DEPARTMENT OF ECOLOGY
State of Washington

Sediment Quality in the Eastern Strait of Juan de Fuca: Changes over a 10-Year Period

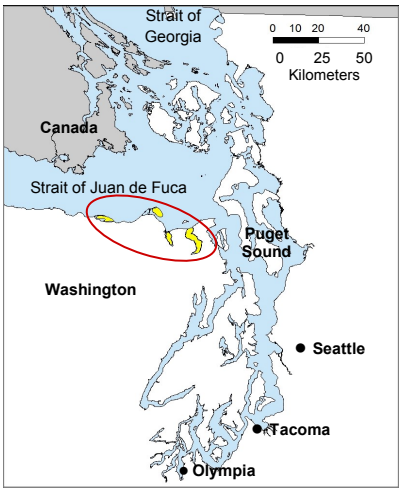
Findings

- Sediment quality did not change significantly from 2002-2003 to 2013.
- Overall sediment quality did not meet the Puget Sound Partnership target.
- Exposure to chemical contaminants, as measured by the Chemistry Index, was *minimum* or *low*.
- Spatial extent of *low* and *moderate* sediment toxicity categories increased from 2002-2003 to 2013.
- Incidence of adversely affected bottom-dwelling communities increased, particularly in Port Angeles Harbor.

In 2013, the Washington State Department of Ecology (Ecology) surveyed sediment conditions throughout the Eastern Strait of Juan de Fuca and compared them to conditions from a similar survey in 2002-2003 as part of a Puget Sound status-and-trends monitoring program. The study area included the embayments within the Strait (red circle in map at right). Surface sediments (top 2-3 cm) from 40 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 combined to compute Ecology's Chemistry, Toxicity, Benthic, and Triad Indices.



Overall Results

None of the sediment quality indices changed significantly from 2002-2003 to 2013 in the Eastern Strait of Juan de Fuca. Although the Chemistry Index met the Puget Sound Partnership (PSP) target value of 93.3, overall sediment quality, as measured by the Triad Index, did not meet the PSP target of 81 in either 2002-2003 or 2013 (Figure 1).

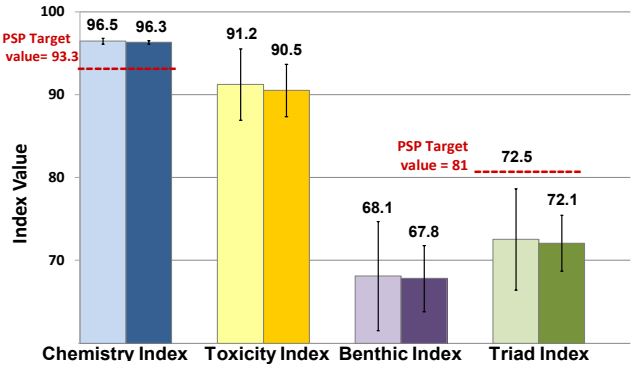


Figure 1. A comparison of weighted mean index values for the Eastern Strait of Juan de Fuca in 2013 (dark bars) and 2002-2003 (light bars), with 95% confidence intervals. Also shown are the PSP target values for the Chemistry and Triad Indices (red dashed lines). Numerical values of the indices range from 0 (poor) to 100 (high quality).

Want more information?

This report covers only the primary results of the 2013 survey. Data and supporting information, including methods, are available on Ecology's website: www.ecy.wa.gov/programs/eap/sediment.

Sediment Monitoring of the Eastern Strait of Juan de Fuca

Ecology sampled sediments throughout the Eastern Strait of Juan de Fuca in June 2013 under the Puget Sound Ecosystem Monitoring Program (PSEMP). The region had been studied previously in 2002-2003 (Long et al., 2008) with the same field and laboratory methods. A new set of sampling stations was randomly selected for the 2013 survey. The survey design weights sample results by area. This enables Ecology to estimate the percent of area (spatial extent) with given sediment conditions and compare results from multiple surveys. Comparisons of spatial extent of sediment conditions follow Kincaid (2015). The study design, sampling and analytical methods, and list of parameters are described in Dutch et al. (2009, 2012) and on Ecology's website.

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Physical Conditions

Twenty-five percent of the study area sediments were sand or silty sand; 75% of the study area sediments were mixed grain sizes or predominantly silt-clay. The silt content was higher in 2013, with a simultaneous decrease in sand content, than in 2002-2003; however, the change in overall percent fines (silt + clay) was not statistically significant.

Total organic carbon (TOC) content in 2013 ranged from <0.2% to 7.3%, with a mean of 2.1%. TOC was significantly higher in 2013 than in 2002-2003.

Chemical Contamination

With the exception of one station in Port Angeles Harbor, representing 0.7 km^2 of the 2013 study area, contaminant concentrations met the Washington State Sediment Management Standards (Ecology, 2013). At that station, mercury and zinc concentrations were higher than their respective Sediment Cleanup Objectives (SCO). In the 2002-2003 survey of the region, only fluoranthene did not meet the SCO, at a different site in Port Angeles Harbor, representing 0.88 km^2 of the total study area.

None of the priority pollutant metals indicated any significant increases or decreases in overall concentrations. Concentrations of several polycyclic aromatic hydrocarbons (PAHs) had statistically significant increases, including those of 1,6,7-trimethylnaphthalene; 1-methylnaphthalene; 2-methylnaphthalene; carbazole; and chrysene.

There was some indication that concentrations of several metals and other individual PAHs may have been significantly different from those in the 2002-2003 survey, but only for about 20% of the study area, reflecting the different geographic distribution of sampled locations rather than overall changes in concentration.

The majority of the polychlorinated biphenyl aroclors and congeners (PCBs), polybrominated diphenyl ethers (PBDEs), pesticides, and base neutral acids (BNAs) concentrations were below method detection limits; therefore, no trend could be determined.

Chemistry Index

The Sediment Chemistry Index (Long et al., 2013) showed that 97% of the study area in 2013 had *minimum exposure* to 39 chemical contaminants for which the State of Washington has Sediment Management Standards (Figure 2). The remainder of the area had *low exposure* to those contaminants. The slight change in proportions from 2002-2003 to 2013 (Figure 2) was not statistically significant.

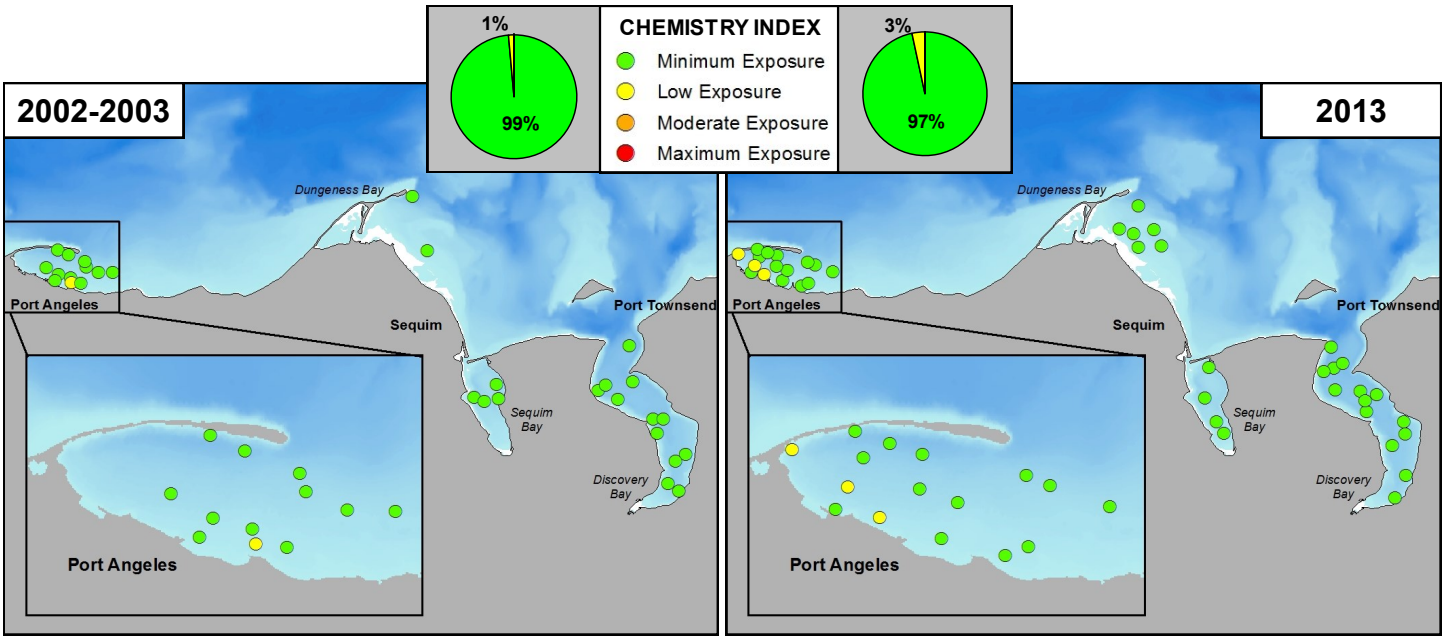


Figure 2. Spatial patterns and estimated spatial extent (percent of area, shown in pie chart) for the Chemistry Index categories for the Eastern Strait of Juan de Fuca 2002-2003 and 2013 surveys.

Toxicity Index

In the 2013 survey, sediments were tested for acute toxicity using two different laboratory tests: (1) 10-day survival of adult amphipods exposed to solid-phase sediments and (2) fertilization of sea urchin gametes exposed to sediment porewater. Test results fall into four toxicity ranges, from non-toxic to high toxicity (Table 1).

The amphipod survival test results characterized 100% of the study area as *non-toxic*. The urchin fertilization test, however, indicated *moderate toxicity* for 15% of the study area.

The test results were combined and characterized into the four toxicity categories as Ecology's Toxicity Index (Dutch et al., 2014). The Toxicity Index showed that 71% of the study area in 2013 had *non-toxic* sediments (Figure 3). *Low toxicity* was found in Port Angeles, Sequim Bay and Discovery Bay, representing 19% of the total area. *Moderate toxicity* sediments were found in the southern portion of Discovery Bay, representing 10% of the study area. No sediments with *high toxicity* were found in the Eastern Strait of Juan de Fuca study area.

The total area represented by *low* and *moderate* sediment toxicity increased slightly from 2002-2003 to 2013, while the total area with *non-toxic* sediments decreased over the ten-year period. However, none of the four Toxicity Index categories changed statistically significantly.

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

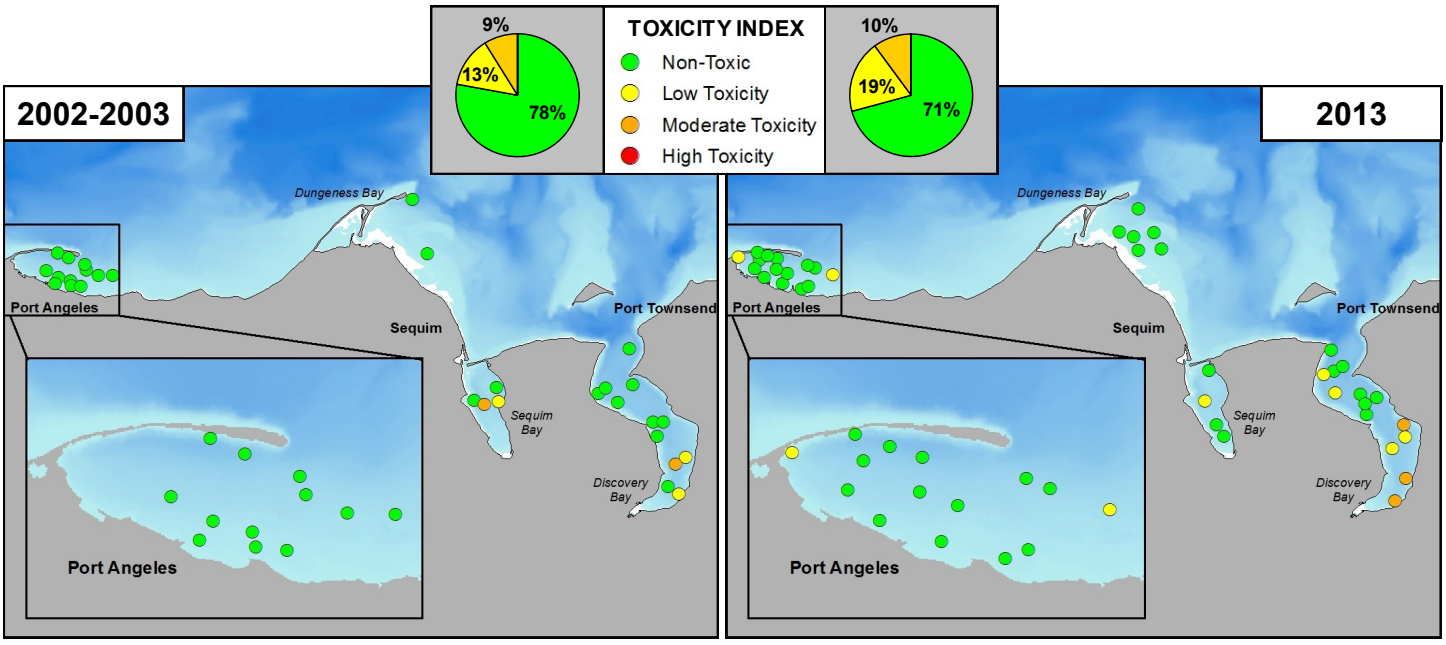


Figure 3. Spatial patterns and estimated spatial extent (percent of area, shown in pie chart) for the Toxicity Index categories for the Eastern Strait of Juan de Fuca 2002-2003 and 2013 surveys.

Benthic Invertebrates

Benthic invertebrate organisms (benthos) were identified and counted for all 40 locations sampled in 2013. Polychaetes (marine worms) were numerically dominant at 34 stations in the Eastern Strait of Juan de Fuca study area. The remaining 6 stations were dominated by molluscs. All except two stations had arthropods present, although this phylum represented less than 20% of the total abundance at all sites except one in Port Angeles (30%). Very few echinoderms were found in the study area, at only 10 sites, where they represented less than 1% of the total abundance.

The animals found in highest abundance and frequency were species known or suspected to be tolerant of stressful conditions, including the small bivalve *Axinopsida serricata*, occurring at 78% of the sites, and three polychaetes: *Aphelochaeta glandaria Complex* and *Heteromastus filobranchus*, both occurring at 55% of the sites, and *Scoletoma luti*, occurring at 35% of the sites.

Abundances of all four species mentioned above increased substantially from the 2002-2003 survey. Overall, there were no statistically significant changes in any benthic community measures calculated, with the exception of species dominance, which declined from the previous survey of the region. A decrease in species dominance indicates that fewer species account for a larger proportion of the total abundance, which could indicate lower diversity.

Benthic Index

Multiple community measures were calculated from the benthic invertebrate species data to characterize abundance and diversity. 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 2013 Eastern Strait of Juan de Fuca survey were judged to be *adversely affected* for the majority of the study area, 64% (Figure 4). The remainder of the study area had *unaffected* benthos. *Adversely affected* assemblages were found in inner Port Angeles Harbor, inner Sequim Bay and inner Discovery Bay.

The area represented by *adversely affected* benthic assemblages did not change from the 2002-2003 survey of the region. However, the incidence of sites with *adversely affected* assemblages did increase by 13%. This increase can be attributed to the different geographic distribution of sampling locations rather than overall degradation of assemblages.

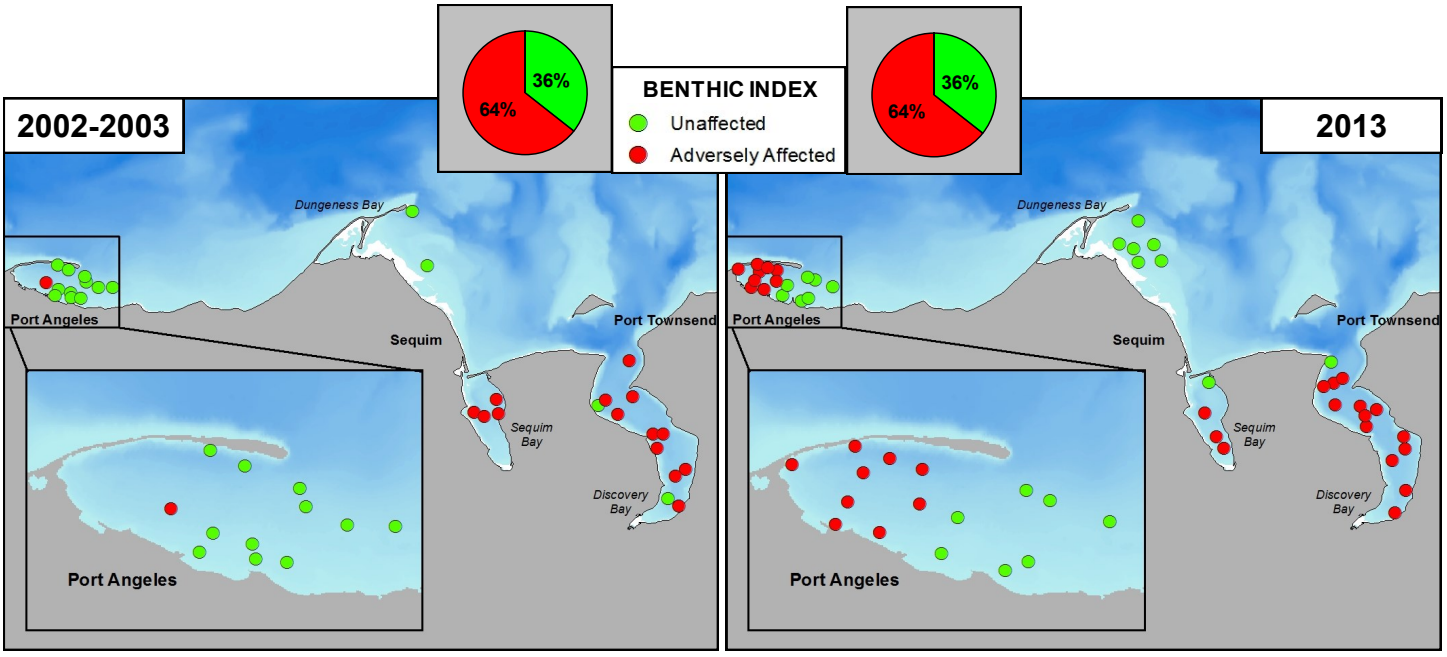


Figure 4. Spatial patterns and estimated spatial extent (percent of area, shown in pie chart) for the Benthic Index categories in the Eastern Strait of Juan de Fuca 2002-2003 and 2013 surveys.

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 (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 2013, more than one-third of the area (36%) was classified as having *unimpacted* sediment quality, and an equal proportion was classified as *likely unimpacted* (Table 2; Figure 5). The remainder of the study area had either *possibly impacted* (11%) or *inconclusive* (17%) sediment quality. *Possibly impacted* sediments were confined to the inner portions of Port Angeles Harbor and Discovery Bay. No *likely* or *clearly impacted* sediments were found in this study.

Table 2. Specific combinations of index results (chemistry, toxicity, benthic) that led to Triad Index categories for the 2013 Eastern Strait of Juan de Fuca study area. Spatial extent (percent of study area) is given for each combination.

Chemistry Index	+ Toxicity Index	+ Benthic Index	= Triad Index	% of Area
Minimum exposure	Low	Unaffected	Unimpacted	36%
Low exposure	Non-toxic		Likely unimpacted	36%
Minimum exposure	Low	Adversely affected	Possibly impacted	11%
	Moderate			
	Low		Inconclusive	17%

There was a spatial gradient of increasing sediment quality from inner to outer Port Angeles Harbor, Sequim Bay, and Discovery Bay. Dungeness Bay sediments were all of *unimpacted* quality.

In the Eastern Strait of Juan de Fuca region, the Triad Index appears to be driven by significant responses in laboratory tests of toxicity and the presence of *adversely affected* benthic communities.

Comparison of the 2013 Eastern Strait of Juan de Fuca Triad Index results showed no significant changes in sediment quality over the 10-year period (Figure 5).

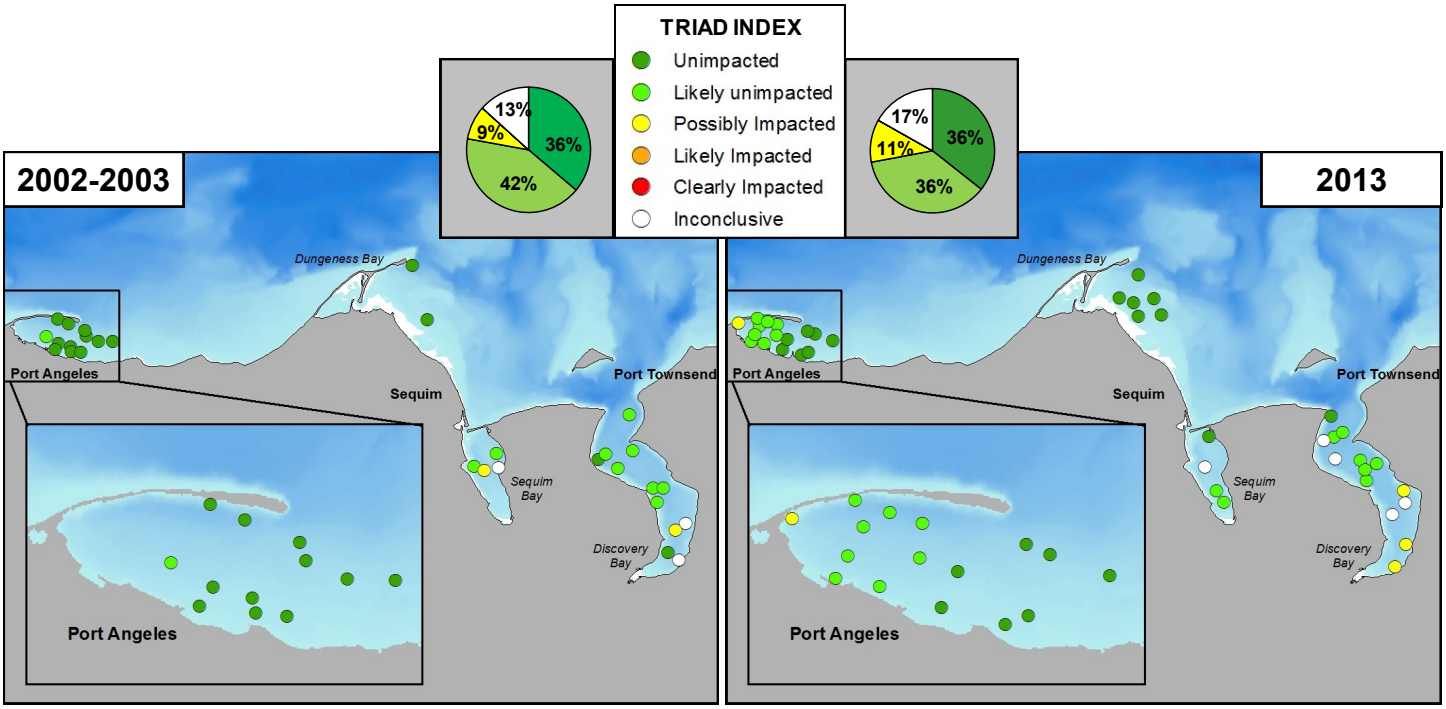


Figure 5. Spatial patterns and estimated spatial extent (percent of area, shown in pie chart) for the Triad Index results in the Eastern Strait of Juan de Fuca 2002-2003 and 2013 surveys.

The Eastern Strait of Juan de Fuca Compared to All of Puget Sound

The Eastern Strait of Juan de Fuca had significantly less *unimpacted* sediments and significantly more *possibly impacted* and *inconclusive* results than the 2004-2014 Puget Sound survey.

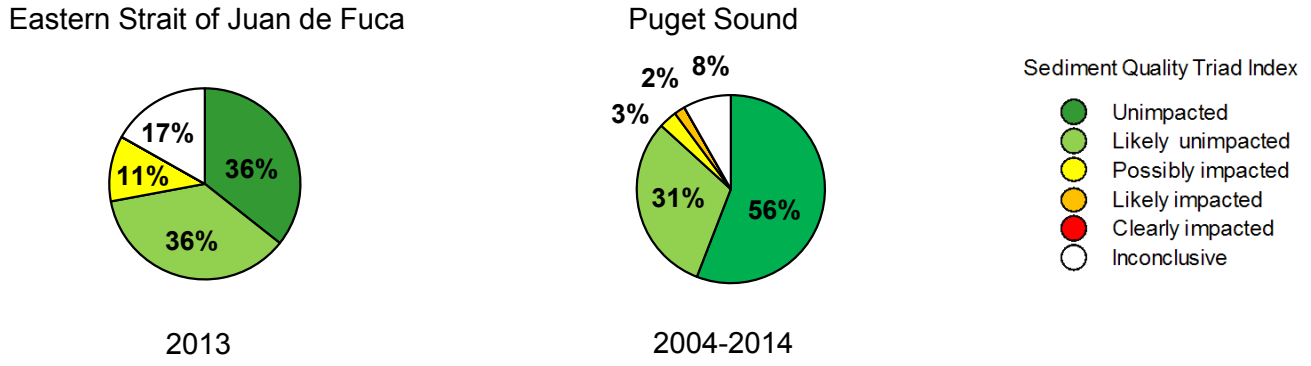
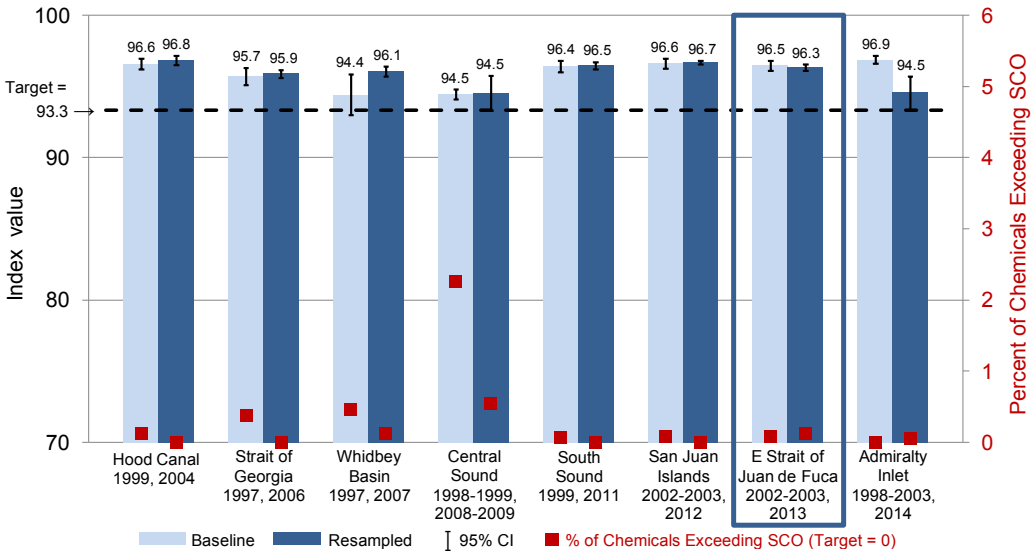


Figure 6. Spatial extent (percent of area) for the Triad Index categories for the Eastern Strait of Juan de Fuca in 2013 (from Figure 5), compared to 2002-2003 and to the entire Puget Sound. Proportions smaller than 1% are not shown.

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 not meeting the Washington State Sediment Cleanup Objective (SCO) benthic chemical criteria (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 to target values for highest quality, adopted by the PSP.

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



The Chemistry Index value for the Eastern Strait of Juan de Fuca region was statistically unchanged from 2002-2003 to 2013 and was above the target value of 93.3 (Figure 7). The Eastern Strait of Juan de Fuca region was similar to several other regions of Puget Sound.

The percent of chemicals in the Eastern Strait of Juan de Fuca region did not meet SCO chemical criteria and did not meet the PSP target of zero in 2013 (Figure 7).

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 not meeting SCO criteria.

The Triad Index for the Eastern Strait of Juan de Fuca region was below the PSP target value of 81 (Figure 8) in both 2002-2003 and 2013. The target value corresponds to the minimum value in the *unimpacted* Triad category.

In comparison to other Puget Sound regions, the Eastern Strait of Juan de Fuca has some of the lowest overall sediment quality, as measured by the Triad Index. Only the Hood Canal region had lower sediment quality.

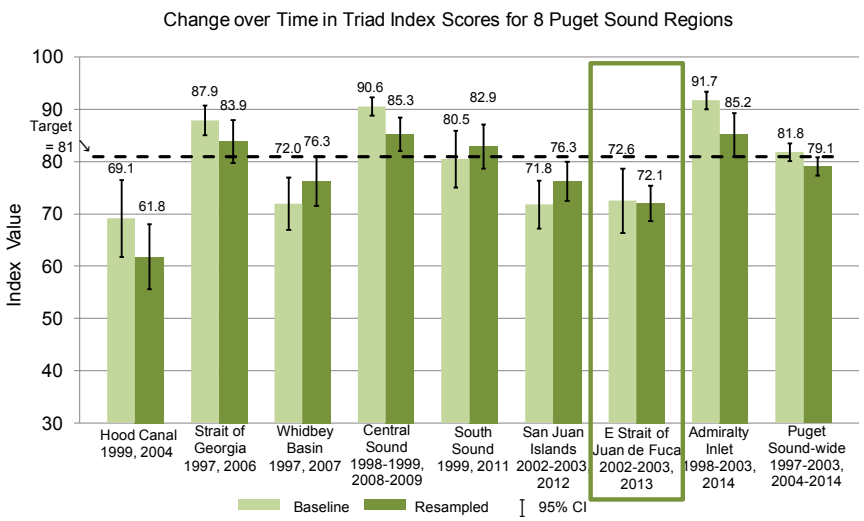


Figure 8. Change over time in Triad Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. Also shown is the PSP's 2020 target value of 81 (dashed black line).

Summary and Conclusions

Sediment quality in the Eastern Strait of Juan de Fuca sampling region was *unimpacted* or *likely unimpacted* in most of the 2013 study area; however, more than one-quarter of the study area was classified as having some level of impact.

Exposure to chemical contaminants measured was not a factor in classifying sediments as *possibly impacted*. Yet, the relationship between the responses of acute toxicity in laboratory tests and *adversely affected* benthic assemblages is notable and requires further investigation. Additional parameters may need to be monitored to determine what is adversely affecting the benthic community and causing toxic responses in laboratory tests.

The relatively large area with *inconclusive* sediment quality, areas with conflicting Chemistry, Toxicity, and Benthic Index results, should continue to be monitored for changing sediment quality. Sites with inconclusive sediment quality are located between *unimpacted* sites and those with lower sediment quality; therefore, the inconclusive sites may be transitional.

All sites in the Eastern Strait of Juan de Fuca monitoring region had benthic assemblages that included at least one species known or suspected to be tolerant of stressful conditions. Most sites in the region had several tolerant species in the top 10 most abundant species. This is indicative of the benthic communities in the region being under pressure.

Overall sediment quality in the Eastern Strait of Juan de Fuca declined slightly from the previous survey of the region and did not meet the Puget Sound Partnership target. Compared to other regions and Puget Sound as a whole, the Eastern Strait of Juan de Fuca region had sediment of poor quality; only Hood Canal had sediments of poorer quality.

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

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