Humboldt Bay, California: Surface Sediments 2000–2001

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Abstract

The surface sediments in Humboldt Bay are generally distributed with mean grain sizes decreasing with increasing elevation and distance landward from the ocean inlet. Comparison of grain-size data collected during this study with those of a similar survey conducted about 30 years ago (Thompson 1971) suggests that the main tidal channels in 2000–2001 have larger average grain sizes and contain less clay-sized material than in 1970. These changes in sediment size likely reflect an increased propagation of silt- and sand-sized particles away from the ocean inlet into the bay. The suggestion is that the sand-dominated marine sediments, characteristic of the channels in the lower reaches of the bay, have propagated both northward and southward in the main tidal channels and away from the inlet. The major process that drives the transport and sorting of sediments in most regions of the bay is tidal currents. Waves entering the inlet from offshore are also important near the bay entrance.

Introduction

This paper summarizes the results of a re-examination of the surface sediments of Humboldt Bay, California at the start of the twenty-first century. Humboldt Bay is a well-mixed estuarine system located on the North Coast of California (40° 45′ N, 124° 13′ W) approximately 360 km north of San Francisco (Figure 1). The bay morphology developed primarily in response to the active tectonism in the area. The bay is generally described consisting of three sub-basins: North Bay (a.k.a. Arcata Bay), Entrance Bay, and South Bay that are connected by a long, narrow thalweg. About 70% of the bay consists of intertidal flats that are exposed at lowest tides (Costa 1982); only the Entrance Bay section remains submerged at low tide. Due to a large tidal prism and extensive tidal mixing, a vertically homogenous water column develops during most of the year (Gast and Skeesick 1964). Tidal oscillations in Humboldt Bay are mixed.

The bay is of vital importance to the economy of the region and is the largest commercially important harbor between San Francisco to the south and Coos Bay, Oregon, to the north. To facilitate safe navigation of large commercial vessels, the bay has been subject to several modifications over the years, including the construction of jetties, maintenance dredging, and the deepening and widening of portions of the tidal channels through engineering practices conducted by the U.S. Army Corps of Engineers.

The surface sediment distribution in the bay was previously studied by Thompson (1971). He noted that the general pattern for sediments in Humboldt Bay was for grain size to decrease with increasing elevation and distance landward from the ocean inlet. Dredged channel sediments were found to contain greater percentages of gravels and muds than their undredged counterparts. The focus of this paper is to compare and contrast the sediment size distribution seen in 2000–2001 with the sediments sampled by Thompson (1971) 30 years earlier.

Sample Collection and Analysis

A total of 315 surface sediment samples were collected from Humboldt Bay during 2000 and 2001. Two hundred, twenty-three samples were collected during June and July 2001 using a Peterson grab sampler from aboard either a small skiff or pontoon boat. These samples were supplemented by 92 samples that had been collected from the deeper sections of the bay's main channels during the prior fall. The supplemented samples were collected using a Smith-McIntyre grab sampler aboard the R/V *Coral Sea* and M/V *Ironic* as a part of a survey identifying nonindigenous species in Humboldt Bay (Boyd et al. 2002).

The locations of all 315 samples are shown in Figure 2. Samples were collected on transects orthogonal to the primary tidal channels and were nominally spaced at 0.5 nautical mile intervals. Generally, each transect consisted of five samples. Samples were collected from the main tidal channel, the intertidal flats on both channel flanks, and the high tidal flats on either side. A hand-held acoustic depth sounder was used to locate the center and the flanks of the channel on each transect, at the time of collection. Salt marsh environments were not sampled during this study.

From each sediment sample collected, the upper 5 cm was analyzed in bulk for sediment grain size using standard sieve and pipette techniques (Ingram 1971; Galehouse 1971). The analytical techniques were chosen to match the techniques that were used by Thompson (1971) in a previous examination of the sediments in the bay, in order to allow a direct comparison of the sediment grain-size distributions. Samples were disaggregated and the organic

material was oxidized using 30% hydrogen peroxide. Particles of coarse silt size and larger were separated from the fine silts and clays by passing samples through a 5.25 (0.25 µm) wet sieve. The portion that did not pass through the wet sieve was dried and shaken for 30 minutes through nested sieves at intervals of 0.25 ϕ (Ingram 1971). The grain-size distribution of the portion that passed through the wet sieve was determined using a settling column and Stoke's Law (Galehouse 1971). Sodium hexametaphosphate was added to inhibit flocculation of the particles in the settling column. The fine silts were separated at intervals of 0.50 ϕ while the clays were separated at intervals of 1.00 ϕ. The graphical technique of Inman (1952) was used to determine sediment-size statistics.

Results

The mean grain-sizes of the surface sediments (upper 5 cm of sediment) in Humboldt Bay are shown in Figure 3. In general, the mean grain size decreased with increasing elevation and distance landward from the ocean inlet, as Thompson (1971) noted previously. The sample with the largest mean diameter was obtained from the bay inlet, between the two entrance jetties.

The trend of decreasing sediment size with distance from the inlet was not followed in areas where:

1) the main channel constricted and coarser-grained sediments were encountered, or
2) dredging had widened the channel and finer-grained sediments were sampled.

The break in trend can be easily seen in a graph of mean sediment size of channel sediments versus the distance to the bay inlet (Figure 4). Other statistical parameters such as median, dispersion and, to a lesser degree, kurtosis show similar trends with variations occurring in the up-channel direction and laterally from the center of the channel up onto the tidal flats.

Discussion

Primary Sediment Distribution

In estuaries similar to Humboldt Bay, the sediment distribution has been described as being controlled primarily by tidally driven circulation (Nichols 1979; Dyer 1994). During both the ebbing and flooding tides, current speeds in Humboldt Bay should be highest within the inlet and in the channel thalweg that connects the North Bay with the harbor entrance. Greater speeds should occur in the North Bay thalweg, as compared to the South Bay thalweg, due primarily to the larger tidal prism in the northern section of the bay. The highest speeds should occur in areas of channel constriction. These estimates are in good agreement with measurements of current velocities made in the field using various Lagrangian drifters in different parts of the bay (e.g., Gast and Skeesick 1964; Casebier and Toimil 1973).

The locations of highest expected current speeds provide a qualitative match to the locations of largest mean sediment diameter (Figure 3). In the shallow areas near the bay entrance, waves are also important. One result is that the surface sediments near the harbor entrance are better sorted than elsewhere in the bay.

The less vigorous circulation in South Bay, as compared to North Bay, provides an explanation for the differences in sediments encountered. At a similar distance from the inlet, South Bay sediments are finer grained than North Bay sediments (Figure 4). In addition, very coarse sand-sized and larger particles were encountered in a number of locations in North Bay, where almost none were found in South Bay.

Have Bay Sediments Changed? 1970 vs. 2000–2001

The influence of harbor modification and maintenance on sedimentary processes has been the subject of some prior research in Humboldt

Bay (Thompson 1971; Costa 1982; U.S. Army Corps of Engineers 1994). Thompson (1971) compared sediments from dredged and undredged portions of the tidal channels in Humboldt Bay and found that the dredged portions contained greater percentages of gravel and silt- and clay-sized particles than the undredged portions of the bay. The increased gravel content was thought to represent lag deposits that were exposed by dredging. The increased percentage of silt and clay was attributed to decreased current speeds where dredging had deepened the channel below its equilibrium level and had allowed for the deposition of fine-grained material. In a study of the Upper James Estuary in Virginia and the Thames River in England, Nichols (1979) suggested two main reasons for the increase in sedimentation that was observed following channel deepening: 1) decreased tidal currents caused by an increase in the channel's cross-sectional area, and 2) increased stratification leading to trapping of sediment in the lower layer by density-driven currents and an increased chance for deposition.

In 1994, numerical modeling was used to predict changes that might occur as a result of dredging on the sedimentary processes operating in Humboldt Bay (U.S. Army Corps of Engineers 1994). In essence, the model predicted that any deepening or widening of the bay channel would cause decreased current speeds in the increased cross-sectional areas and increased sedimentation rates in the channels in the vicinity of the inlet.

To examine any variations in sediment size that may have occurred since 1970, the sediments in this study were analyzed using the same techniques used by Thompson (1971). Thompson employed sediment textural triangle diagrams (Shepard 1954) to display his results; the data from this study have been similarly displayed. Figure 5 shows the sediment sizes of samples collected from the high tidal flats in 1970 and in 2000–2001; Figure 6 shows the sediment sizes of samples collected from the main tidal channels in 1970 and in 2000–2001.

Comparison of the sediments collected from the high tidal flats (Figure 5) suggests that the sediment size did not significantly change between 1970 and in 2000–2001. The textural triangle diagrams are suggestive that the sediments collected from the high tidal flats in 2000–2001 may have had less clay-sized fraction than the samples collected in 1970. However, this suggestion may be misleading due to some differences in sample collection for the two studies. Thompson (1971) extensively sampled the high tidal flats as well as the fringes of salt marsh environments, where he encountered the highest clay-sized fractions of his collected samples. In this study, the salt marsh environments were not sampled extensively and the silty clays sampled by Thompson (1971) may have been missed. The data suggest that the processes controlling sedimentation in the environments where the finest-grained sediments accumulate in the bay may not have significantly changed.

However, comparison of the sediments collected from the main tidal channels (Figure 6) indicate that the 2000–2001 samples had larger average grain sizes and contained less clay-sized material than in 1970. This apparent difference in sediment type cannot be explained by a sampling bias; the main tidal channels were sampled similarly during both studies and the samples were analyzed using the same techniques. The data suggest that the processes controlling sedimentation in the main tidal channels have changed.

These results are seemingly contrary to what would have been predicted by earlier numerical modeling (U.S. Army Corps of Engineers 1994). In a similar result, Costa (1982) observed an apparent shift in the sediment type in the central portion of Humboldt Bay after

dredging had widened the North Bay channel in 1977 and 1978. The channels that had contained significant portions of silt- and clay-sized particles prior to dredging became dominated by sand after the channel had been widened. Costa (1982) provided no explanation for these observations.

These data suggest that the processes controlling sedimentation in the bay may have changed. Either the currents in the main tidal channels have become more vigorous and can better inhibit the accumulation of clay-sized sediments, or the sediments supplied to the channels are different. Prior modeling suggests that an increase in tidal currents is unlikely following the channel deepening or widening that occurred between 1970 and 2000 (U.S. Army Corps of Engineers 1994). The implication is that the sand-dominated marine sediments, characteristic of the channels in the lower reaches of the bay, have propagated both northward and southward in the main tidal channels and away from the inlet.

Conclusions

In general, the distribution of surface sediments in Humboldt Bay is similar to that observed by previous investigators (Thompson 1971; Boyd et al. 1975; Burdick 1976; Moore 1977; Costa 1982). The major process that drives the transport and sorting of sediments in most regions of the bay is tidal currents. Waves entering the inlet from offshore are also an important process in Entrance Bay.

Comparison of grain-size data collected during this study with results of a similar survey conducted by Thompson (1971) suggests that the main tidal channels have larger mean sediment sizes today than they had previously. These changes in sediment size may reflect an increased propagation of silt- and sand-sized particles away from Entrance Bay and into the North and South Bay Channels.

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Figures

Figure 1. Humboldt Bay, California, study area showing North Bay, South Bay and Entrance Bay (after Costa 1982). The major tidal channels including Entrance, North Bay Channel, Samoa, Mad River Slough, Arcata, Bracut, Eureka, Hookton and Southport Channels are indicated by dashed lines. Major sources of freshwater to the bay, including Jacoby Creek, Freshwater Creek, Elk River and Salmon Creek, are shown.

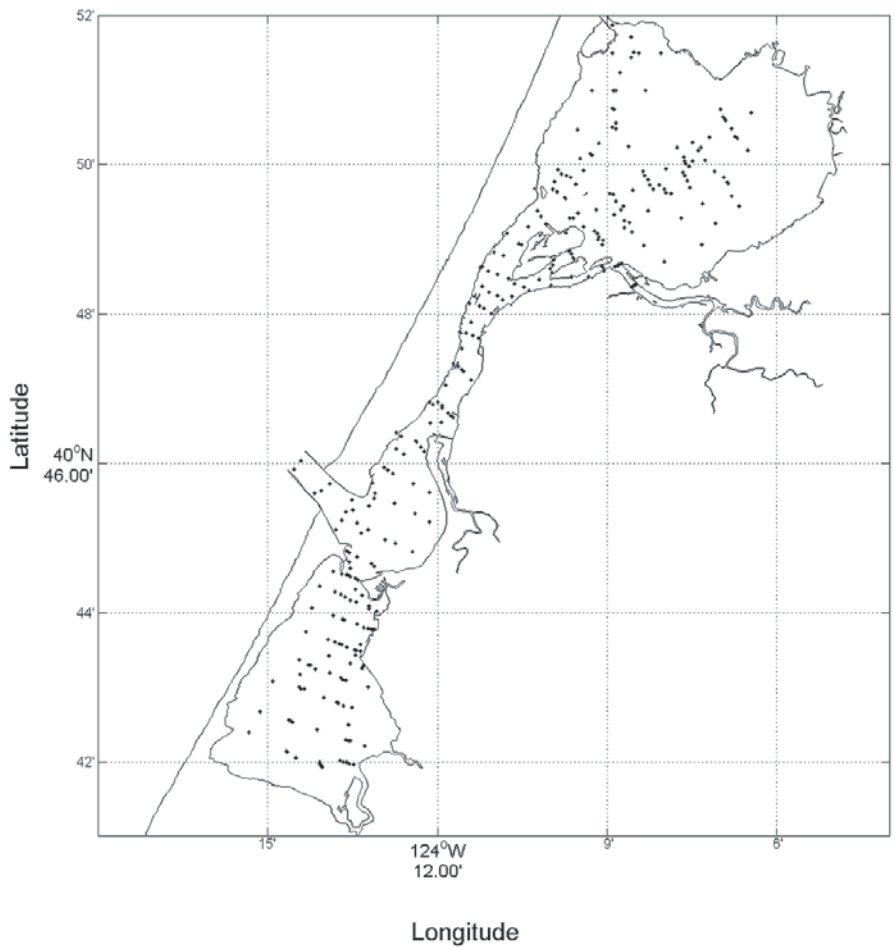

Figure 2. Locations of 315 surface sediment samples collected in 2000 and 2001. Two hundred, twenty-three samples were collected in June and July 2001 using a Peterson grab sampler from aboard either a small skiff or pontoon boat. Ninety-two samples were collected from the deeper sections of the main bay channels during fall 2000 using a Smith-McIntyre grab sampler aboard the R/V *Coral Sea* and M/V *Ironic* (the majority of the supplemented samples were collected as a part of a survey identifying nonindigenous species in Humboldt Bay, Boyd et al. 2002).

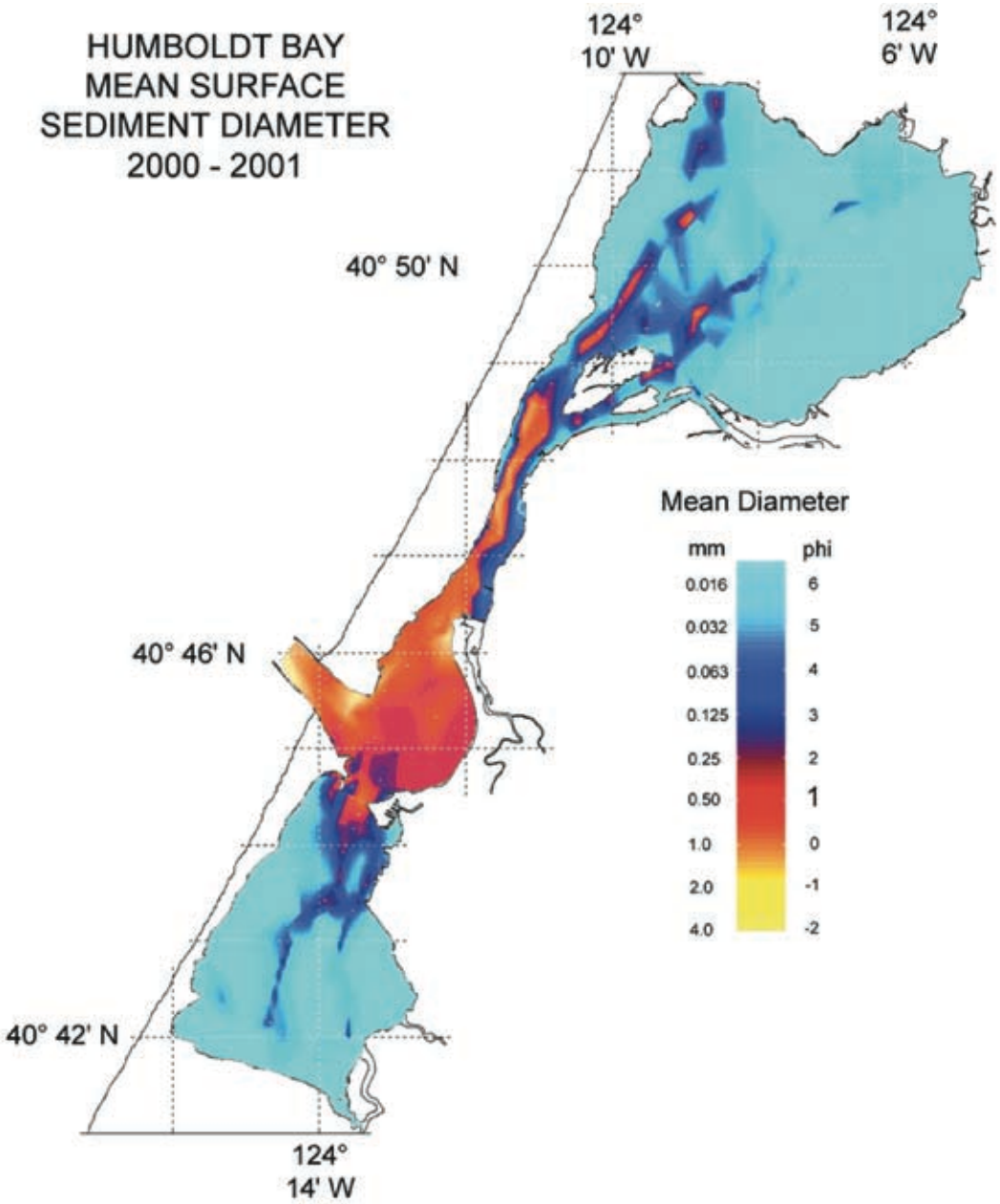

Figure 3. Mean sediment diameter of the upper 5 cm of the surface sediments in Humboldt Bay, 2000–2001. The upper 5 cm of each sediment sample was analyzed in bulk using standard sieve and pipette techniques (Ingram 1971; Galehouse 1971). Sediment size statistics were determined using the graphical technique of Inman (1952). The color-coded map was constructed using a simple contouring algorithm.

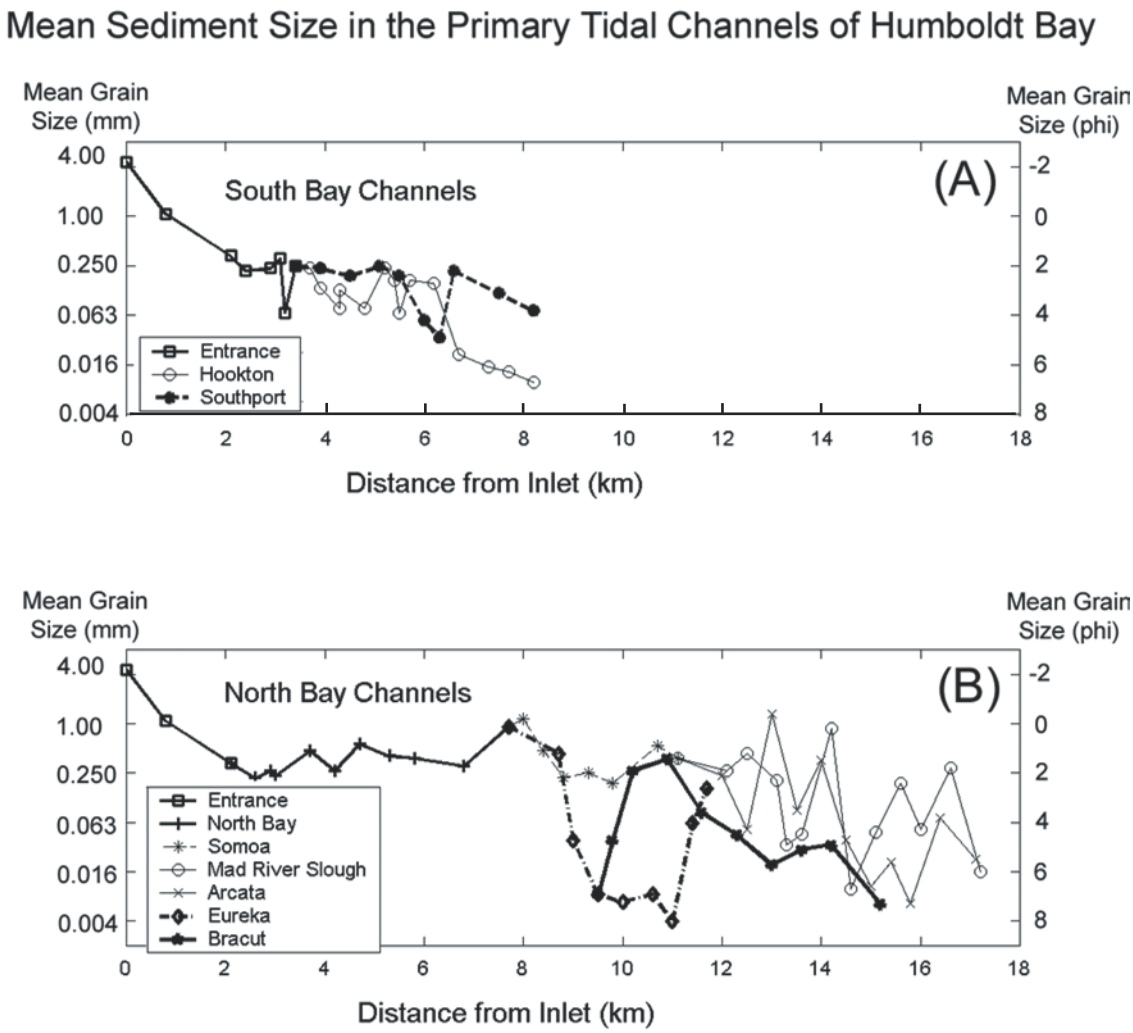

Figure 4. Graphs of the mean sediment diameter in the main tidal channels of Humboldt Bay versus the distance upstream from the ocean inlet. Two graphs are presented: (A) for the channels in South Bay and (B) for the channels in North Bay.

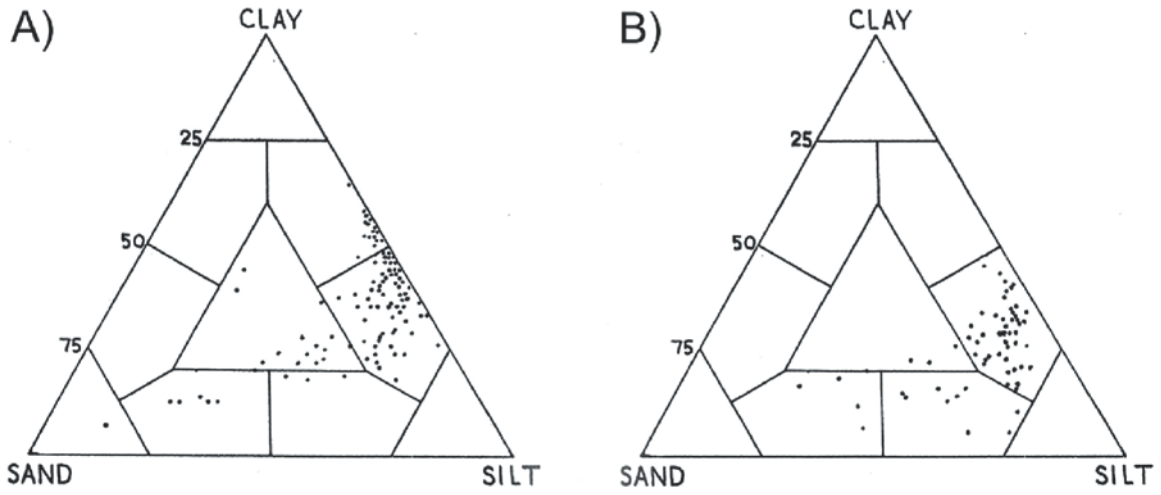

Figure 5. Textural triangle diagrams of sediment samples collected from the high tidal flats of Humboldt Bay based on sand, silt and clay weight percentages. The plots are (A) from 1970, after Thompson (1971), and (B) from 2000 to 2001.

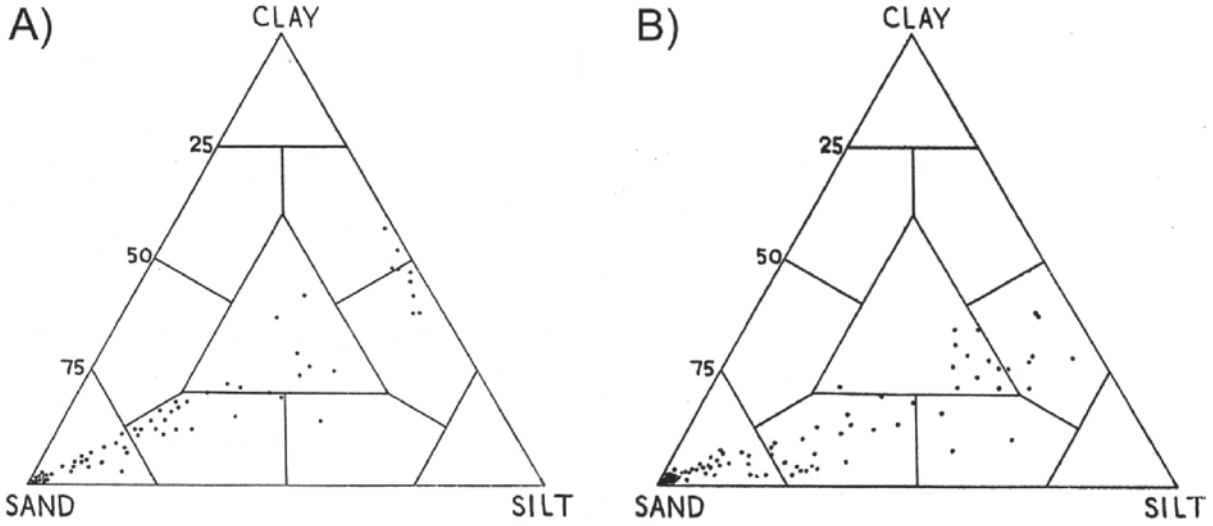

Figure 6. Textural triangle diagrams of sediment samples collected from the main tidal channels of Humboldt Bay based on sand, silt and clay weight percentages. The plots are (A) from 1970, after Thompson (1971), and (B) from 2000 to 2001.

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