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ISSUE PAPER

HABITAT CONSIDERATIONS FOR LARGE-SCALE SEDIMENT CAPPING PROJECTS

Washington State Department of Ecology
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by Joanne Polayes
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HABITAT CONSIDERATIONS FOR LARGE-SCALE SEDIMENT CAPPING PROJECTS

Background

Contaminated marine sediments in Puget Sound have been a recognized problem since the early 1980s when lesions were first found in bottom dwelling fish in urban bays. In 1991, the Department of Ecology (Ecology) adopted Sediment Management Standards, Chapter 173-204 WAC, to address contaminated sediments. Since then Ecology has developed and implemented additional guidance and policies governing sediment cleanup, including a ranked list of contaminated marine sediment sites and maps. Small-scale sediment cleanups have been undertaken in Puget Sound's urban bays, often in conjunction with upland cleanups or water-associated development projects. Many of these projects have included capping of contaminated sediments, usually with up to three feet of clean sand dredged for navigation purposes.

Relatively large scale sediment remediation projects are now being considered in a few urban bays. The Elliott Bay/Duwamish Restoration Program is considering a coordinated cleanup of Seattle central waterfront sediments. Sediment capping will likely be a remedial alternative for this area, since the depth of contamination in the sediments at certain locations eliminates dredging alone as a cleanup measure. While habitat impacts of capping may not have been a significant consideration for small projects, larger capping projects may have a correspondingly greater impact on benthic biota and the ecosystem of the bay. Simply isolating contaminants from the water column may suffice for small sediment capping projects; however, as larger portions of the nearshore area of major bays are considered for capping, the quality of the resulting habitat needs to be considered.

Purpose and Scope

The purpose of this discussion paper is to identify habitat issues related to sediment capping, summarize current scientific knowledge about those issues and their significance, and, if appropriate, suggest actions to minimize habitat impacts. The following are key habitat-related issues related to sediment capping:

- the ability of the benthic community to quickly recolonize a large cap;
- the relative quality of the benthic community present before and after capping;
- the importance of grain-size shifts in influencing benthic community structure;
- the relative significance of organic matter composition versus sediment grain sizes in influencing habitat function;

- the significance of shifting one benthic community type to another;
- the relevance of habitat patch size;
- the impact of simultaneously capping a large area of nearshore sediments on food for key species, such as salmon.

In exploring the above issues, it is important to keep the following factors in mind.

(1) Most sediment capping projects are occurring in highly impacted urban/industrial aquatic environments. For example, in addition to chemical pollution, the amount of organic matter is generally high in the sediment near sewage and combined sewer discharges. Very few species and individuals of benthic invertebrates occur in this organic-enriched zone near sewage outfalls, and large numbers of a few tolerant species occur at greater distance from the outfalls (Armstrong, 1980). Also, it seems plausible that the predominance of fine substrates in many urban bays is not entirely natural. A mixture of fine and coarse materials making up estuarine sand and mud flats may have been the norm prior to modern changes. The construction of artificial settling basins for coarse sediments upriver, the cutting off of feeder bluffs by man-made structures, and maintenance dredging have removed the source of sand that may otherwise have been deposited in the near shore area. These man-made alterations have left the fine river sediments to be deposited as the primary substrate type in these areas. Combined sewer overflows (CSO's) have further influenced sediment composition by contributing a high organic load along with additional fine sediments. Thus, the existing benthic community is most likely not optimum for the location, and enhancement measures that intentionally alter the substrate from what currently exists may well be justified.

(2) After capping, the benthic community may be different from pre-disturbance conditions (which we would have to infer from less impacted estuaries in Puget Sound). Any potential change in the biological community must be balanced with the obvious gain of preventing contamination from entering the water column, or being bio-accumulated through benthic organisms to salmon and other species higher on the food chain. Understanding the likely results of capping, with or without substrate enhancement, will improve our ability to make intelligent management decisions.

Observations and Key Points from Research

Estuaries are not really 'fragile ecosystems'. They are actually able to absorb considerable stresses and perturbations, rapidly returning to their original state after the perturbing factor disappears (Wolff, 1990). The key to recovery is that the source of disturbance must be significantly reduced or eliminated. Chronic pollution and/or permanent physical alteration (as in Elliott Bay) prevent or impede ecosystem recovery, causing further changes that result in a ecosystem that is different and probably less desirable than the original.

Repopulation Following Disturbance

From a biological point of view, Sousa (1984) defines a *disturbance* as "a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established". Disturbance has always been part of the natural environment. As such, disturbance is both an agent of natural selection and a major source of temporal and spatial heterogeneity in the structure and dynamics of natural communities (Sousa, 1984). Causes of disturbance may be either (or both) physical or biological. Physical agents of natural disturbances are paramount in estuaries and include high winds, large waves, floods, and desiccation stress. Biological agents of disturbance include predation and parasitic infections (Sousa, 1984).

A number of factors influence the rate and pattern of repopulation of sessile organisms following a disturbance. These factors (not necessarily in order of importance) include:

1. the morphological and reproductive traits of the species present at the site when the disturbance occurs;
2. the reproductive biology of species within dispersal distance of the site; and
3. characteristics of the disturbed patch, particularly:
   a. the severity of the disturbance that created it,
   b. its location relative to source of colonists,
   c. its size and shape,
   d. the time it was created (e.g. season),
   e. the environmental heterogeneity within the patch (Sousa, 1984).

When the cause of disturbance is a sediment cap, some of these factors appear to be more relevant than others. For example, the reproductive biology of species within dispersal distance of the site is of far greater importance to repopulation of the cap than characteristics of species buried under three feet of sediments. Buried individuals or their propagules are highly unlikely to survive to repopulate the cap. The lack of on-site survivors makes sediment capping a severe disturbance on the same order of magnitude as a major landslide on land.

The recovery time of benthic communities following disturbance is generally from months to years (Wolff, 1990). The larvae of many, but not all, marine invertebrates spend days to months as plankton in the water column before they settle, and they can be dispersed long distances from their parent organism (Sousa, 1984). In benthic communities, most early colonizing species following disturbance tend to feed at the sediment surface and have a life stage that is dispersed in the water column (Thistle, 1981). Dispersal of most epibenthic populations is often continuous and dynamic, resulting from tidal resuspension and circulation (Simenstad, 1995). Consequently, the abundance of propagule releasing adults in the *immediate vicinity* of the disturbed patch is rarely a factor in recruitment of species with planktonic larval stages (Sousa, 1984).

The size of a sediment cap also would not be expected to have a significant effect on the rate of recolonization by species with planktonic larval stages, since these propagules are found throughout the water column. Dispersion of some species of infauna may be seasonal, however. Due to spring dispersion, observed abundances of some infaunal species are more than 100% higher in mid-summer than in mid-winter (Lie, 1968). Therefore the season of capping may have a *short term* influence on the rate of colonization by benthic organisms.

Within-patch heterogeneity in substrate characteristics can affect the patterns and rates of colonization in marine communities. Relatively small scale differences in the surface texture or composition of hard substrates can affect settlement and survival of propagules. Larger cracks and crevices in rock surfaces can provide refuges from predators and grazers (Sousa, 1984). Also, variations in sediment grain size favor different infaunal species and have a significant effect on the pattern of colonization.

Sediment Grain Size

Sediment grain size and water depth are the two most important factors influencing infaunal benthic community structure (Striplin, 1996). Grain size and water depth are highly correlated: as the water deepens, sediment tends to become finer. Within a given water depth category (e.g. shallow subtidal), variation in grain size is the major factor driving changes in community composition (Striplin, 1996). Total organic carbon (TOC) also strongly co-varies with grain size: TOC tends to increase as grain size decreases. Salinity is important in shallow benthic communities near river mouths, but effects are minimal or absent at depth (Striplin, 1996), because salinity at depth is less variable than near the surface.

From January 1963 to August 1964, Ulf Lie (1968) conducted quarterly sediment sampling and benthic infaunal taxonomic analysis at eight stations with a range of grain sizes in Puget Sound. He found that both the number of species and the number of individuals were highest at stations with substrate dominated by fine sand. Both measures decreased in either finer or coarser sediments (Lie, 1968). Table 1 summarizes the substrate types and depths characteristic of the numerically dominant benthic species Lie identified in his Puget Sound study.

When placing sand over mud (coarse sediment over fine sediment), the species diversity increases over the first few years following capping, with benthic communities typical of coarser materials. Since the processes that resulted in the fine substrate being present have not changed, the cap surface gradually shifts to a finer mixture due to the deposition of new fine material on top; and the benthic community transitions as well to one more typical of a fine substrate (Personal communications, Dean Wilson, 1996; Personal communications, Charles Simenstad, 1996).

Succession

The succession of benthic species recolonizing a sediment cap or other bottom areas of marine environments that have been denuded of benthic infauna is similar to the successional changes of a benthic community in response to pollution (Wilson and Romberg, 1996). Early in the recolonization process a community develops that is composed of a few opportunistic species and very high numbers of individuals. These opportunistic species are short lived and small, so biomass is low. As recolonization progresses, the overall number of individuals declines as the few opportunistic species are replaced by a greater diversity of species. Biomass increases as many of the new species are larger and longer lived than the initial opportunistic species. Stable and undisturbed benthic communities are characterized by greater number of species, higher biomass, and lower number of individuals than during the initial phases of recolonization (Wilson and Romberg, 1996, from Pearson and Rosenberg, 1978).

Sediment Caps -- Case Studies

Denny Way Cap

The Denny Way cap was completed in 1990, covering three acres of contaminated sediment with a three-foot-thick layer of clean sand (Wilson and Romberg, 1996). The cap is located near Denny Way CSO, an untreated outfall in Myrtle-Edwards Park, just south of downtown Seattle. Implementation of plans for control and treatment of sewer overflows at Denny Way is underway and will be completed in a few years. Optimally, source control should be completed before capping. As a demonstration project, however, the Denny Way cap provides an opportunity to study the rate of recontamination, as well as the effectiveness of capping in isolating contaminants and the rate of biological recolonization.

Benthic colonization of the Denny Way cap followed the general pattern discussed above. The 1991 benthic taxonomy study showed that abundance, number of species, and biomass increased in the 12 months after the cap was placed in 1990. While the benthic community was still largely made up of opportunistic species, particularly polychaetes, it was beginning to transition toward a community typically found in a less disturbed environment. By 1992, organism abundance and biomass had increased, with polychaetes still the most abundant by all measures; however, crustaceans and mollusks were increasing in numbers and biomass (Metro, 1994).

The 1994 benthic taxonomy analysis showed that total biomass increased and crustaceans and mollusks made up a greater proportion of the community than in previous studies. The number of species identified continued to increase and the types of species became more diverse in terms of feeding type and grain size preference. At the same time, the total number of organisms decreased significantly from 1992, because fewer, larger, and more mature organisms comprised a greater proportion of species inhabiting the cap (Wilson and Romberg, 1996).

Denny Way cap placement dramatically changed the grain size composition of the bottom sediment from mostly fine-grained mud to a uniform medium-grained sand (Wilson and Romberg, 1996.) Comiskey et al (1984) correlated benthic species with preferred grain size in Elliott Bay and Puget Sound. Using these correlations, benthic monitoring studies of the Denny Way cap showed a progression from species associated mostly with fine-grained muds in 1990 to species associated with coarser sediments in 1992. This transition of species types most likely occurred because initial larval recruitment was primarily from organisms living in the fine-grained bottom muds. Over time (1990-1992), the species that became dominant were those better adapted to the coarser texture of the cap (Wilson and Romberg, 1996).

In 1994, the top six most dominant species found in the Denny Way cap were associated with a mix of sediment types ranging from mud to gravel. Of the top 15 most dominant species, roughly 42 percent were associated with fine grained sediments and 58 percent were associated with coarse-grained sediments (Wilson and Romberg, 1996).

The 1994 benthic samples showed that the cap was supporting a larger percentage of organisms associated with finer textured sediments than in the 1991 and 1992 studies. This suggests that the cap was becoming more heterogeneous in grain-size makeup, due to the continual deposition of fine material onto the cap through sedimentation. Wilson and Romberg presumed that sedimentation eventually would cause the cap to become more like the pre-cap bottom muds. Meanwhile, the heterogeneity of the sediment appeared to be supporting a diverse benthic population (Wilson and Romberg, 1996).

Analysis showed that the trophic or feeding type of the infauna present on the cap in 1994 was also more diverse than in previous years. Among the top 15 most numerically dominant species, four were filter or subsurface deposit feeders, five were surface deposit feeders, two were burrowing deposit feeders, and four were omnivores. By comparison, in 1990, most of the numerically dominant species were surface deposit feeders (Wilson and Romberg, 1996).

Considering the continuing organic and sediment inputs from the Denny Way CSO, it is questionable whether reversion of the cap area to 'native' bottom muds through sedimentation will be beneficial from a habitat perspective. Continued monitoring could eventually show the benthic community becoming less diverse and more typical of an area impacted by high organic and pollution inputs. This would be the result of capping being undertaken before source control is completed, and would not necessarily be a factor in sediment capping projects where there is not a significant ongoing source of potential pollution.

Pier 53 to 55 Cap

The Pier 53 to 55 cap covers four and one-half acres of chemically contaminated bottom sediments along the downtown Seattle waterfront. The clean sand cap was placed in March, 1992, covering about 1.6 acres nearshore with one foot of capping material (referred to as enhanced natural recovery (ENR)) and covering the remaining 2.9 acres farthest offshore with a standard capping depth of three feet. The ENR area was considered experimental. Monitoring was aimed at comparing the relative effectiveness of the ENR and the three-foot cap in isolating contaminated sediments, as well as determining whether there were any differences in benthic recolonization (Wilson and Romberg, 1995).

Although there are only two years of post-cap monitoring data available for the Pier 53 to 55 sediment cap, the benthic taxonomy data appears to be following the same general pattern as at Denny Way. Benthic taxonomy data are available from the pre-cap monitoring and from post cap sampling completed in August of 1992 and 1993, (Wilson and Romberg, 1995). At less than one and a half years post disturbance, the 1993 data are representative of a benthic community still in a relatively early successional stage.

Taxonomy counts showed that there were no consistent productivity differences between the three-foot cap and the ENR area. Analysis of core chemistry samples also showed that chemicals from the underlying sediments had not migrated up into the three-foot cap or the ENR area (Wilson and Romberg, 1995).

A comparison of the 1993 benthic taxonomy study to the 1992 baseline data showed that the average number of individuals in each replicate sample increased by approximately 400 percent, the number of species increased by 55 percent, and the biomass increased by 30 percent. In comparison with the pre-cap study, the average number of individuals in each sample and the total number of species was higher in the 1993 study; however, biomass was 600 percent higher in the pre-cap study. The greater number of individuals and lower biomass in 1993 indicated that, as expected about a year after capping, the individual organisms were smaller than before capping (Wilson and Romberg, 1995).

One ampharetid species (*Asabellides lineata*), representative of a taxon considered "sensitive or intolerant" to sediment contamination, increased from very few individuals pre-capping to the fourth most abundant species in the 1993 study. On the other hand, a capitellid polychaete (*Heteromastus filobranchus*) went from being in the top four most abundant species in the pre-cap study to very few individuals in the 1993 study. Capitellid polychaetes have been used as indicators of organically polluted sediments. These changes in species are an apparent response to the improved sediment quality. The colonization by more sensitive species has occurred despite surface recontamination, most likely due to the demolition of the ferry terminal wing wall (Wilson and Romberg, 1995).

In comparison with the Denny Way cap one year after cap placement, the total number of species for all taxonomic groups was higher at Pier 53, with a total of 215 species compared to 159 at Denny Way. The total average number of individuals per sample was also higher at Pier 53, with 923 compared to 572 at Denny Way; however, biomass was almost two times greater at Denny Way. Fewer species and higher biomass probably means that organic enrichment from the Denny Way CSO was having an effect on the nearby benthic community (Wilson and Romberg, 1995).

The 1993 video survey of the Pier 53 cap showed many burrows, tubes, and other evidence of benthic life in the remediation area. Many flounders, anemones, nudibranches, starfish, and several types of crabs were photographed. Many small plants were beginning to root in the sand. The video also showed that the cap was covered by a tan-colored fine-grain layer of silt. This silt layer appeared to have become thicker since 1992 (Wilson and Romberg, 1995). The silt deposition was probably the beginning of the transition of the capped area to a finer substrate, characteristic of pre-cap sediments.

St. Paul Cap

The St. Paul cap in Commencement Bay, Tacoma, was designed to restore intertidal and shallow water habitats while capping contaminated sediments. The 17 acre area was capped in July and August of 1988 with clean sand, five to 20 feet thick, restoring more than six acres of intertidal habitat and 11 acres of shallow marine habitat. In addition to sand, the cap included some rocks. Varied topography was constructed to allow pools and ridges for diverse habitat and further sculpting by natural forces (Parametrix, 1992).

The five years of monitoring through 1994 have shown that the succession of colonizing species has been occurring as expected and the new habitat has been functioning as planned (Parametrix, 1995). By 1990, a moderately complex community of polychaetes, mollusks and crustaceans had become established in the surface sediments of the new habitat. The community appeared to be a combination of the most common and opportunistic species present in Commencement Bay. A total of 150 species were identified inhabiting the cap, with about 100 species per sampling station. The invertebrate assemblages provided evidence of having established in micro-habitats created by varying contours, producing tidal pools, and adding rock substrate (Parametrix, 1991).

Benthic monitoring in 1991 showed that the total number of taxa was approaching 200; however, the abundance of organisms had dropped at many stations, probably as a result of a shift in sampling times from June to March. The benthic fauna was diverse but the mix of species was relatively homogeneous across the project site. There were at least two depth-associated benthic assemblages found: a low intertidal assemblage dominated by polychaetes, and a slightly deeper subtidal assemblage dominated by small crustaceans. Some expected taxa had not yet colonized the project site (Parametrix, 1992).

Biological monitoring included macrophytes as well as observations of fish and wildlife usage. By 1991, virtually all hard substrate was colonized with algae, including the filamentous red alga *Bangia fuscopurpera* and the green alga *Ulva lactuca* in higher areas; the brown alga *Fucus distichus* on the riprap area and on rocks in deeper areas; and *Laminaria* spp. and *Costaria costata* on rocks lower than two feet below MLLW. The project area habitat was being used by many species of birds, fishes, and large predatory crustaceans (Parametrix, 1992). The 1992 monitoring report indicated that the project continued to provide habitat that was supporting valuable ecological functions, where there was essentially no productive habitat prior to project construction. Shorebirds were observed using the site for feeding and rearing, and tidepools observed at low tide were abundant with invertebrates (Parametrix, 1993).

In 1992, the benthic taxonomy study found that the number of taxa had increased to 215, and that the abundance of organisms had increased 80 percent over the previous year. The sediments had continued to get siltier than previous years, so that the project site could be described as a shallow subtidal to low intertidal muddy sandflat. Except for local microhabitats, the project site was not dominated by any one taxon (Parametrix, 1993). Based on literature review and Parametrix's best professional judgment, benthic taxa considered to be indicators of healthy Puget Sound sediments were present on the site (Parametrix, 1993).

The 1993 monitoring found that the project habitat had continued to become siltier over time, as expected. Parametrix (1994) speculated that the final substrate on the site would be an array of sediments containing a large amount of silt that is slowly being deposited from the Puyallup River. The organic content of the sediments was two to four percent by weight in 1993, and would also probably increase as the silt component of the habitat increases. This change toward a muddier habitat type was expected and was considered by Parametrix (1994) to be a change to a different by equally valuable habitat type.

Benthic taxonomic analysis in 1993 found two different faunal arrays, which did not consistently correlate with physical factors such as depth or sediment characteristics. The total number of taxa found at the site had decreased slightly since 1992. Parametrix hypothesized that this could be a result of the relatively stable benthic communities approaching maturity, with little habitat space left for those opportunistic taxa characterizing communities in transition (Parametrix, 1994).

Reference stations comparable to the St. Paul cap were initially difficult to locate. Beginning in 1993, however, benthic monitoring included comparisons between the project stations and two reference stations. The monitoring plan included a performance measure that the project station abundances should not be less than 50 percent of the reference station abundances. Statistical comparisons of benthic sample abundances between the project and reference stations indicated that, except in a few of the tested cases, project stations met the performance measure. (Parametrix, 1994).

In 1994, examination of benthic species abundance and distribution data indicated that the project stations were thriving. Statistical comparisons of numerical abundances to the reference station (one of the reference stations was eliminated from the study because there were virtually no organisms in 1994) indicated that the project stations were either indistinguishable from the reference site or had significantly higher abundances. Comparisons of the species abundance of epibenthos at the project stations with the reference station indicated that there were generally more taxa at the project stations; however, the faunal arrays at the project stations were also significantly different from the reference station. This was probably due to differences in substrate: the reference station had more fines (83 percent silt/clay) than all of the project stations. Three of the project stations ranged from 13 to 15 percent fines, and the remaining three ranged between 42 and 69 percent fines (Parametrix, 1995).

The benthic community on the St. Paul cap has been slowly changing since the project began. The project benthic environment has become progressively siltier, and many of the abundant taxa found in 1994 sampling were characteristic of silt-dominated habitats. Some of the dominant taxa that had shown decreases in abundance are more characteristic of sandy areas than silty ones, indicating that the silt fraction at many stations had reached a point where sand dwelling animals could be at a disadvantage (Parametrix, 1995). As stated very well by Parametrix (1995): "This succession of dominant taxa is an absolutely normal process and it may continually cause statistically significant differences from year-to-year and station-to-station as natural physical disturbances such as waves from storms, varying amounts of precipitation, temperature extremes at low tides, grain size fluctuations, and other normal events, will continue to affect this environment."

Eagle Harbor Cap

Located off of Bainbridge Island, the Eagle Harbor cap consisted of about 285,000 cubic yards of clean sandy material placed over 53 acres of chemically contaminated bottom sediment. The resulting cap thickness varies from 0.5 feet to greater than 3.9 feet. The cap was completed in 1994 (SAIC, 1996).

The 1995 Environmental Monitoring Report for Eagle Harbor (SAIC, 1996) did not include taxonomic analysis of benthic samples, so data and analysis comparable to Denny Way are not available. (Samples were archived for possible future taxonomic analysis.) Based on field observations on samples taken from a thickly capped zone and a thinly capped zone, benthic infauna a year after cap placement included a nemertean worm, chaetoperid and spionid worms, and various other small polychaete worms. A video survey of the cap found that most of the organisms colonizing the cap appeared to be larger scavengers and epibenthos, along with some bivalves. Varieties included sea pens, anemones, shrimp, demersal flatfish and sculpins and crabs (SAIC, 1996).

The important lesson from the Eagle Harbor cap relative to grain size is physical rather than biological. Placement of a sand cap on top of coarser bottom material will likely not be successful, because the cap will not stay in place. The existence of a rocky or gravelly substrate is indicative of erosive forces preventing the accumulation of finer sediments. Those same hydrodynamics will erode any finer capping material placed over a rocky bottom. A portion of the Eagle Harbor cap was placed in a high energy area associated with the ferry terminal. Monitoring one year after capping showed that the medium to fine sand cap had dispersed in this area and the native rocky substrate was once again exposed (SAIC, 1996).

Conclusions

Returning to the Purpose and Scope of this paper, it appears that there is sufficient information in the literature to address most of the key habitat issues related to sediment capping. These findings are provided in italics following the bullets.

- The ability of the benthic community to quickly recolonize a large cap. *Benthic communities recolonize capped areas rapidly, within months to a few years, with a succession of species. The size (area) of the cap would not be expected to significantly affect the rate of recolonization for species with planktonic larval stages, which are characteristic of most marine invertebrates.*

- The relative quality of the benthic community present before and after capping. *Benthic communities colonize in succession, increasing in species diversity, trophic level diversity, biomass, and organism size during the first three to four years following capping. Relative to the benthic communities that existed prior to capping, which tend to be characterized by large numbers of individuals of a few tolerant species, the post capping communities are generally more diverse in species and trophic levels. Biomass and organism size gradually increase with time after capping, but provide less reliable measures of benthic community quality, because polluted organically enriched sites can have a high biomass of tolerant species.*

- The importance of grain-size shifts in influencing benthic community structure. *Grain size is the most important factor influencing benthic community structure in a given area. However, since the hydrodynamics and sediment sources that resulted in a given substrate type would not have changed, the capped area would be expected to trend back to the condition prior to capping. Therefore, mud capped with clean sand will eventually trend back to mud (hopefully clean mud, assuming adequate source control) and support a benthic community associated with fine sediments. During the transition, when the substrate is a mixture of fine and coarse sediments, the benthic community would have species characteristic of both types of sediments, resulting in increased species diversity. On the other hand, capping gravel or rock substrates with sand is not a viable option, because the cap will erode in the high energy environment.*

Table 1: Ecological Characteristics of Numerically Dominant Benthic Species in Puget Sound, from Lie, Ulf. 1968. A Quantitative Study of Benthic Infauna in Puget Sound, Washington, USA, in 1963-1964. FiskDir. Skr. Ser. HavUnders. 14(5):229-556

The numerically dominant species consisted of 30 polychaetes, nine crustaceans, ten lamellibranchs, three echinoderms, and one sipunculid. Together they comprise from 60.5% to 89.5% of the total number of specimens at the various stations during the first two cruises in 1963. Several species are seasonal in their abundances.

Species	**Family**	**Substrate Type***	**Depth****
Harmothoe imbricata	Polynoidae	coarse substrates	intertidal to 3650 m.
Lepidasthenia berkeleyae	Polynoidae	muddy	63 to 126 m.
Malmgrenia lunulata	Polynoidae	soft to coarse substrates	intertidal to 865 m.
Peisidice aspera	Polydontidae	coarse	intertidal to 335 m.
Pholoe minuta	Sigalionidae	soft to coarse	shallow to 2260 m.
Sigambra tentaculata	Pilargidae	soft sediments	intertidal to 5000 m.
Pionosyllis uraga	Syllidae	gravely sediments	40 to 150 m.
Platynereis bicanaliculata	Nereidae	all substrates, esp. fine sand	intertidal to 35 m.
Nephtys ferruginea	Nephtyidae	all substrates, esp. fine sand	shallow to 400 m.
Glycera capitata	Glyceridae	fine mud to gravelly sand	shallow to slope of continental shelf
Lumbrineris bicirrata	Lumbrineridae	all substrates	shallow to 360 m.
Lumbrineris californiensis	Lumbrineridae	muddy sand to gravel	10 to 400 m.
Lumbrineris cruzensis	Lumbrineridae	all substrates, esp. sand or gravel	shallow to 40 m.
Lumbrineris luti	Lumbrineridae	variable with high mud fraction	20 to 40 m.
Haploscoloplos pugettensis	Orbiniidae	sandy, muddy sand to gravel	intertidal to 530 m.
Laonice cirrata	Spionidae	soft-bottom and fine sand	
Laonice sp.	Spionidae	sand and gravel	
Prionospio cirrifera		fine sand, mud	
Prionospio malmgreni		muddy sand to gravel	
Prionospio pinata		variable	
Caulleriella alata	Cirratulidae	sand and gravel	shallow, sub-littoral
Chaetozone setosa	Cirratulidae	all substrates, esp. sand	littoral to 4436 m.
Chaetozone sp.		very coarse	
Armandia brevis	Opheliidae	silty sand to gravelly sand	shallow

Species	Family	Substrate Type*	Depth**
Travisia pupa	Opheliidae	very soft substrates	40 to 400 m.
Euclymene zonalis	Maldanidae	fine sand	45 to 55 m.
Praxillella affinis pacifica		silt	continental shelf and slope
Praxillela gracilis		silty sand	continental shelf and slope
Pectinaria californiensis	Pectinaridae	soft mud	
Pectinaria granulata	Pectinaridae	very fine sand to medium sand	Intertidal to 340 m.
Golfingia pugettensis	sipunculid	sand, all but the softest substrates	
Euphilomedes carchardonta	Cypridinidae	all substrates, esp. fine sand	
Euphilomedes producta	Cypridinidae	soft bottoms	
Paraphoxus variatus	Phoxocephalid	sand	9 to 110 m.
Byblis veleronis	Ampeliscidae	all substrates	9 to 417 m.
Leptochelia dubia	Tanaidae	fine sand	intertidal to 46 m.
Eudorella pacifica	Leuconidae	soft sediment	deeper than 27 m.
Pinnixa schmitti	Pinnotheridae	sand	shallow
Lophopanopeus bellus	Xanthidae	hard bottoms (rocks and sand)	
Nucula bellotii	Nuculidae	fine sand with high % silt	
Crenella columbiana	Mytilidae	sand	
Psephidia lordi	Veneridae	fine sand	shallow
Mysella tumida	Monticutidae	soft and hard sediments	
Axinopsida sericata	Thyasiridae	variable	
Macoma carlottensis	Tellinidae	fine sediments	
Macoma alaskana	Tellinidae	sand	
Macoma calcarea	Tellinidae	sand	
Semele rubropicta	Semelidae	very coarse	
Mya arenaria	Myidae	coarse sand	
Amphiodia urtica	Amphiuridae	variable	
Leptosynapta clarki	Synaptidae	coarse	
Brisaster townsendi	Schizasteridae		35 to 1900 m.

*Substrate types are from Puget Sound data.
**Depths are from throughout the range of the species in question, as recorded in scientific literature.

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