitat – Preceeded by an asterik. Use parentheses for geologic attributes, brackets for biologic attributes. Based on observed small-scale seafloor features.

Geologic attributes (note percent grain sizes when possible)
(b) = boulder
(c) = cobble
(d) = deformed, faulted, or folded
(e) = exposure, bedrock (sedimentary, igneous, or metamorphic)
(f) = fans
(g) = gravel
(h) = halimeda sediment, carbonate slates or mounds
(i) = interface
(j) = joints, cracks, and crevices
(m) = mud, silt, or clay
(p) = pebble
(q) = coquina (shell hash)
(r) = rubble
(s) = sand
(t) = terrace-like seafloor including sedimentary pavements
(w) = wall, scarp, or cliff

Biologic attributes
[a] = algae
[b] = bryozoans
[c] = corals
[d] = detritus, drift algae
[g] = gorgonians

[n] = anemones
[o] = other sessile organisms
[s] = sponges
[t] = tracks, trails, or trace fossils
[u] = unusual organisms, or chemosynthetic communities
[w] = worm tubes

Seafloor Slope - Use category numbers. Estimated from video, still photos, or direct observation.

1	Flat (0-1º)
2	Sloping (1-30º)
3	Steeply Sloping (30-60º)
4	Vertical (60 - 90°)
5	Overhang (90°+)

Seafloor Complexity - Use category numbers. Estimated from video, still photos, or direct observation. Numbers represent seafloor rugosity values calculated as the ratio of surface area to linear area along a measured transect or patch.

A	Very Low Complexity (1 to 1.25)
B	Low Complexity (1.25 to 1.50)
C	Moderate Complexity (1.50 to 1.75)
D	High Complexity (1.75 to 2.00)
E	Very High Complexity (2+)

Examples: *(m)[w]1C - Flat or nearly flat mud (100%) bottom with worm tubes; moderate complexity.

*(s/c)1A - Sand bottom (>50%) with cobbles. Flat or nearly flat with very low complexity.

*(h)[c]1E - Coral reef on flat bottom with halimeda sediment. Very high complexity.

Shp$_d$1D(Q/R)*(m)[w]1C - *Large-scale habitat type:* Continental shelf megahabitat; flat, highly complex hard seafloor with pinnacles differentially eroded. Geologic unit = Quartenary/Recent. *Small-scale habitat type:* Flat or nearly flat mud (100%) bottom with worm tubes; moderate complexity.