Sediment Quality in the Whidbey Basin, Changes from 1997 to 2007

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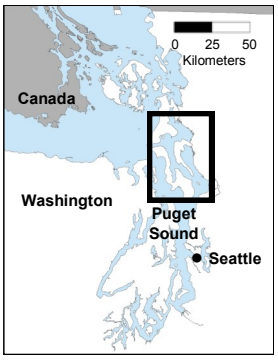
Overall sediment quality did not change significantly from 1997 to 2007

Improvement

- Decreased concentrations of most metals and polycyclic aromatic hydrocarbons (PAHs)
- Decreased toxicity

Deterioration

- Increased concentrations of lead, biphenyl, and naphthalene
- Decreased arthropod abundance



In 2007, the Washington State Department of Ecology (Ecology) surveyed surface sediment conditions throughout the Whidbey Basin region of Puget Sound (box in map at right) and compared them to those from a similar survey conducted with the same methods in 1997. Overall sediment quality in the Whidbey Basin did not change significantly over this ten-year period. However, there were significant changes in several individual parameters.

Sediment contaminant, toxicity, and sediment-dwelling (benthic) invertebrate data were summarized as Ecology's respective Chemistry, Toxicity, and Benthic Indices and combined Sediment Quality Triad Index (Dutch et al., 2012). These indices were developed to display the different types of information on a scale from 0 (poorest quality) to 100 (highest quality).

The survey design weights sample results to enable estimation of percent of area (spatial extent) with given sediment conditions and comparison of results from the two surveys at a glance. The weighted mean sediment quality indices increased slightly, but not statistically significantly, suggesting possible improvements (Figure 1).

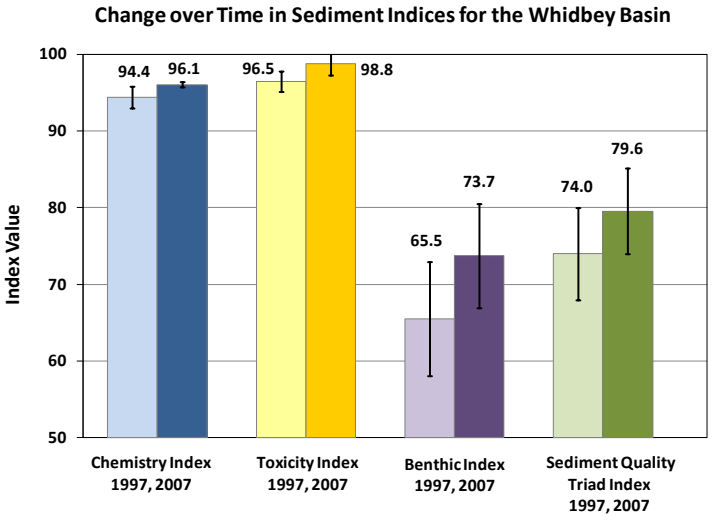


Figure 1. Weighted mean index values and 95% confidence intervals, showing slight, but not statistically significant, increases (suggesting improvements) from 1997 to 2007.

We are on the web

The primary results of the 2007 survey and comparisons to the 1997 results are given here. Data and supporting information, including methods, are available on Ecology's website: www.ecy.wa.gov/programs/eap/psamp.

Sediment Monitoring of the Whidbey Basin

Ecology surveyed the Whidbey Basin region as part of the Puget Sound Ecosystem Monitoring Program (PSEMP). The region extends from Possession Sound to Deception Pass and includes all marine waters east of Whidbey Island. The study area consists of rural embayments and passages from 2 m to 180 m deep, plus the shallow industrialized harbors of Port Gardner and Everett. This region previously had been studied in a baseline survey conducted jointly by Ecology and the National Oceanic and Atmospheric Administration in 1997 (Long et al., 2005), with the same field and laboratory methods. New sampling sites were selected for the 2007 survey, and some analyses of the 1997 data were updated for consistency with current statistical methods, for comparison. The study design, sampling and analytical methods, and list of parameters are described in Dutch et al. (2009) and on Ecology's website.

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Physical Conditions in the Whidbey Basin

Sediments throughout the region were evenly divided between sand or silty sand (< 40% silt-clay) and finer-grained mixtures. Total organic carbon (TOC) content of most of the sediment samples was less than 2%, ranging up to almost 6% by weight. TOC content was highest in harbor areas, especially Everett Harbor.

Compared to 1997, TOC content in 2007 was lower overall, but when weighted by area was not statistically significantly different at α=0.05 (95% confidence). Grain size, however, displayed a significant shift toward sandier sediments, especially when weighted by area, though the median percent fines (silt+clay) did not change significantly (α=0.05).

Sediment Chemistry Index

Samples were analyzed for the concentrations of 129 potentially toxic chemicals, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other organic compounds (Dutch et al., 2009). Metals and PAHs were almost always detected and measurable (91% of samples). The other target organic compounds (e.g., PCBs, pesticides) were detected in only 8% of samples.

Two chemicals were found in concentrations not meeting (exceeding) the Washington State Sediment Quality Standards (SQS) (Ecology, 1995), each at one station. By contrast, in 1997, five chemicals exceeded the SQS at five stations, multiple chemicals at multiple stations each.

Ecology's Sediment Chemistry Index (Long et al., 2013) indicated that 97% of the study area had *minimum exposure* to chemical contaminants in 2007 (Figure 2). The Chemistry Index is an effects-based, multi-chemical index that accounts for the presence, concentrations, and potential toxicity of mixtures of chemicals. It is used to categorize sediments as

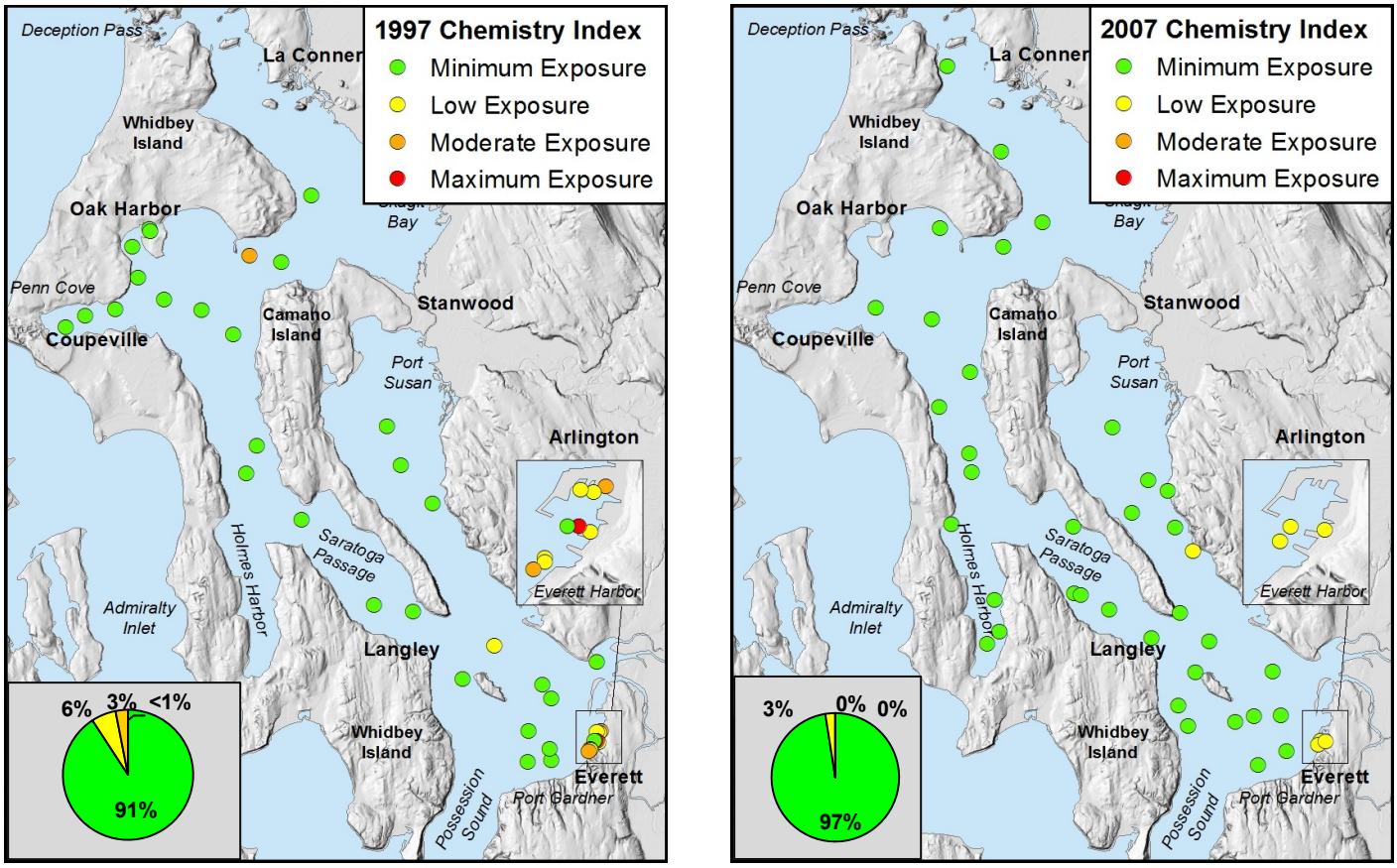

Figure 2. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Sediment Chemistry Index categories for the Whidbey Basin region. There was no statistically significant change (α=0.05) in spatial extent of the four Chemistry Index categories of exposure from 1997 to 2007.

having *minimum*, *low*, *moderate*, or *maximum* levels of exposure to the chemicals for which SQS have been defined. In 2007, none of the study area was classified as having *moderate* or *maximum exposure*. The spatial extent (% of area) in the four Chemistry Index categories in 2007 was not significantly different from the spatial extent in 1997 (α=0.05).

Although the spatial extent in the four Chemistry Index categories did not change, there were significant changes (α=0.05) in some individual contaminants. The concentrations of several metals (arsenic, cadmium, copper, mercury, silver, tin, zinc) decreased throughout the region from 1997 to 2007, but lead concentrations increased except in Everett Harbor. Most PAHs decreased, though naphthalene increased. Levels of the PAHs acenaphthylene and methyl-substituted naphthalenes remained unchanged.

Sediment Toxicity Index

In the 2007 survey, each sediment sample was analyzed with a laboratory toxicity test of sea urchin egg fertilization. The test results were used in Ecology's Sediment Toxicity Index (Dutch et al., 2012) and characterized into four toxicity ranges, from *non-toxic* to *high toxicity* (Table 1). The Toxicity Index indicated that the majority (95%) of the study area had *non-toxic* sediments.

Table 1. Toxicity Index category descriptions.

Toxicity Index	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

Overall, the spatial extent of sediments characterized by the four Toxicity Index categories did not change significantly from 1997 to 2007 (α=0.05). The spatial extent of toxicity remained effectively unchanged at 6% in 1997 vs. 5% in 2007 (Figure 3).

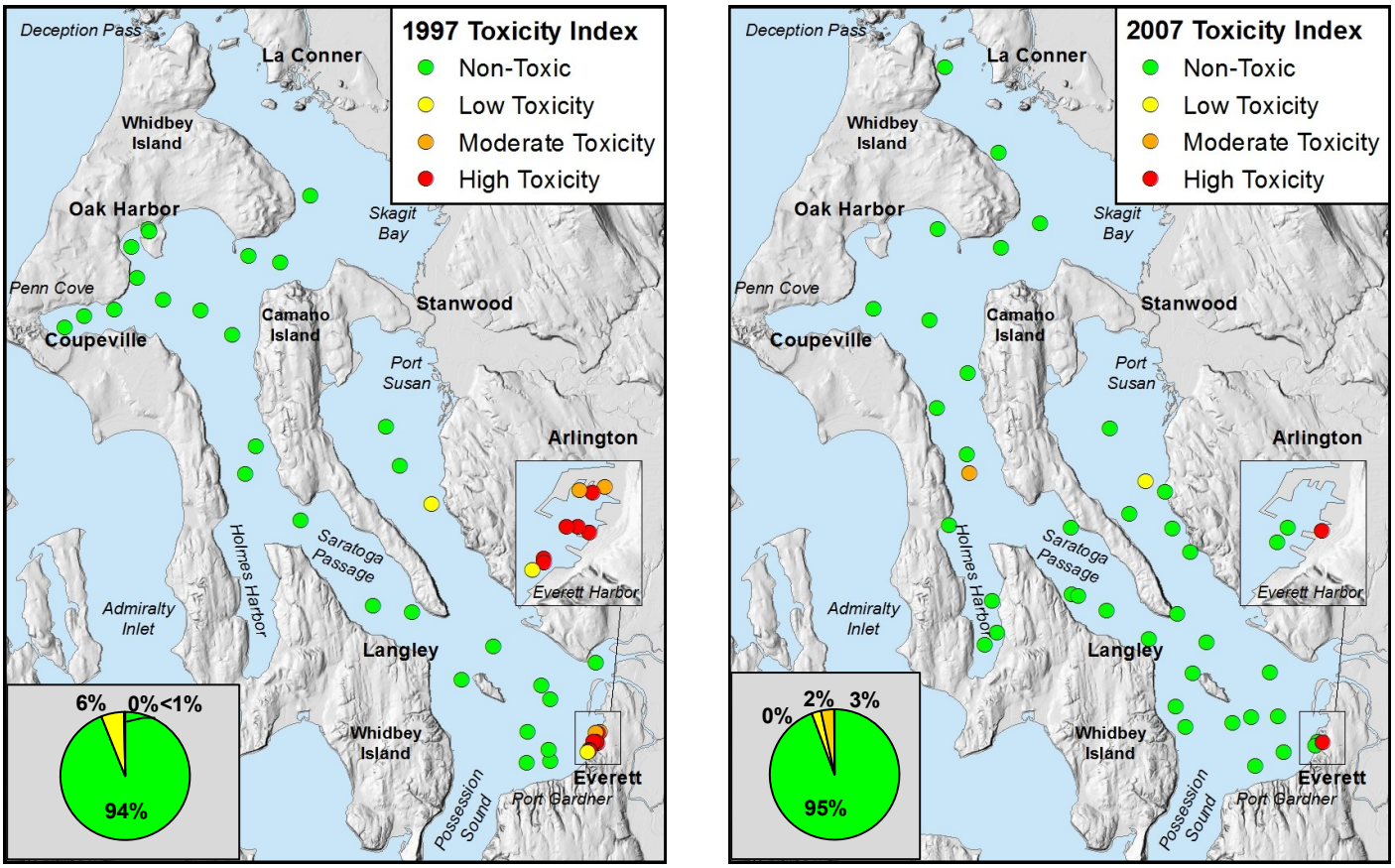

Figure 3. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Sediment Toxicity Index categories for the Whidbey Basin region. There was no statistically significant change (α=0.05) in spatial extent of the four Toxicity Index categories from 1997 to 2007.

Sediment Benthic Index

Benthic invertebrate organisms (benthos) were identified and counted for all 40 locations sampled in 2007, and several measures of benthic abundance and diversity were calculated. Total abundance and taxa richness (number of taxa, or species) tended to be slightly higher in northern Skagit Bay and Port Gardner than elsewhere in the region. Annelids (marine worms) and molluscs were numerically dominant in northern Skagit Bay, whereas annelids and arthropods were the most numerous in outer Everett Harbor. Although arthropod abundance increased from 1997 to 2007 in Everett Harbor, it decreased significantly throughout the rest of the region. Other benthic measures remained unchanged overall.

Ecology's Benthic Index was calculated by examining the data to determine whether the invertebrate assemblages appeared to be *adversely affected* or *unaffected* by natural and/or anthropogenic (human-caused) stressors. The determination was made by benthic experts based on a best-professional-judgment assessment of a suite of calculated indices (total abundance, major taxa abundances, taxa richness, evenness, and species dominance). These indices were compared to median values calculated from benthos data collected throughout Puget Sound. Abundances of stress-sensitive and -tolerant species at each station were considered as well. The benthos data for all samples collected in Puget Sound from 1997 through 2007 were assessed at the same time, by the same experts, using the same methods, with species standardized across the years, for consistency over all surveys.

The benthic assemblages from the 2007 Whidbey Basin survey were judged to be *adversely affected* in slightly more than half (53%) of the Whidbey Basin study area. By contrast, in 1997, 69% of the study area had *adversely affected* benthos. Although there was a decrease in spatial extent from 69% of the study area in 1997 to 53% in 2007, it was not statistically significant (α=0.05). The geographic patterns in occurrence of *adversely affected* assemblages were similar in the two years surveyed (Figure 4).

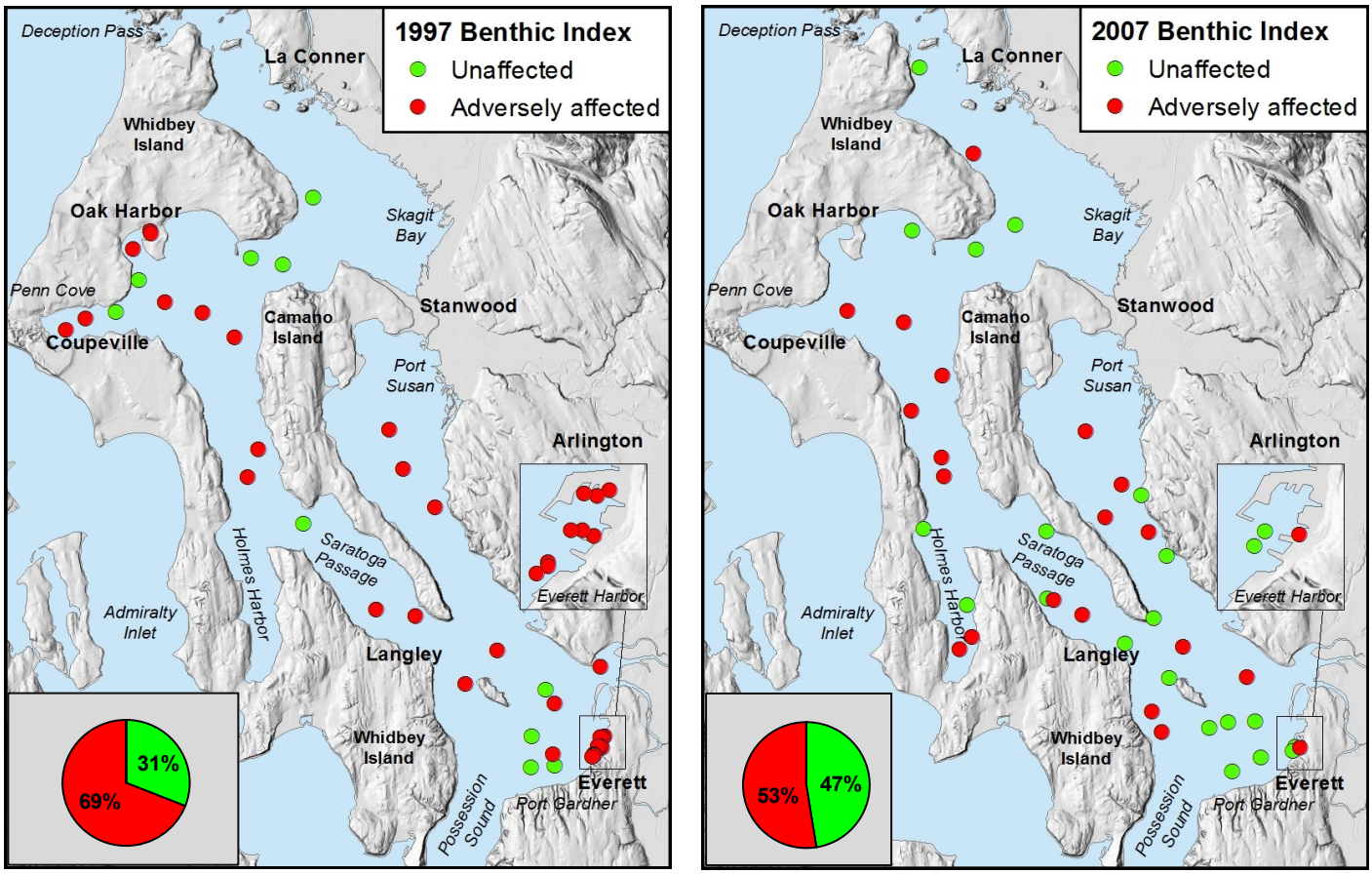

Figure 4. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Sediment Benthic Index categories for the Whidbey Basin region. There was no statistically significant change (α=0.05) in spatial extent of the two Benthic Index categories from 1997 to 2007.

Sediment Quality Triad Index

Ecology's Sediment Quality Triad Index combines the evidence from the triad of measures (chemistry, toxicity, benthos) to classify sediment quality into six categories of impact by chemical contamination and/or other environmental stressors (Dutch et al., 2012). 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 2007, slightly under half (48%) of the study area was classified as *unimpacted* (Table 2; Figure 5). Another 47% of the area was determined to be *likely unimpacted*. Sediments which were *possibly impacted* and *likely impacted* by chemical contamination and/or other environmental stressors were found in about 3% of the study area. None of the area was classified as *clearly impacted*, and conditions at one station were *inconclusive*.

Table 2. Specific combinations of index results (chemistry, toxicity, benthos) that lead to Sediment Quality Triad Index categories for Whidbey Basin in 2007. Spatial extent (percent of study area) is given for each combination.

Triad Index =	Benthic Index +	Toxicity Index +	Chemistry Index	% of Area
Unimpacted	Unaffected	Non-Toxic	Minimum exposure	45.0
	Unaffected	Non-Toxic	Low exposure	2.5
Likely unimpacted	Adversely affected	Non-Toxic	Minimum exposure	46.9
Possibly impacted	Adversely affected	Moderate toxicity	Minimum exposure	3.3
Likely impacted	Adversely affected	High toxicity	Low exposure	0.1
Inconclusive	Adversely affected	Low toxicity	Minimum exposure	2.3

Spatial extent of the Triad Index categories did not significantly change from 1997 to 2007 (α=0.05). The geographic patterns in occurrence of Triad Index categories region-wide also were similar in the two years surveyed (Figure 5). The data suggested improvements in sediment quality in inner Everett Harbor, but the numbers of samples were very small.

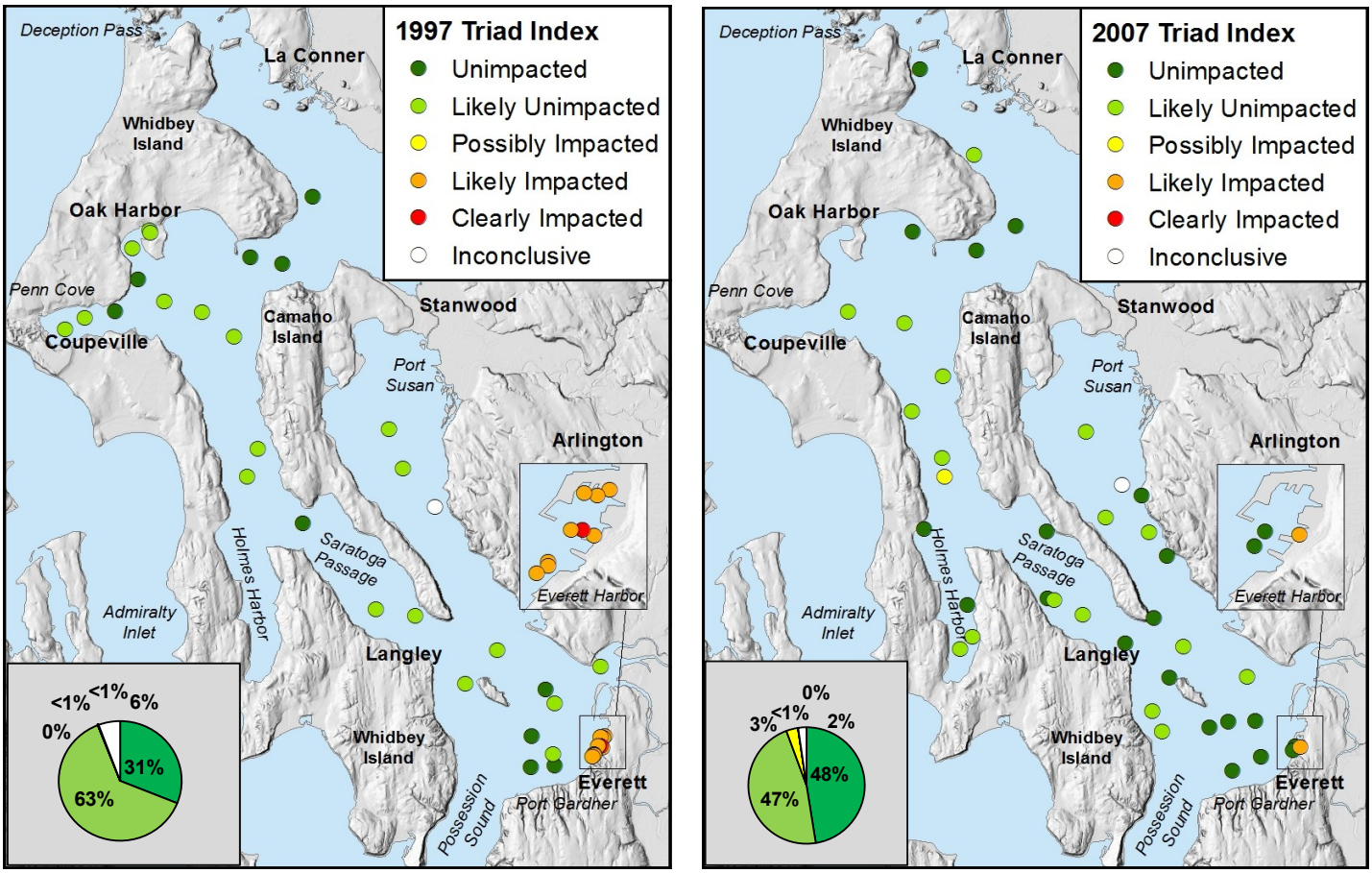

Figure 5. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Sediment Quality Triad Index results in the Whidbey Basin region. There was no statistically significant change (α=0.05) in spatial extent of the six Triad Index categories from 1997 to 2007.

Whidbey Basin Sediment Quality Compared to All of Puget Sound

Comparison of the 2007 Whidbey Basin Sediment Quality Triad Index results to those for the 1997-2003 Puget Sound baseline shows that a significantly (α=0.05) lower proportion of area in Whidbey Basin was classified as *unimpacted* than in Puget Sound as a whole (Figure 6). Correspondingly, the Whidbey Basin had a significantly higher proportion of area classified as *likely unimpacted* than did all of Puget Sound. The condition of the benthos was the primary factor influencing the extents of the Triad Index categories for the region and Puget Sound-wide.

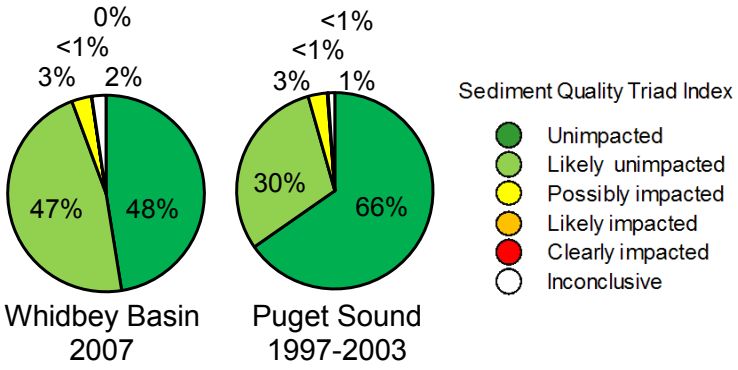

Figure 6. Spatial extent (percent of area) for the Sediment Quality Triad Index categories for the Whidbey Basin region in 2007 (from Figure 5), compared to the Puget Sound 1997-2003 baseline. The differences in the *unimpacted* and *likely unimpacted* categories are significant (α=0.05).

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

Ecology's Chemistry and Triad Indices, and also the percent of chemicals exceeding Washington State Sediment Quality Standards (SQS), were adopted by the Puget Sound Partnership (PSP) in 2010 to serve as "Vital Signs" indicators of the condition of Puget Sound (www.psp.wa. gov/vitalsigns/index.php).

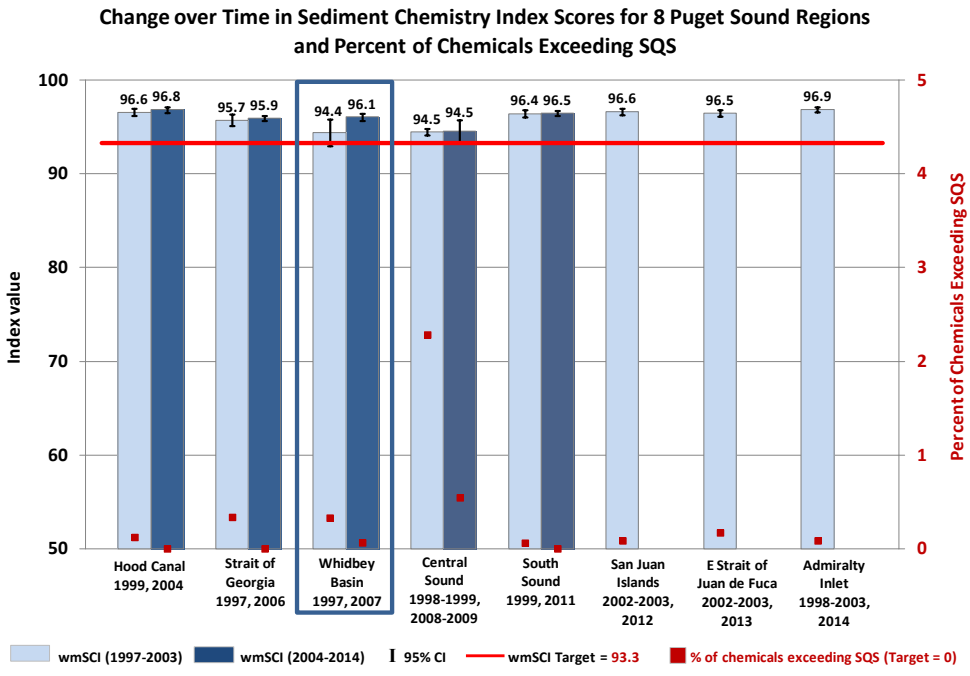

Figure 7. Weighted mean Sediment Chemistry Index values and 95% confidence intervals for all sediment monitoring regions sampled from 1997 to 2003 (Puget Sound baseline) and resampled from 2004 to 2009. Also shown is the percent of chemicals whose concentrations exceed Washington Sediment Quality Standards.

Weighted mean Chemistry and Triad Index values are compared among regions and between repeated years of sampling to determine changes over time. They are also compared with 2020 target values selected by the PSP.

The weighted mean Chemistry Index values for Whidbey Basin and seven other regions all surpass the 2020 target value of 93.3, indicating highest quality (Figure 7). The target value corresponds to the minimum value of the *minimum exposure* category, not weighted by percent area.

The percent of chemicals exceeding SQS in Whidbey Basin decreased from 1997 to 2007, but did not meet the target of zero.

Comparisons of regional Triad values show Whidbey Basin not meeting the PSP target value of 81 in 1997, but improved and statistically meeting the target when resampled in 2007 (Figure 8). The target value corresponds to the minimum value, unweighted, in the *unimpacted* category. The condition of the benthos was the primary contributing factor to Triad values in the Whidbey Basin being below target.

Other sediment monitoring regions not meeting the Triad Index target value were Hood Canal, the San Juan Islands, and the Eastern Strait of Juan de Fuca. Triad values declined slightly but not significantly in Hood Canal and the Strait of Georgia, and decreased in Central Sound (significant at α=0.05).

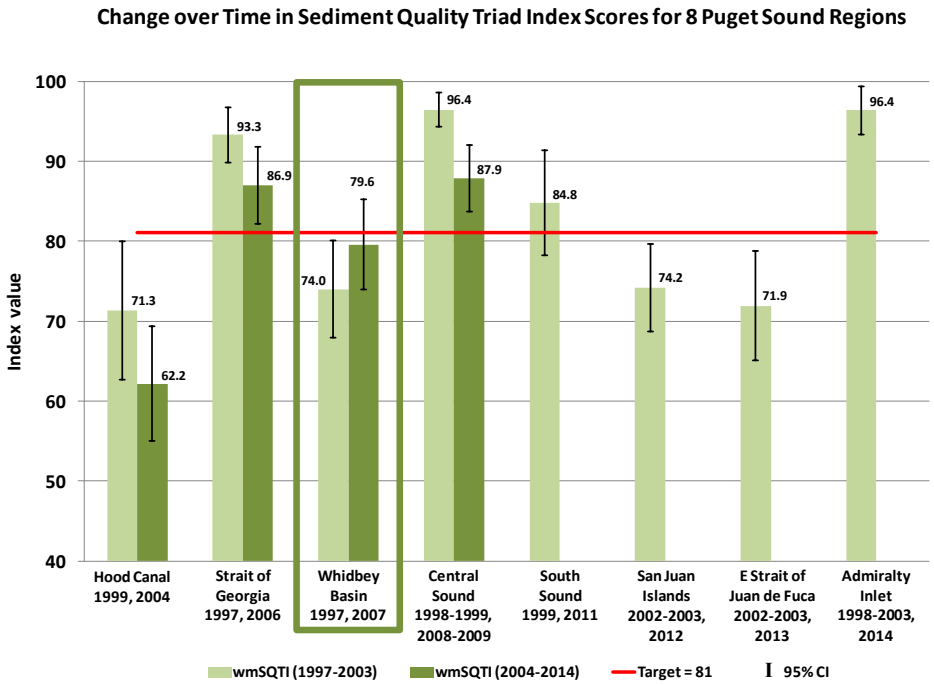

Figure 8. Weighted mean Sediment Quality Triad Index values and 95% confidence intervals for all sediment monitoring regions sampled from 1997 to 2003 (Puget Sound baseline) and resampled from 2004 to 2009.

Summary and Conclusions

Results indicated both *minimum exposure* to chemical contaminants and *non-toxicity* (combined) for 92% of the area of the Whidbey Basin in 2007. The benthos, however, were *adversely affected* by natural or anthropogenic stressors at over half the stations, suggesting that communities may be influenced by stressors other than chemical contamination. Triad Index values classified 95% of the area as having either *unimpacted* or *likely unimpacted* sediment quality. Although the comparisons of the sediment quality indices for the region in 1997 vs. 2007 did not show statistically significant changes, there were suggestions of improvements in all four indices.

The weighted mean Chemistry Index values for the Whidbey Basin region surpassed the target value adopted by the PSP for that "Vital Signs" indicator. The weighted mean Triad Index value for Whidbey Basin was initially below its PSP target, due primarily to benthic community condition, but improved to meet the target in 2007.

Recommendations

- Continue annual PSEMP sediment quality monitoring to determine spatial status and temporal trends in regions and bays. Expand surveys to other environmentally important bays and the nearshore.
- Continue to update, refine and improve Puget Sound chemistry, toxicity, and benthic indicators by (1) quantifying new suites of chemicals of concern, (2) adopting more current and comprehensive methods of toxicity testing, including toxicity tests which are responsive to chemicals of emerging concern, and (3) continuing development and validation of a multivariate benthic index for Puget Sound.
- Determine additional environmental parameters to examine in conjunction with sediment monitoring which may be affecting the benthos, such as (1) water quality measures, including near-bottom dissolved oxygen, pH, and nutrient levels, and (2) rates of sediment deposition, mixing, and resuspension.
- Perform additional statistical analyses to examine relationships among the chemistry, toxicity, and benthos data.

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

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