Sediment Quality in Budd Inlet, 2011

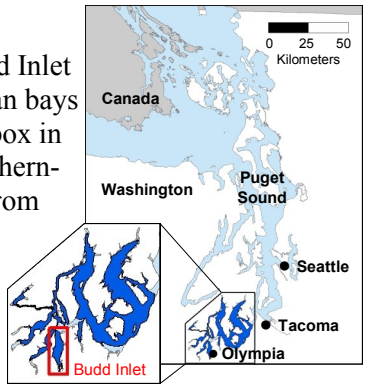
Valerie Partridge, Sandra Weakland, Margaret Dutch, Edward Long, and Kathy Welch
Environmental Assessment Program, Marine Monitoring Unit

Findings

- More than half the area of Budd Inlet had *possibly* or *likely impacted* sediments, according to Triad Index results.
- Although sediment contaminant levels met Puget Sound Partnership targets, the combined Triad Index value did not.
- *Adversely affected* benthos was the primary factor contributing to the *possibly and likely impacted* sediments.
- *Low* and *moderate toxicity* were found throughout Budd Inlet.
- Sediment quality improved from inner (southern) to outer (northern) Budd Inlet.

In 2011, the Department of Ecology (Ecology) sampled Budd Inlet sediments to characterize sediment quality, as part of an urban bays status-and-trends monitoring program. The study area (red box in inset map of South Sound) is a small inlet located in the southern-most part of Puget Sound. Surface sediments (top 2-3 cm) from 30 randomly selected locations were analyzed to determine:

- Concentrations of potentially toxic chemicals.
- Degree of response in laboratory tests of toxicity.
- Condition of sediment-dwelling invertebrates (benthos).



The sediment contaminant, toxicity, and benthic invertebrate data were rolled up into Ecology's Chemistry, Toxicity, Benthic, and combined Triad Indices.

Overall Results

Sediment quality index values for Budd Inlet (Figure 1, light bars) were significantly lower than those for the South Sound region (dark bars), indicating poorer sediment quality in the inlet than in the region as a whole. Overall sediment quality, as measured by the Triad Index, did not meet the Puget Sound Partnership (PSP) target.

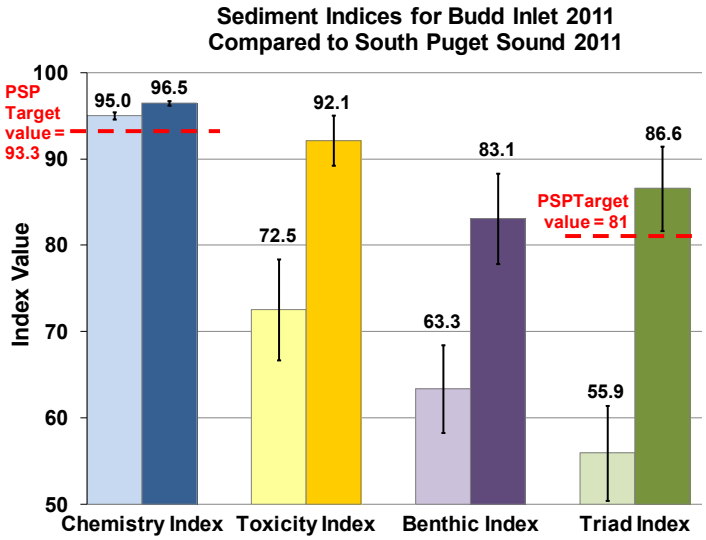


Figure 1. A comparison of weighted mean index values for Budd Inlet in 2011 (light bars) and the surrounding South Puget Sound region in 2011 (dark bars), with 95% confidence intervals. Also shown are the PSP target values for the Chemistry and Triad Indices (red dashed lines).

We are on the web

This report covers only the primary results of the 2011 Budd Inlet survey. Data and supporting information, including methods, are available on Ecology's website: **www.ecy.wa.gov/programs/eap/sediment.**

Sediment Monitoring of Budd Inlet

Ecology sampled sediments in Budd Inlet and the encompassing South Sound region in June 2011 under the Puget Sound Ecosystem Monitoring Program (PSEMP). The two surveys were separate, but used the same field and laboratory methods and some of the same stations. The survey designs weight sample results by area, which enables Ecology to estimate the percent of area (spatial extent) with given sediment conditions and to compare results from two surveys at a glance. Comparisons of spatial extent of sediment conditions follow Kincaid (2012). The study design, sampling and analytical methods, and list of parameters are described in Dutch et al. (2009, 2012) and on Ecology's website.

For results of the South Sound survey, see the companion report, "Sediment Quality in South Puget Sound, Changes from 1999 to 2011" (Partridge et al., 2014).

Publication 14-03-005

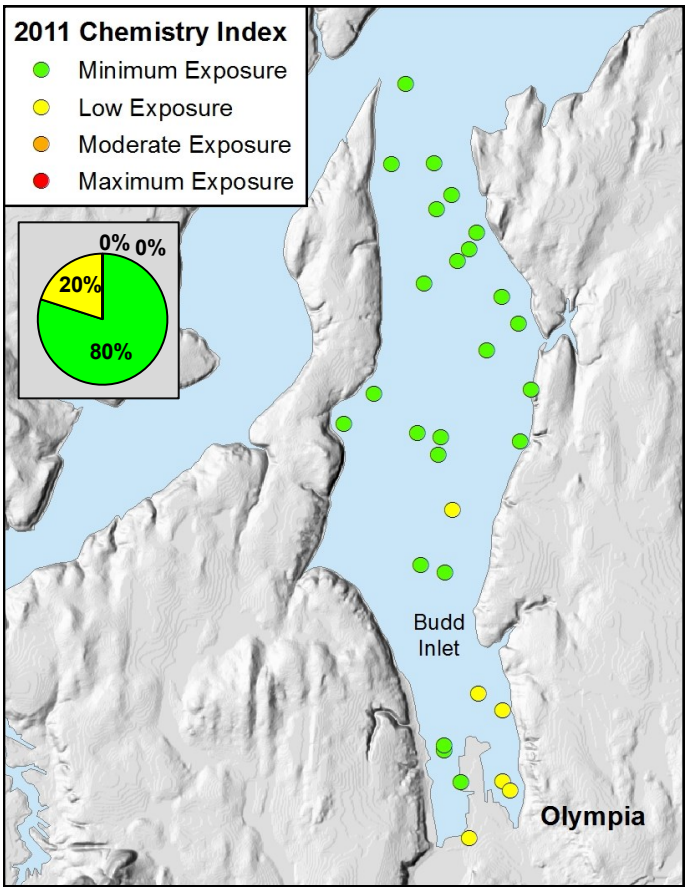
March 2014

Physical Conditions

Sediments throughout Budd Inlet were predominantly mixed (40 to 80% silt-clay) and fine-grained (> 80% silt-clay). Total organic carbon (TOC) content of most of the sediment samples averaged 3% by weight, with most values between 2% and 4%. TOC content tended to increase from the outer (northern) to the inner (southern) bay.

Chemical Contamination

Samples were analyzed for the concentrations of 268 potentially toxic chemicals, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other organic compounds. Metals and PAHs were almost always detected and measurable (99.8% of samples). The other target organic compounds (e.g., PCBs, pesticides) were detected in only 7% of samples.



No chemical concentrations were found higher than the Washington State numerical Sediment Quality Standards (SQS) (Ecology, 2013) at any of the sites.

Chemistry Index

Ecology's Chemistry Index (Long et al., 2013) is a multi-chemical index that accounts for the presence, concentrations, and potential toxicity of mixtures of chemicals. It is used to categorize sediments as having *minimum*, *low*, *moderate*, or *maximum* levels of exposure to the chemicals for which SQS (Ecology, 2013) have been defined.

In 2011, none of the study area was classified as having *moderate* or *maximum exposure*. The Chemistry Index indicated that 80% of the study area had *minimum exposure* to chemical contaminants (Figure 2). *Low exposure* to chemicals was found primarily in the southern portion of Budd Inlet and represented 20% of the study area.

Figure 2. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Chemistry Index categories for Budd Inlet in 2011.

Toxicity Index

In the 2011 survey, each sediment sample was analyzed with two laboratory tests of acute toxicity: (1) 10-day survival of adult amphipods exposed to solid-phase sediments and (2) fertilization of sea urchin gametes exposed to sediment porewater.

The test results were combined into Ecology's Toxicity Index (Dutch et al., 2014) and characterized into four toxicity ranges, from *non-toxic* to *high toxicity* (Table 1).

Table 1. Toxicity Index category descriptions.

Category	Description
Non-Toxic	Mean control-adjusted test results were not significantly lower than the controls
Low Toxicity	Mean control-adjusted test results were significantly lower than the controls, but ≥80% of controls
Moderate Toxicity	Mean control-adjusted test results were significantly lower than controls and between <80-50% of controls
High Toxicity	Mean control-adjusted test results were significantly lower than the controls and <50% of controls

The Toxicity Index indicated that 27% of the study area in 2011 had *non-toxic* sediments. *Low* and *moderate toxicity* were found throughout Budd Inlet and represented the majority (70%) of the study area (Figure 3). Sediments with *high toxicity* were found at one site in the east-central portion of the bay.

There was no consistent pattern in the locations of the various levels of toxicity.

Although laboratory toxicity tests may indicate that the sediment and/or porewater is harmful to benthic organisms under controlled conditions, they do not indicate why, i.e., what specific factor(s) may be causing the adverse effects.

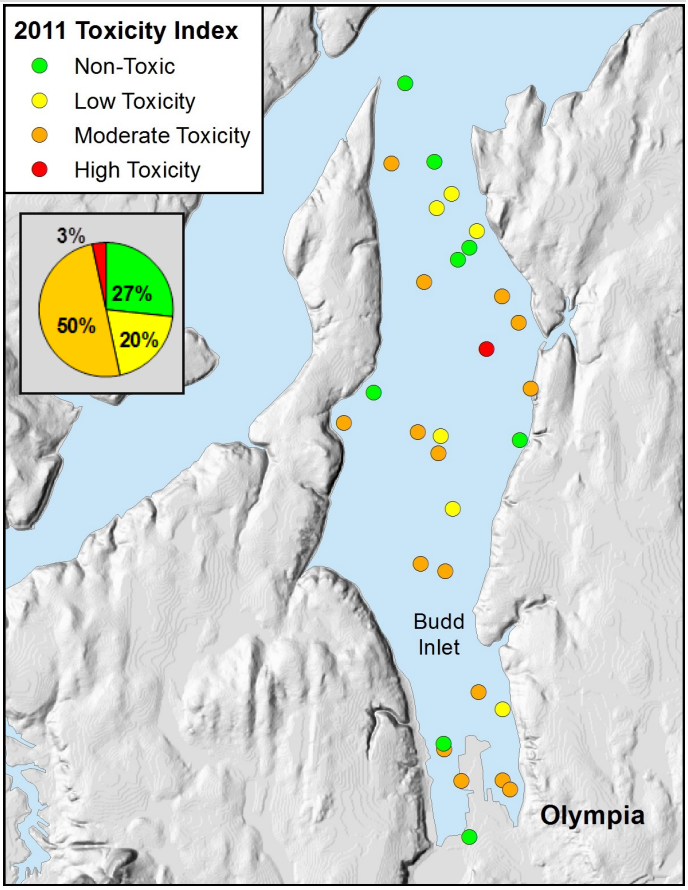
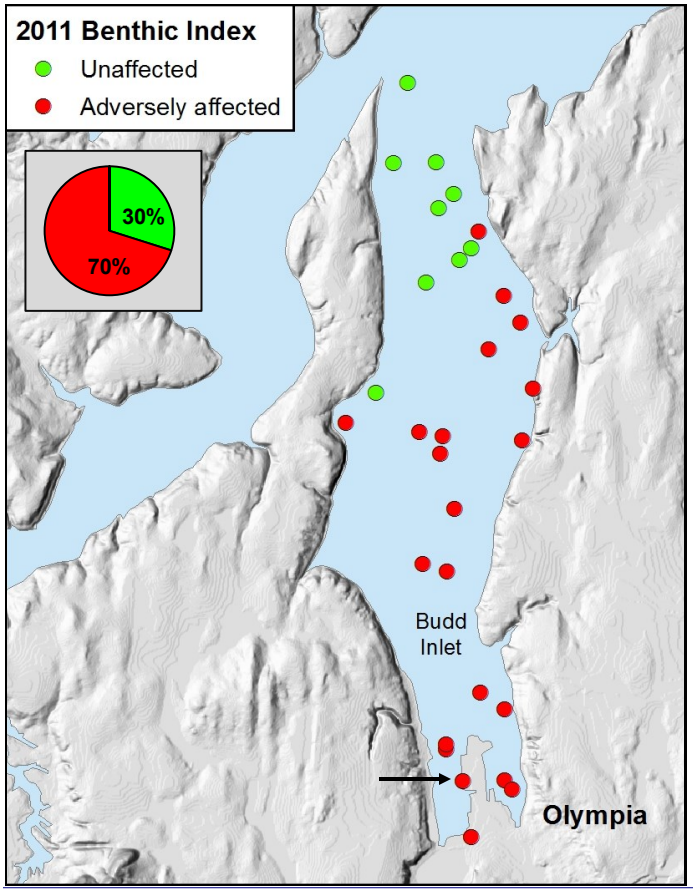


Figure 3 (right). Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Toxicity Index categories for Budd Inlet in 2011.

Figure 4 (below). Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Benthic Index categories in Budd Inlet in 2011. One site (arrow) had no organisms larger than 1 mm.



Benthic Index

Benthic invertebrate organisms (benthos) were identified and counted for 29 of the 30 locations sampled in 2011. One site in the southwest corner of the inlet had no invertebrates large enough to be retained on a 1-mm mesh screen. At another site in the southeast corner, the only invertebrates found were 1 small arthropod and 2 small molluscs.

Ecology's Benthic Index is a determination of whether the invertebrate assemblages appear to be *adversely affected* or *unaffected* by natural and/or human-caused stressors. The determination is made by benthic experts, based on a suite of calculated indices, including total abundance, major taxa abundances, taxa richness, evenness, and species dominance, compared to median values for all of Puget Sound. Abundances of stress-sensitive and stress-tolerant species at each station are also considered.

The benthic assemblages from the 2011 Budd Inlet survey were judged to be *adversely affected* for 70% of the samples, representing 70% of the study area (Figure 4). Only samples from near the mouth of the bay were judged to be *unaffected*.

Annelids (marine worms) were numerically dominant at most *adversely affected* sites, though none were found at two sites. The pollution-tolerant *Aphelochaeta* spp. annelids were among the dominant species. Among the *unaffected* sites, echinoderms were well-represented and frequently numerically dominant; at *adversely affected* sites, however, echinoderms were sparsely represented and usually absent. With the exception of one site, mollusc abundance was generally low, even among *unaffected* samples.

One location at the southeastern tip of the bay had high total abundance, predominantly oligochaete annelids. Aside from that site, total abundance was generally higher in the northern portion of the bay than elsewhere. Taxa richness (number of species) and abundances of arthropods, echinoderm, and miscellaneous taxa tended to be highest in the northern part of the bay.

Triad Index

The sediment triad concept of characterizing sediment condition is an empirical weight-of-evidence approach, originally conceived of and reported for Puget Sound (Long and Chapman, 1985).

Ecology's Triad Index combines evidence from the triad of measures (chemistry, toxicity, and benthos) to classify sediment quality into six categories of impact by chemical contamination and/or other environmental stressors (Dutch et al., 2014). Categories range from *unimpacted* to *clearly impacted*, and *inconclusive* when lines of evidence are conflicting. This multiple-lines-of-evidence approach was adapted from methods developed for the state of California to classify sediment quality (Bay and Weisberg, 2012).

In 2011, 30% of the study area was classified as *unimpacted* (Table 2; Figure 5). *Unimpacted* sediments were found only in the northern portion of Budd Inlet. *Likely unimpacted* sediments represented 10% of the area and were found in the southwest and east-central portions of the inlet.

The majority (53%) of the area was classified as *possibly impacted* or *likely impacted*. These sediments were distributed throughout the central and southern portions of the inlet.

No *clearly impacted* sediments were found in Budd Inlet.

The remaining 7% of the area was classified as *inconclusive*, with conflicting Chemistry, Toxicity, and Benthic Index results (Table 2).

Adversely affected benthos in 70% of the samples was the primary contributor to the *impacted* Triad Index results.

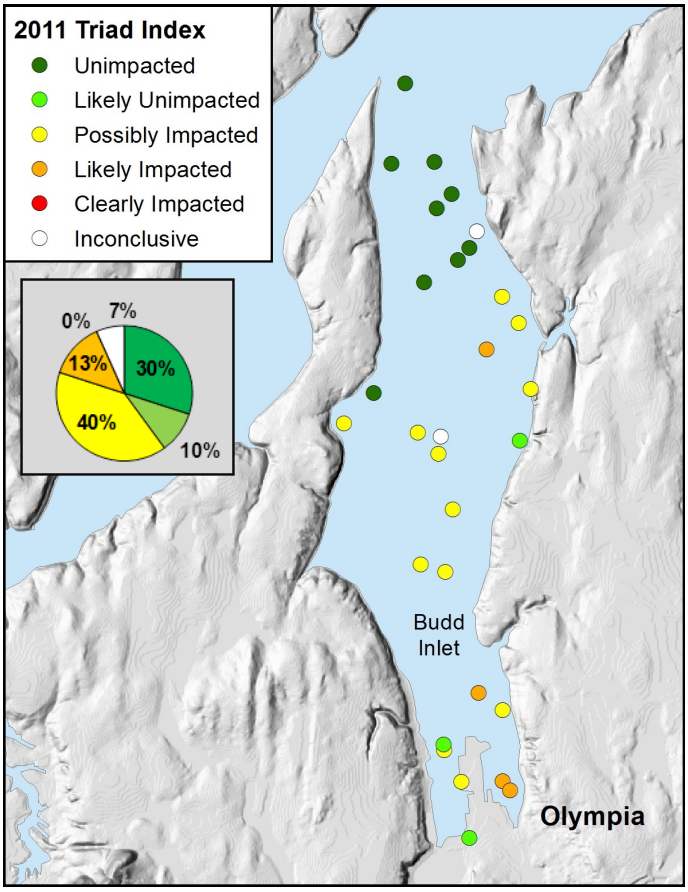


Figure 5. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie

Table 2. Specific combinations of index results (chemistry, toxicity, benthic) that led to Triad Index categories for Budd Inlet in 2011. Spatial extent (percent of study area) is given for each combination.

Chemistry Index	Toxicity Index	Benthic Index	Triad Index	% of Area
Minimum exposure	Non-Toxic	Unaffected	Unimpacted	16.7
	Low			6.7
	Moderate			6.7
Minimum exposure	Non-Toxic	Adversely affected	Likely unimpacted	6.7
Low exposure				3.3
	Low		Possibly impacted	6.7
Minimum exposure	Moderate			33.3
Low exposure			Likely impacted	10.0
Minimum exposure	High			3.3
	Low		Inconclusive	6.7

Budd Inlet Compared to South Puget Sound and All of Puget Sound

Comparison of the 2011 Budd Inlet Triad Index results to those for the South Sound region in 2011 and the 1997-2003 Puget Sound baseline shows that Budd Inlet had significantly lower sediment quality than the encompassing region and Puget Sound as a whole (Figure 6).

The *adversely affected* condition of the benthos was the primary factor influencing the extents of the Triad Index categories for Budd Inlet.

More information on sediment conditions in South Sound is available in the companion report, "Sediment Quality in South Puget Sound, Changes from 1999 to 2011" (https://fortress.wa.gov/ecy/publications/summarypages/1403006.html).

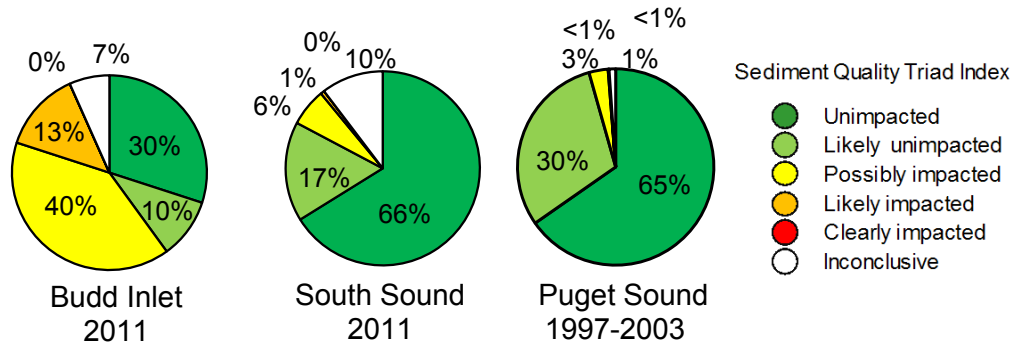


Figure 6. Spatial extent (percent of area) for the Triad Index categories for Budd Inlet in 2011 (from Figure 5), compared to the surrounding South Puget Sound region and the Puget Sound 1997-2003 baseline.

The Chemistry Index and the Triad Index as "Vital Signs" Indicators for the Puget Sound Partnership

Ecology's Chemistry and Triad Indices, and also the percent of chemicals exceeding (not meeting) Washington Sediment Quality Standards (SQS) (Ecology, 2013), were adopted by the Puget Sound Partnership (PSP) to serve as "Vital Signs" indicators of the condition of Puget Sound (www.psp.wa.gov/vitalsigns/index.php).

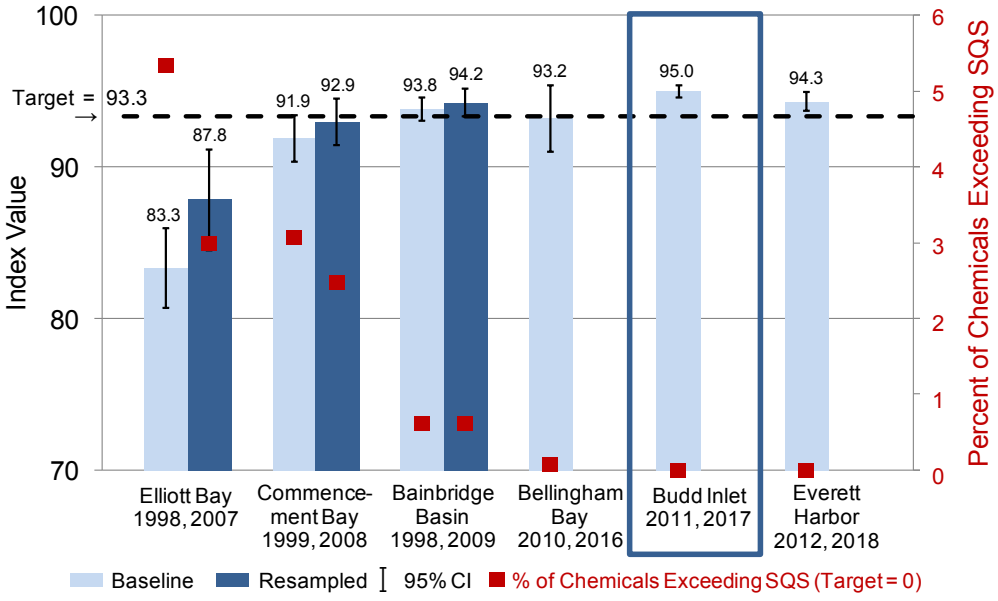


Figure 7. Change over time in Chemistry Index values for six urban bays in Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. The PSP's 2020 target value of 93.3 is shown as a dashed black line. Red squares illustrate the percentages of chemicals with concentrations exceeding (not meeting) SQS.

Weighted mean Chemistry and Triad Index values are compared with target values for highest quality for 2020, adopted by the PSP. The indices also are compared between years of repeated sampling to determine changes over time, as well as among urban bays.

The weighted mean Chemistry Index value for Budd Inlet was above the 2020 target value of 93.3 (Figure 7). Budd Inlet was similar to the other urban bays except Elliott Bay.

The percent of chemicals in Budd Inlet in 2011 exceeding SQS met the PSP target of zero (Figure 7).

The weighted mean Triad Index value for the 2011 Budd Inlet survey was below the PSP target value of 81 (Figure 8). The target value corresponds to the minimum value in the *unimpacted* Triad Index category.

Furthermore, the 2011 Budd Inlet Triad Index value was statistically significantly lower than that of any of the other urban bays except Bellingham Bay (Figure 8).

The condition of the benthos was the largest driver of the Triad Index results for Budd Inlet, with widespread toxicity the secondary contributor.

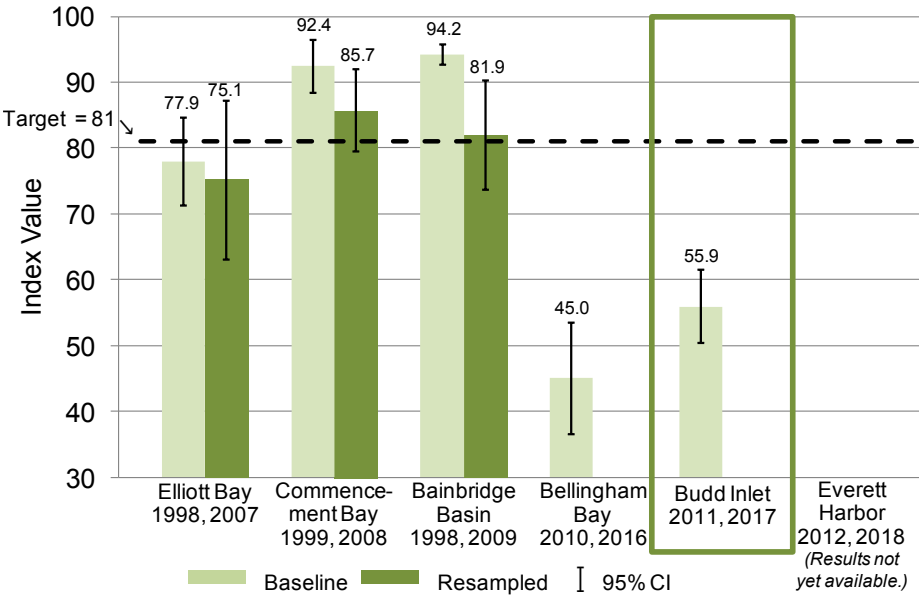


Figure 8. Change over time in Triad Index values for six urban bays in Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. Also shown is the PSP's 2020 target value of 81 (dashed black line).

Summary and Conclusions

The condition of the sediments in Budd Inlet was significantly worse than in the encompassing South Sound region as a whole and worse than in the entire Puget Sound. Overall sediment quality, as measured by the Triad Index, was similar to that in Bellingham Bay and significantly lower than that in some other urban bays.

Low to *moderate toxicity* was found throughout Budd Inlet, with no apparent geographical pattern. Other geographical patterns were evident, however: *low exposure* to contaminants occurred primarily in the southeastern corner, and *adversely affected* benthos were found throughout the central and southern portions of the inlet. *Unaffected* benthic invertebrate communities and overall *unimpacted* sediment conditions occurred only at or near the mouth of the inlet.

Puget Sound Partnership targets for contamination were met, but the target for overall sediment quality was not, suggesting that the chemicals for which Washington State numerical Sediment Quality Standards have been defined are not the problem. The widespread *adversely affected* condition of the benthic invertebrate communities and sediment toxicity drove the sediment quality characterization.

Although there was overlap in the geographical occurrence of *adversely affected* benthos and sediment toxicity, it cannot be concluded from this survey alone that declines in the benthic invertebrate communities resulted from toxic conditions. Other factors, natural or human-caused, not measured in this study could have been important. Further study is required to identify possible factors and their effects.

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[1] Now called the Puget Sound Ecosystem Monitoring Program.

Department of Ecology Contacts

Authors: Valerie Partridge, Sandra Weakland, Margaret Dutch, Edward Long, and Kathy Welch
Environmental Assessment Program
P.O. Box 47600
Olympia, WA 98504-7600

Communications Consultant
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov/

Headquarters, Olympia	(360) 407-6000
Northwest Regional Office, Bellevue	(425) 649-7000
Southwest Regional Office, Olympia	(360) 407-6300
Central Regional Office, Yakima	(509) 575-2490
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