Sediment Quality in South Puget Sound, Changes from 1999 to 2011

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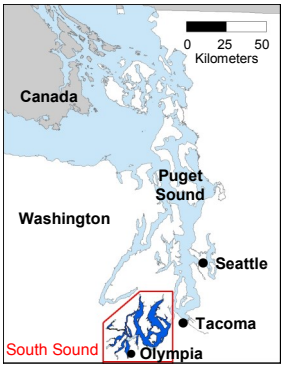
Findings

- Overall sediment quality in 2011 was categorized by the Triad Index as *unimpacted* for about two-thirds of the area of South Sound, the same as in 1999.
- A few areas, mostly in Budd Inlet, had *possibly* or *likely impacted* sediment.
- Exposure to chemical contaminants was *minimum* almost everywhere.
- More than half the area in 2011 had some degree of toxicity, a significant increase from 1999.
- Bottom-dwelling organisms were *adversely affected* in about one-third of South Sound, the same as in 1999.

In 2011, the Department of Ecology (Ecology) surveyed sediment conditions throughout South Puget Sound and compared them to conditions from a similar survey in 1999, as part of a Puget Sound status-and-trends monitoring program. The study area included all of the area south and west of the Tacoma Narrows (red box in map at right). Surface sediments (top 2-3 cm) from 55 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

Chemistry and Triad Index values for South Sound met Puget Sound Partnership (PSP) targets (Figure 1). The Chemistry, Benthic, and Triad Indices did not change significantly from 1999 to 2011, but the Toxicity Index was significantly lower in 2011 than in 1999, indicating greater toxicity in 2011.

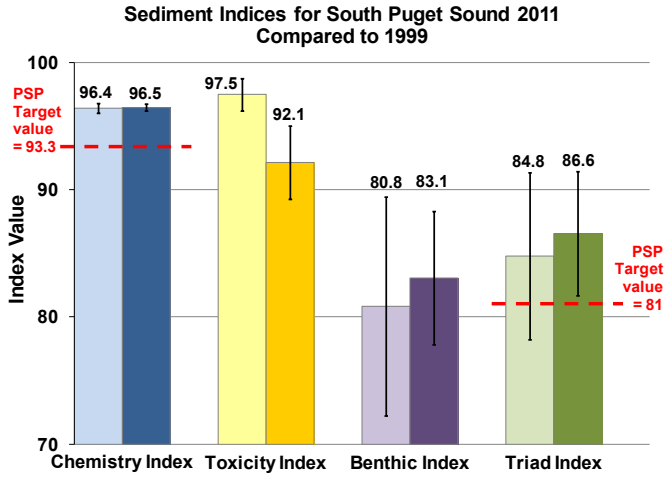


Figure 1. A comparison of weighted mean index values for the South Puget Sound region in 2011 (dark bars) and 1999 (light bars), with 95% confidence intervals. Also shown are the PSP target values for the Chemistry and Triad Indices (red dashed lines).

Want more information?

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

Sediment Monitoring of South Puget Sound

Ecology sampled sediments throughout South Puget Sound in June 2011 under the Puget Sound Ecosystem Monitoring Program (PSEMP). The region had been studied previously in a joint Ecology-National Oceanic and Atmospheric Administration survey in 1999 (Long et al., 2005), with the same field and laboratory methods and some of the same stations. The survey design weights sample results by area, which enables Ecology to estimate the percent of area (spatial extent) with given sediment conditions and to compare results from multiple surveys. 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 a separate, more intensive study of Budd Inlet, also conducted in 2011, see the companion report, "Sediment Quality in Budd Inlet, 2011" (Partridge et al., 2014).

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Physical Conditions

Sediments throughout South Puget Sound were predominantly mixed (40 to 80% silt-clay) and sandy (<20% silt-clay). Fine-grained sediments were found in the terminal inlets of the region, including Henderson, Budd, Eld, and Totten Inlets. Total organic carbon (TOC) content of most of the sediment samples was less than 1%, ranging up to 4% by weight. TOC content was highest in the harbor areas.

Chemical Contamination

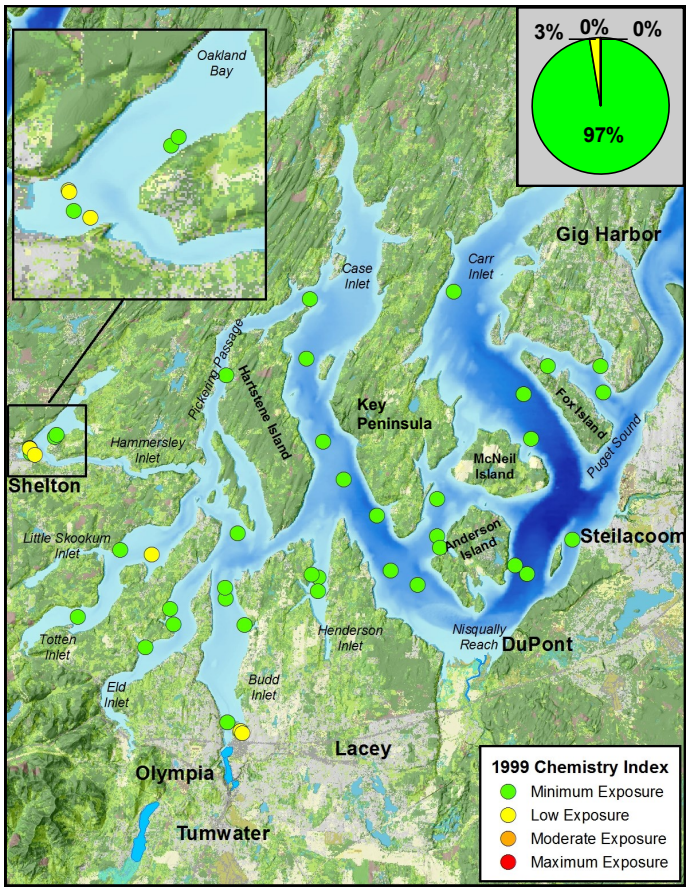
Samples were analyzed for the concentrations of 262 toxic chemicals, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other organic compounds. Metals and PAHs were almost always detected and measurable (93% of samples). The other target organic compounds (e.g., PCBs, pesticides) were detected in only 5% of samples.

Concentrations of individual chemicals decreased or remained unchanged from 1999 to 2011, with the exception of chromium and 2,6-dimethylnaphthalene, both of which increased.

No chemical concentrations were found above (not meeting) 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.



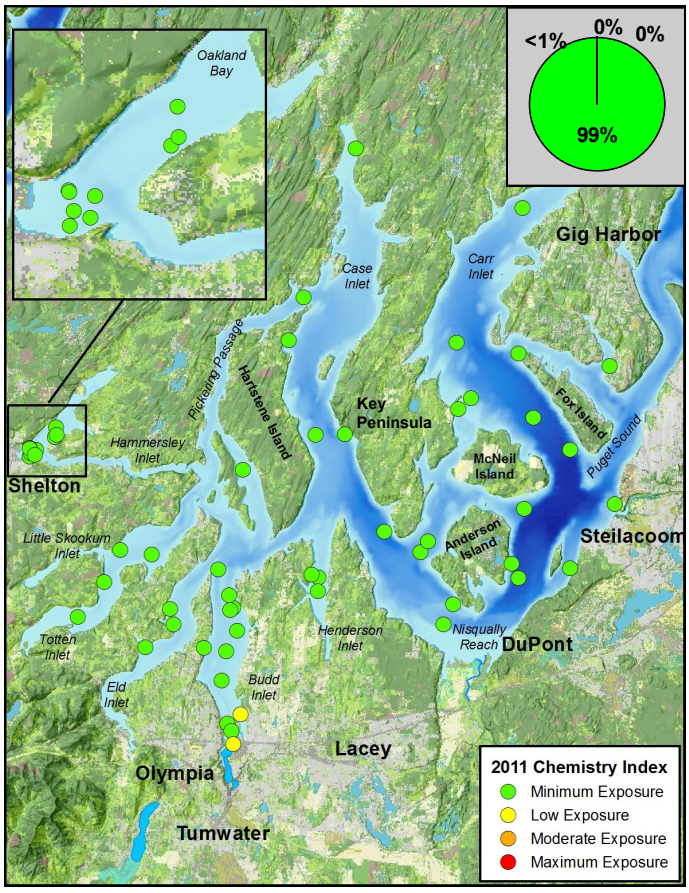


Figure 2. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Chemistry Index categories for South Puget Sound in 1999 and 2011.

The Chemistry Index indicated that nearly the entire (99%) study area had *minimum exposure* to chemical contaminants for which SQS have been defined. Two samples from southern Budd Inlet had *low exposure* to chemical contamination (Figure 2). The spatial extent of exposure to SQS-defined contaminants was not significantly changed from 1999.

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 just under half (48%) of the study area had *non-toxic* sediments. *Low* and *moderate toxicity* sediments were found throughout South Puget Sound (43% of the study area) and were more concentrated in Budd Inlet than elsewhere (Figure 3). Sediments with *high toxicity* were found at one site in the northeast corner of Budd Inlet.

Regionwide, toxicity increased significantly from 1999 to 2011, largely in Budd Inlet and other terminal inlets, but also in more open waters surrounding the Key Peninsula (Figure 3).

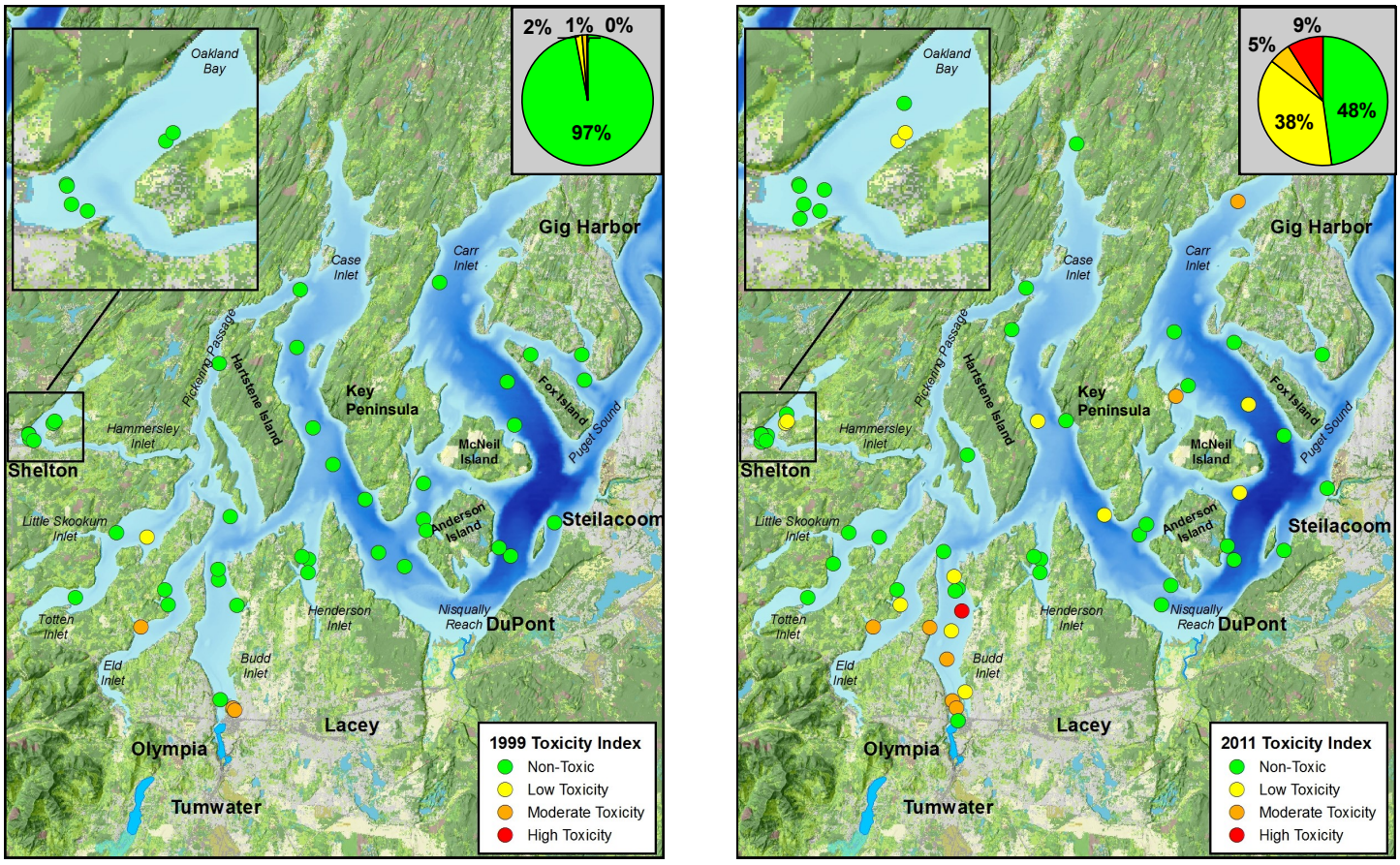


Figure 3. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Toxicity Index categories for South Puget Sound in 1999 and 2011.

Benthic Invertebrates

Benthic invertebrate organisms (benthos) were identified and counted for 54 of 55 locations sampled in 2011. One site in Budd Inlet had no invertebrates large enough to be retained on a 1-mm mesh screen.

Multiple community measures were calculated from the species and count data to characterize benthic invertebrate abundance and diversity. Total abundance was highest in central Carr Inlet and at the mouth of Budd Inlet. Taxa richness (number of species) tended to be higher at the margins of Case and Carr Inlets and east of McNeil and Anderson Islands than elsewhere in the region. Annelids were numerically dominant in central Carr Inlet. Echinoderms were most numerous at the mouth of Budd Inlet and, to a lesser extent, in outer Henderson Inlet. Arthropods were most numerous at the margins of Case and Carr Inlets and, to a lesser extent, in outer Budd, Eld, and Henderson Inlets. Molluscs and miscellaneous taxa were sparsely represented in South Puget Sound.

Benthic Index

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 South Puget Sound survey were judged to be *adversely affected* in 25 of the 55 samples, representing 34% of the area of the region (Figure 4). The spatial extent of *adversely affected* benthos was statistically unchanged from 1999 to 2011. Most of the *adversely affected* benthos were found in terminal inlets, with some surrounding the Key Peninsula (Figure 4).

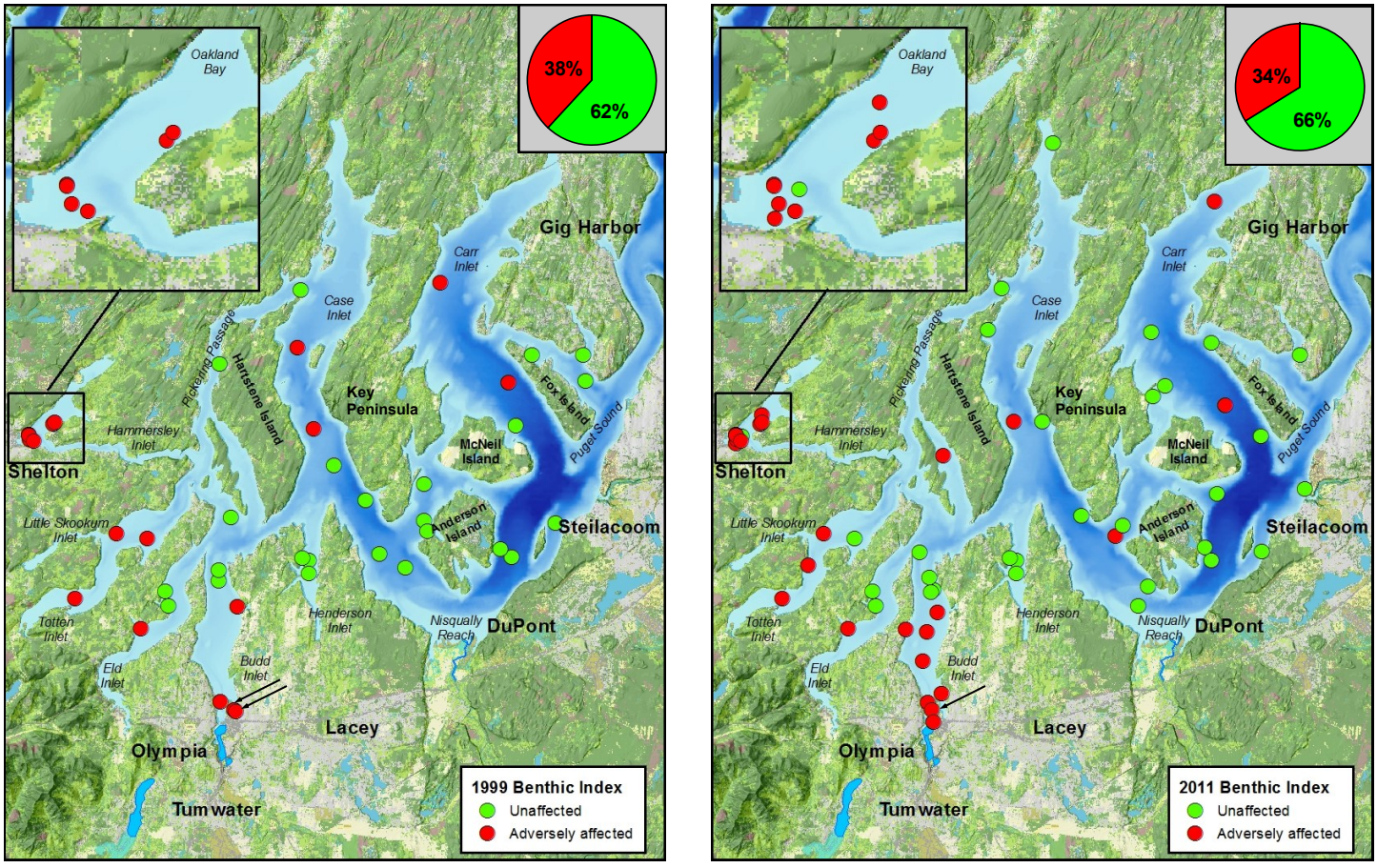


Figure 4. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Benthic Index categories in South Puget Sound in 1999 and 2011. One site in 2011 in southwest Budd Inlet and two sites in 1999 in southeast Budd Inlet, indicated with arrows, had no benthic organisms larger than 1 mm.

Triad Index

Ecology's Triad Index combines 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., 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).

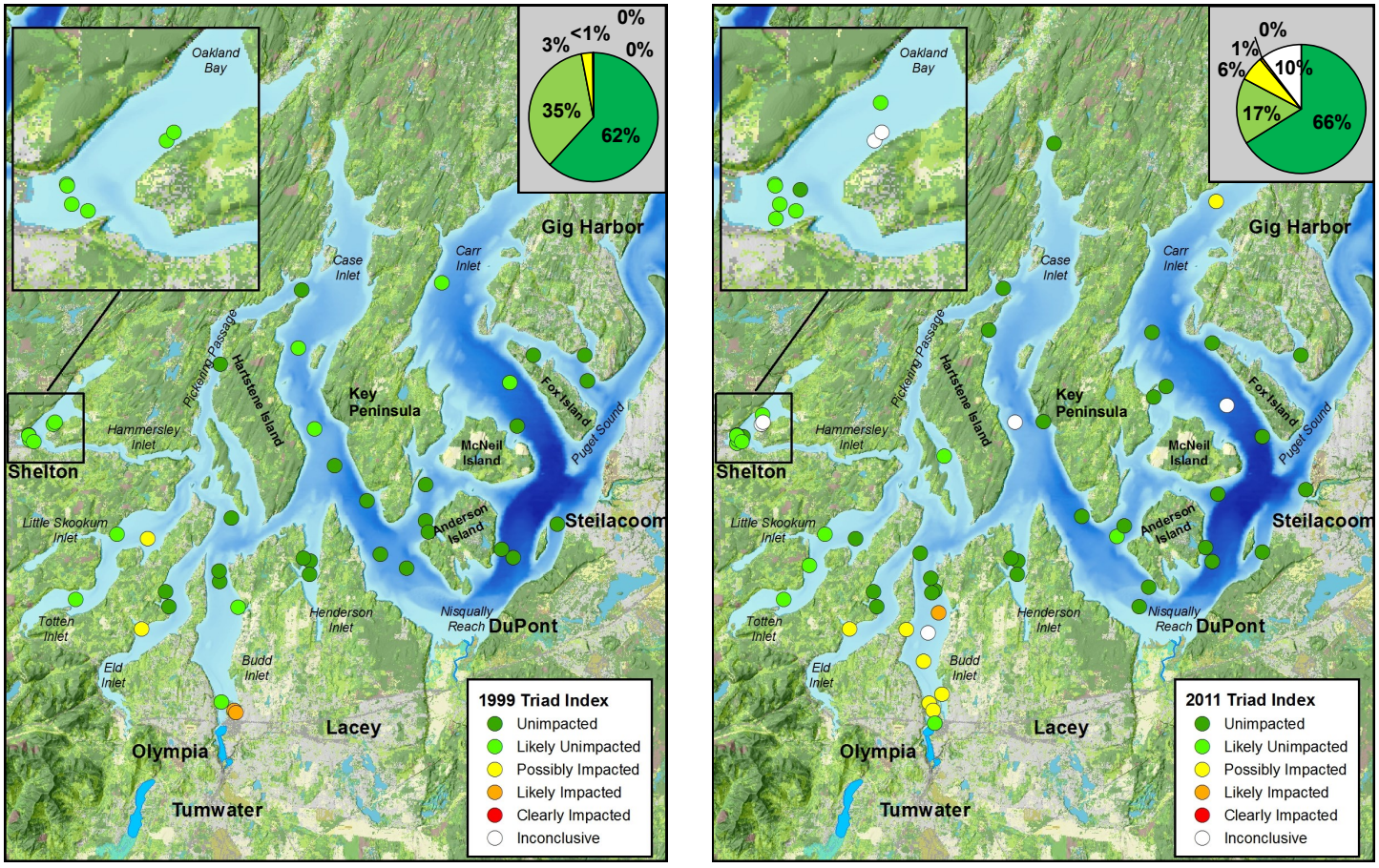


Figure 5. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Triad Index results in South Puget Sound in 1999 and 2011.

In 2011, none of the study area was classified as *clearly impacted*. The majority (55%) of the area was determined to be *unimpacted*, with *minimum* contamination and no toxicity (Table 2; Figure 5). An additional 11% of the area was classified *unimpacted* yet had either *low* or *moderate* toxicity.

Likely unimpacted sediments, which represented 17% of the study area, showed no chemical contamination or toxicity, but had *adversely affected* benthos. Sediments categorized as *possibly* or *likely impacted* were found in about 7% of the region. The remaining 10% was classified as *inconclusive*, with conflicting Chemistry, Toxicity, and Benthic Index results (Table 2).

Except for the increase in *inconclusive* results, the 2011 Triad Index category spatial extents were similar to 1999.

Table 2. Specific combinations of index results (chemistry, toxicity, benthic) that led to Triad Index categories for South Puget Sound 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	55.0
	Low			9.0
	Moderate			2.1
Low exposure	Non-Toxic	Adversely affected	Likely unimpacted	16.6
				< 0.1
	Low		Possibly impacted	< 0.1
Minimum exposure	Moderate			6.2
	High		Likely	0.7
	Low		Inconclusive	10.3

South Puget Sound Compared to All of Puget Sound

Comparison of the 2011 South Sound Triad Index results to those for 1999 shows no significant changes in sediment quality except an increase in *inconclusive* condition (Figure 6). Compared to the 1997-2003 Puget Sound baseline, the South Sound region in 2011 had significantly less *likely unimpacted* area and significantly more *inconclusive* results; otherwise, they were similar.

The *adversely affected* condition of the benthos was the primary factor influencing the extents of the Triad Index categories for South Puget Sound in both 1999 and 2011. The large increase in *low toxicity*, however, was the contributor to the increase in *inconclusive* conditions.

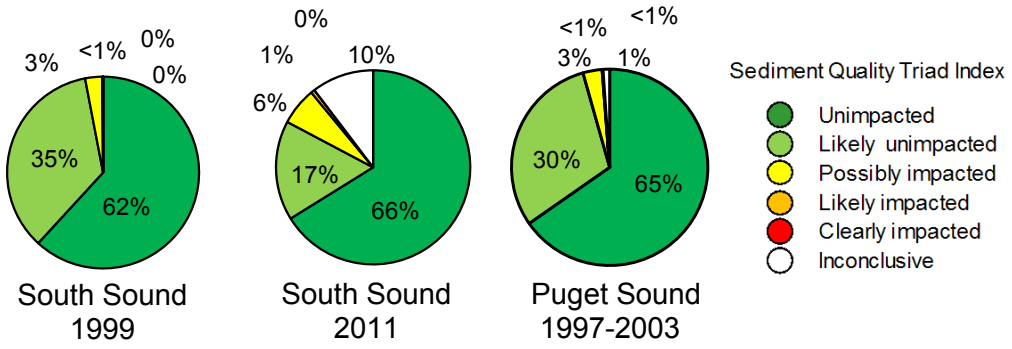


Figure 6. Spatial extent (percent of area) for the Triad Index categories for South Puget Sound in 2011 (from Figure 5), compared to 1999 and to the Puget Sound 1997-2003 baseline.

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 numerical 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). Weighted mean Chemistry and Triad Index values are compared with target values for highest quality, adopted by the PSP.

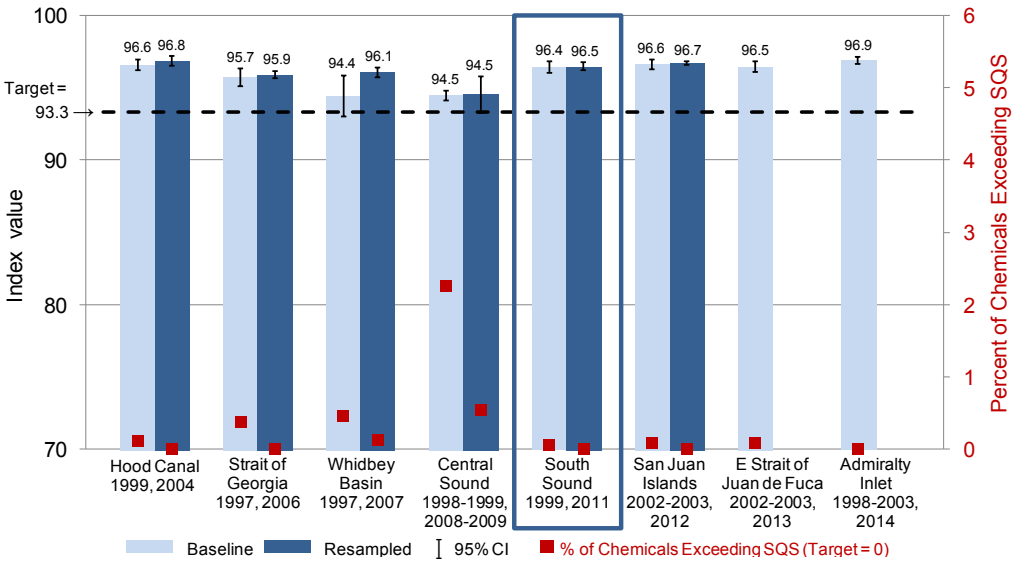


Figure 7. Change over time in Chemistry Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. The PSP's 2020 target value of 93.3 is shown as a dashed black line. Red squares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

The indices also are compared between years of repeated sampling to determine changes over time, and among regions.

The Chemistry Index values for South Sound were essentially unchanged from 1999 to 2011 and were above the target value of 93.3 (Figure 7). South Sound was similar to several other regions of Puget Sound, though it differed from the Central Sound and Strait of Georgia regions.

The percent of chemicals in the Sound Sound region exceeding SQS met the target of zero in 2011 (Figure 7).

The weighted mean Triad Index value for the 2011 South Puget Sound survey met the PSP target value of 81, which corresponds to the minimum value in the *unimpacted* Triad category (Figure 8). The Triad Index value in 2011 was statistically unchanged from that in 1999.

The 2011 South Sound Triad Index value was statistically similar to that in the other recently resampled regions except Hood Canal.

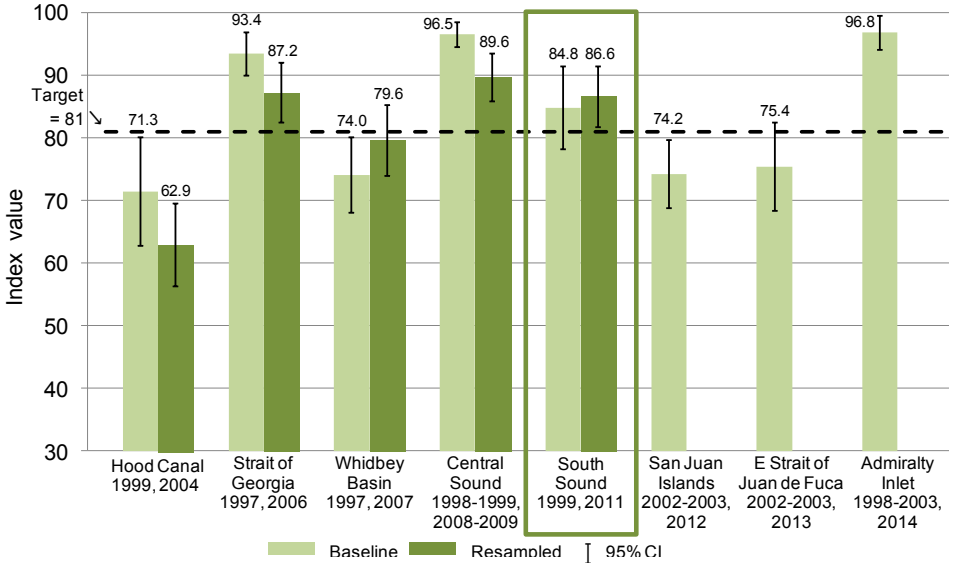


Figure 8. Change over time in Triad Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. Also shown is the PSP's 2020 target value of 81 (dashed black line).

Summary and Conclusions

Overall sediment quality in South Puget Sound in 2011 was classified as *unimpacted* or *likely unimpacted*, according to the Triad Index results, for most of the region. Except for an increase in *inconclusive* conditions (conflicting indications of sediment condition from the Chemistry, Toxicity, and Benthic Indices), sediment quality was statistically unchanged from 1999. Puget Sound Partnership "Vital Signs" targets for sediment chemistry and overall quality were met.

Virtually all of the region had *minimum exposure* to chemical contamination. About one-third of the area, primarily in the terminal inlets, had *adversely affected* benthic invertebrate communities. The spatial extents and geographical patterns of both the sediment chemistry and benthos condition were unchanged from 1999 to 2011. In contrast, toxicity increased from 3% of the area of South Sound in 1999 to just over half (52%) of the area in 2011. That increase in toxicity was the largest contributor to the *inconclusive* Triad Index determination.

Sediment quality tended to be lower in the terminal inlets, primarily Budd Inlet, than in the more open portions of South Sound. Most of the adversely affected benthos occurred in the terminal inlets, while toxicity patterns were more mixed.

None of the chemical or physical parameters measured in this survey explained the observed patterns of toxicity and benthic invertebrate community conditions. Further study is required to identify other factors that may be important.

This report summarizes sediment quality for the South Sound region as a whole. Sediment quality for Budd Inlet has been characterized by a separate, more intensive survey, also conducted in 2011, with the same methods as the South Sound survey and with additional stations. See the companion report, "Sediment Quality in Budd Inlet, 2011" (Partridge et al., 2014), available at https://fortress.wa.gov/ecy/publications/summarypages/1403005.html.

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

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