DEPARTMENT OF ECOLOGY
State of Washington

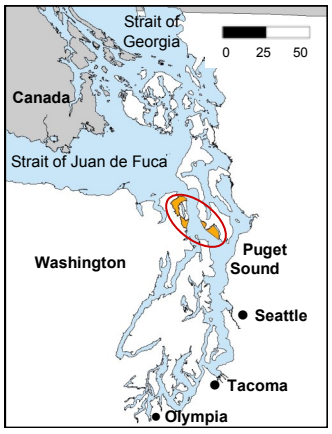
Sediment Quality in Admiralty Inlet, Changes over Time

Findings

- Sediment quality in Admiralty Inlet decreased significantly over a decade.
- However, overall sediment quality met the Puget Sound Partnership targets.
- Exposure to chemical contaminants was *minimum* or *low*.
- Incidence and spatial extent of adversely affected bottom-dwelling communities increased.

In 2014, the Washington State Department of Ecology (Ecology) surveyed sediment conditions throughout the Admiralty Inlet monitoring region and compared them to conditions from similar surveys in 1998 and 2002-2003 (Baseline) as part of a Puget Sound status and trends monitoring program. The study area included Port Townsend and the embayments within Admiralty Inlet (red circle in map at right). Surface sediments (top 2-3 cm) from 43 randomly selected locations were analyzed to determine:

- Concentrations of potentially toxic chemical contaminants.
- 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

Three of the four sediment quality indices decreased in value from the Baseline to 2014 in the Admiralty Inlet region, indicating declines in sediment quality (Figure 1). All decreases were statistically significant. The toxicity index increased in value, but this change was not statistically significant. Overall sediment quality, as measured with the Triad Index, met the Puget Sound Partnership (PSP) target in 2014.

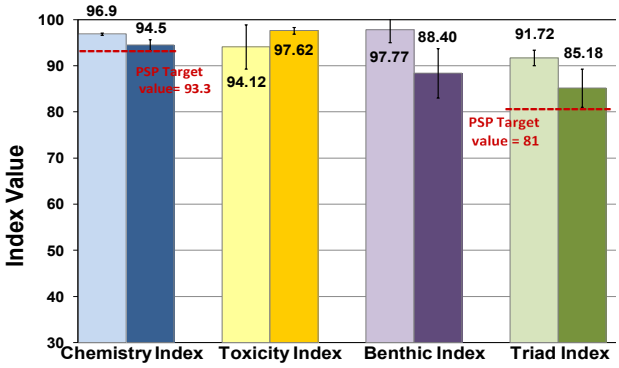


Figure 1. A comparison of weighted mean index values for Admiralty Inlet in 2014 (dark bars) and the Baseline (light bars), with 95% confidence intervals. Also shown are the PSP target values for the Chemistry and Triad Indices (red dashed lines). Numerical values of the indices range from 0 (poor) to 100 (high) quality.

Want more information?

This report covers only the primary results of the 2014 survey. Data and supporting information, including methods, are available on Ecology's website: www.ecy.wa.gov/programs/eap/sediment.

Sediment Monitoring of Admiralty Inlet

Ecology sampled sediments throughout Admiralty Inlet in June 2014 under the Puget Sound Ecosystem Monitoring Program (PSEMP). The region had been studied previously (Long et al., 2008), with the same field and laboratory methods, as part of the Puget Sound Baseline survey. A new set of sampling stations was randomly selected for the 2014 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 to 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.

Publication 16-03-008

February 2016

Physical Conditions

The Admiralty Inlet study area is relatively shallow. Station depths ranged from 6 to 92 meters, with 75 percent of the stations having a depth of 35 meters or less.

Seventy percent of the study area sediments were sand or silty sand; 30% of the area sediments were mixed grain sizes or silt-clay. The silt content was higher in 2014, with simultaneous decrease in sand content, than in the Baseline; however, the change in overall percent fines (silt + clay) was not statistically significant.

Total organic carbon (TOC) content in 2014 ranged from <0.1% to 2.7%, with a mean of 1.0%. TOC was lower than in the Baseline, but not significantly.

Chemical Contamination

All samples meet the Washington State Sediment Management Standards Sediment Cleanup Objectives (SCO), with the exception of Bis(2-ethylhexyl)Phthalate at one station located in Mutiny Bay. This station represents 2.82 km^2 of the 2014 Admiralty Inlet study area.

With the exception of chromium, metals decreased or stayed the same between sampling events. None of the high-molecular-weight polycyclic aromatic hydrocarbons (PAHs) changed between the two surveys except for perylene, which decreased significantly. On the contrary, many of the low molecular weight PAHs increased statistically significantly, including: 1-methylnaphthalene: 2-methylnaphthalene, acenapthene, acenaphthylene, biphenyl, and fluorine. The majority of the PCB, pesticide, and base neural acids (BNAs) concentrations were below reporting limits; therefore, no trend could be determined.

Chemistry Index

The Sediment Chemistry Index (Long et al., 2013) indicated that 76% of the study area in 2014 had *minimum exposure* to 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 Chemistry Index indicates that exposure to chemical contaminants significantly increased from the Baseline to 2014 (Figure 2).

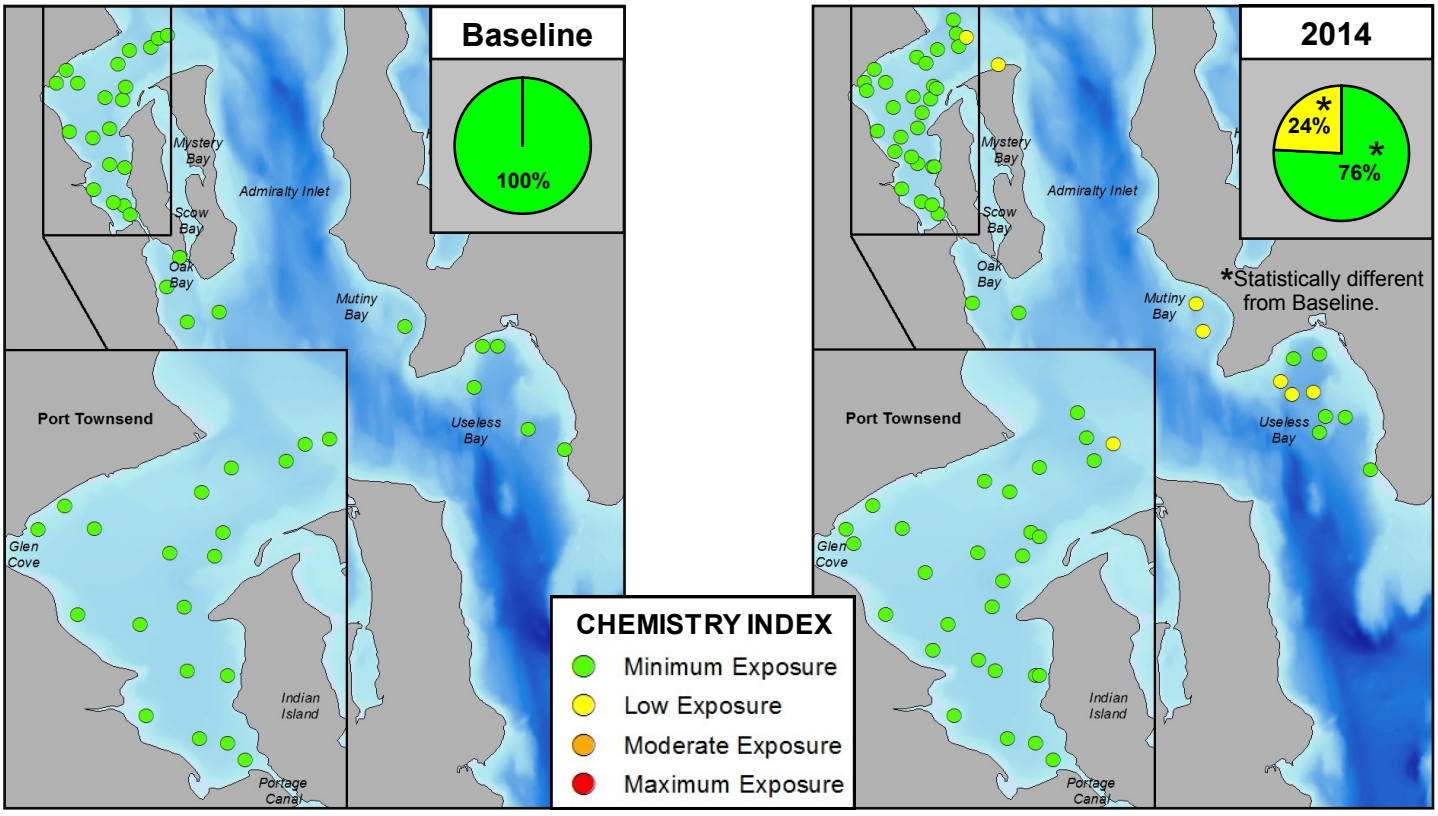


Figure 2. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Chemistry Index categories for the Admiralty Inlet region in the Baseline and 2014.

Toxicity Index

In the 2014 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. Test results were characterized into four toxicity ranges, from non-toxic to high toxicity (Table 1).

Results from the amphipod survival and the urchin fertilization tests characterized the majority of the study area as *non-toxic*. Each test identified two stations with *low toxicity;* however, the tests were not in agreement on the locations.

The test results were combined and characterized again into the four toxicity categories, as Ecology's Toxicity Index (Dutch et al., 2014). The Toxicity Index indicated that 89% of the study area in 2014 had *non-toxic* sediments. *Low toxicity* was found at two stations in Port Townsend, one in Mutiny Bay, and one in Useless Bay, representing 11% of total area (Figure 3). No sediments with *moderate* or *high toxicity* were found in the Admiralty Inlet study area.

Compared to the Baseline study of the region, toxicity did not significantly change for any of the four toxicity categories.

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

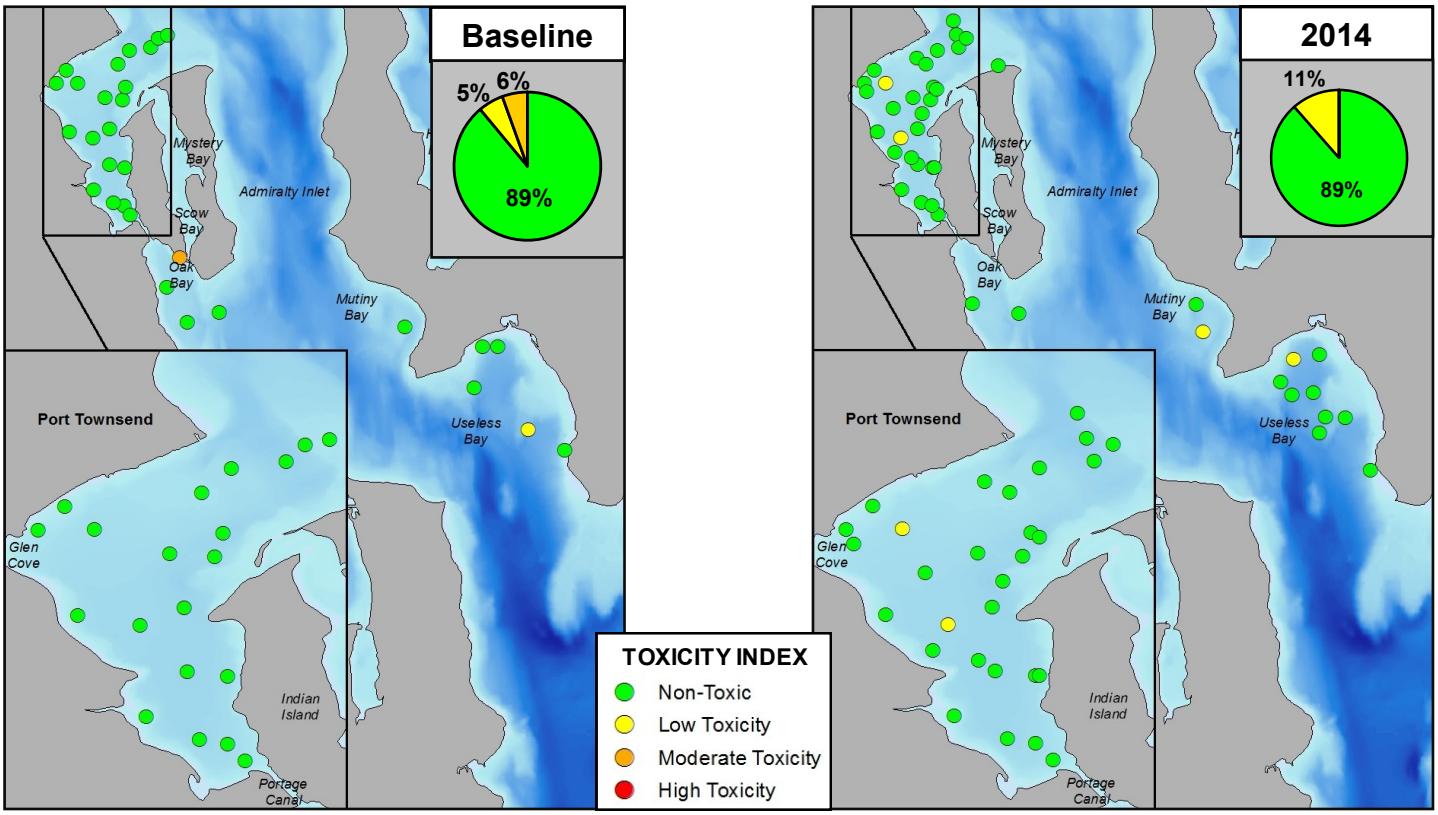


Figure 3. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Toxicity Index categories for the Admiralty Inlet region in the Baseline and 2014.

Benthic Invertebrates

Benthic invertebrate organisms (benthos) were identified and counted for all 43 locations sampled in 2014. Multiple community measures were calculated to characterize benthic invertebrate abundance and diversity.

Clams were numerically dominant at 30 stations, marine worms were dominant at 11 stations, and arthropods were dominant at the remaining two stations. All except one site had arthropods present, and miscellaneous taxa were found at all but four sites. Echinodermata was the least-represented phylum in this region, with only one-third of the sites having echinoderms, representing < 1.5% of the total abundance.

The animals found in highest abundance and frequency were two small bivalve species, *Axinopsida serricata* and *Acila castrensis,* occurring at 93% and 63% of the sites, respectively. These species accounted for 6% and 12% of the total abundance of the region.

Overall, average and median values for all calculated benthic community measures stayed the same or declined from the previous survey of the region, and there were significant declines in arthropod, echinoderm, and total abundance measures.

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 2014 Admiralty Inlet survey were judged to be *unaffected* for the majority of the study area, 77% (Figure 4). The number of sites and the area represented by *adversely affected* benthic assemblages increased significantly from the Baseline survey of the region.

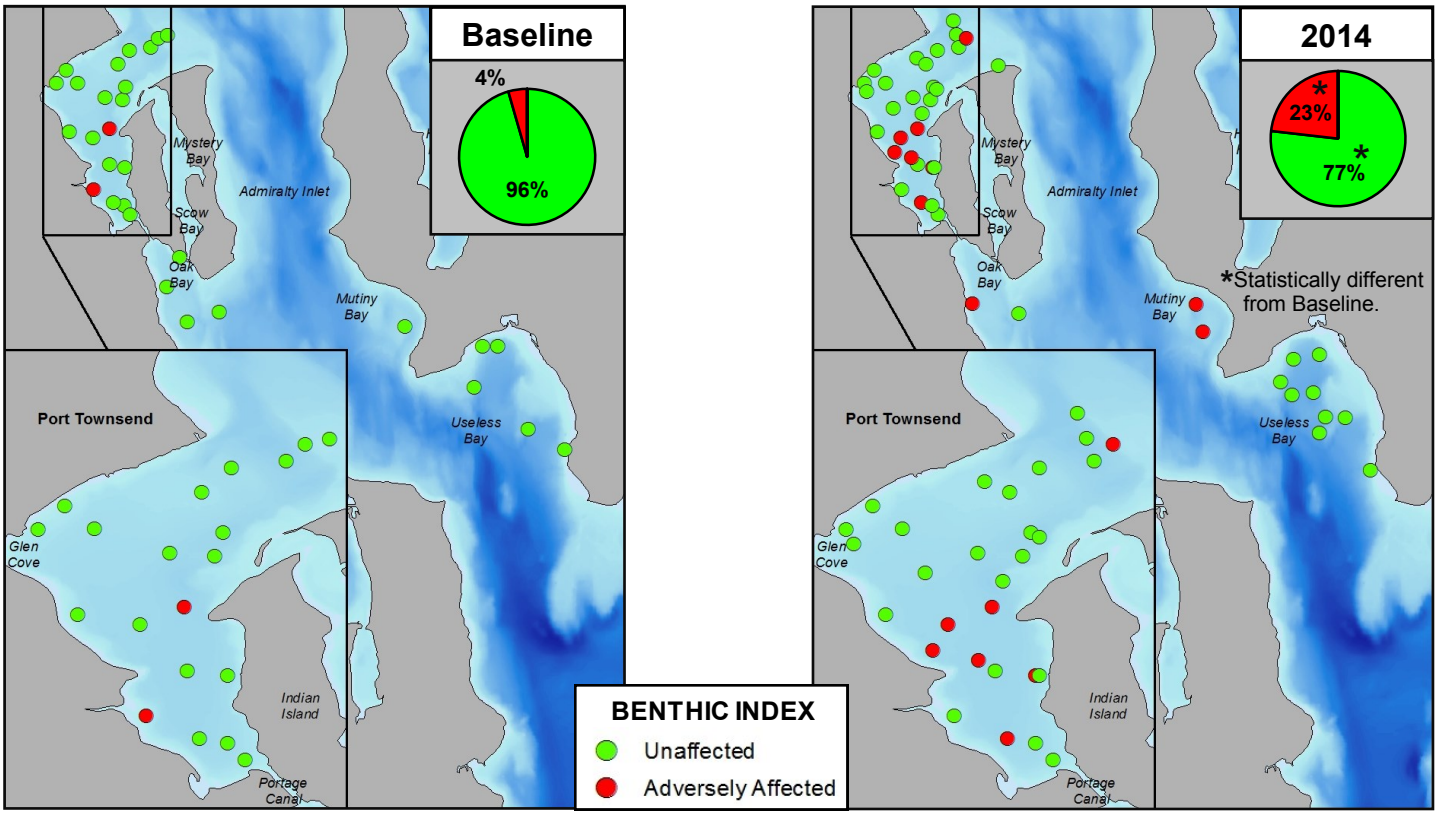


Figure 4. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Benthic Index categories for the Admiralty Inlet region in the Baseline and 2014.

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 three 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).

The vast majority of the study area (94%) was classified as having *unimpacted* and *likely unimpacted* sediment quality (Table 2; Figure 5). *Possibly impacted* sediments were found at only one site in Mutiny Bay (4 %). The remainder of the study area had *inconclusive* (2%) sediment quality. 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 2014 Admiralty Inlet study area. Spatial extent (percent of study area) is given for each triad category.

Chemistry Index	+ Toxicity Index	+ Benthic Index	= Triad Index	% of Area
Low exposure	Non-Toxic	Unaffected	Unimpacted	76.8
Minimum exposure	Low			
Low exposure	Non-Toxic	Adversely affected	Likely unimpacted	17.5
Minimum exposure	Low		Possibly impacted	4.2
			Inconclusive	1.5

Overall sediment quality in Admiralty Inlet, as measured with the Triad Index, declined over the study period, with significantly less *unimpacted* sediment and significantly more *likely unimpacted* sediment in 2014. *Possibly impacted* and *inconclusive* results were not present in the previous survey.

The decline of sediment quality appears to be driven primarily by the presence of *adversely affected* benthic communities.

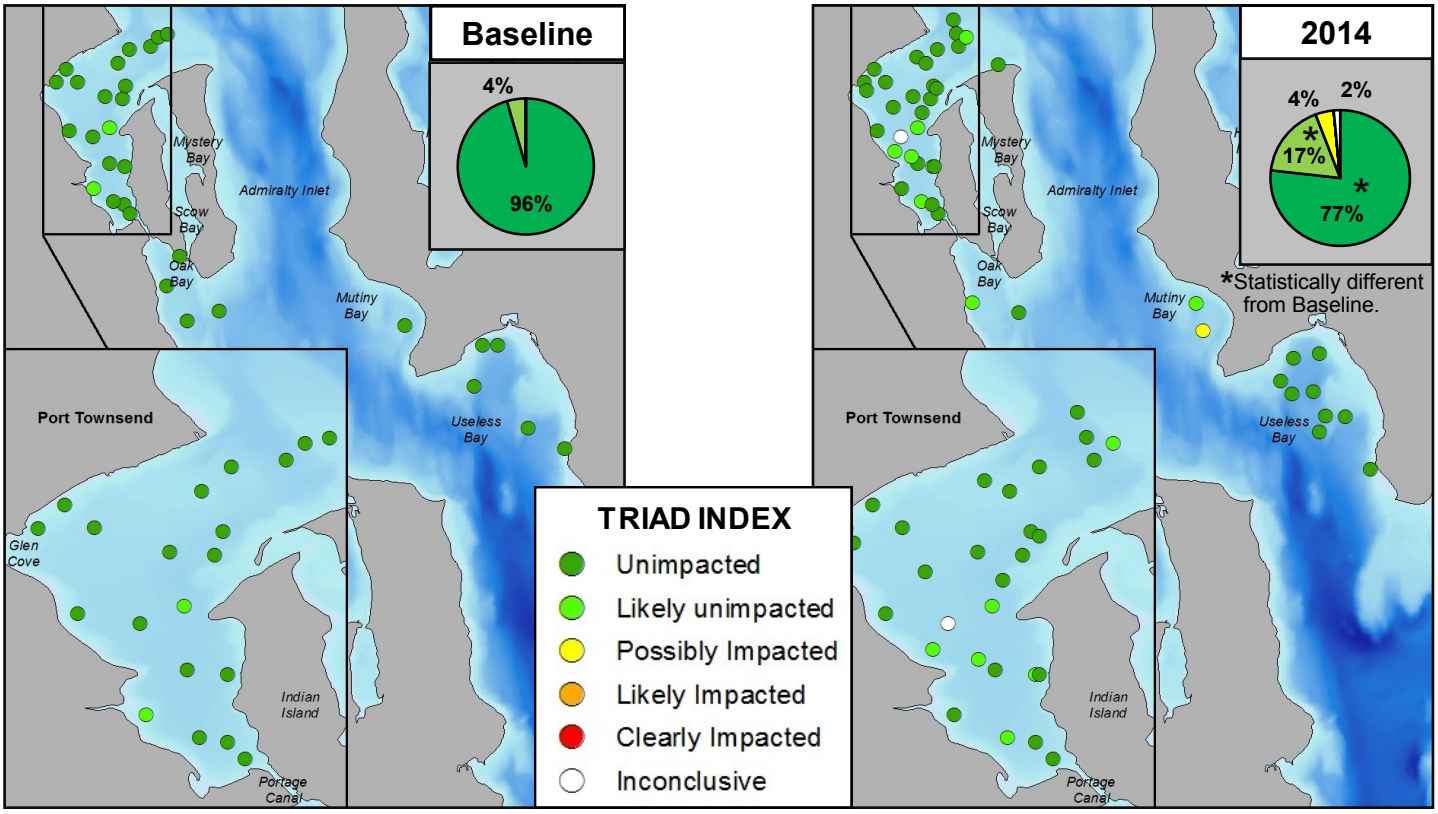


Figure 5. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Triad Index results for the Admiralty Inlet region in the Baseline and 2014.

Admiralty Inlet Compared to All of Puget Sound

The Triad Index results for 2014 showed that the Admiralty Inlet region had higher quality sediments than Puget Sound as a whole, with significantly more *unimpacted* sediment and significantly less *possibly unimpacted* sediment (Figure 6).

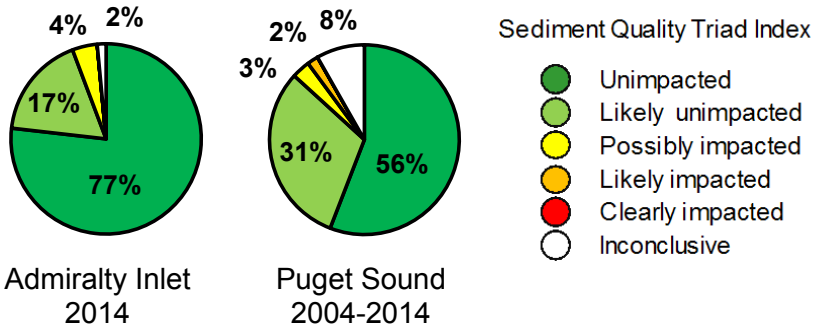


Figure 6. Spatial extent (percent of area) for the Triad Index categories for Admiralty Inlet in 2014 compared to Puget Sound, 2004-2014. Proportions smaller than 1% are not shown.

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

The Chemistry Index value for Admiralty Inlet significantly decreased from the Baseline to 2014, but was above the target value of 93.3 (Figure 7). The Admiralty Inlet region was similar to the Central Puget Sound region, with one of the lowest Chemistry Index values, indicating higher exposure to contaminants. The percent of chemicals not meeting the SCO chemical criteria did not meet the PSP target of zero in 2013 (Figure 7).

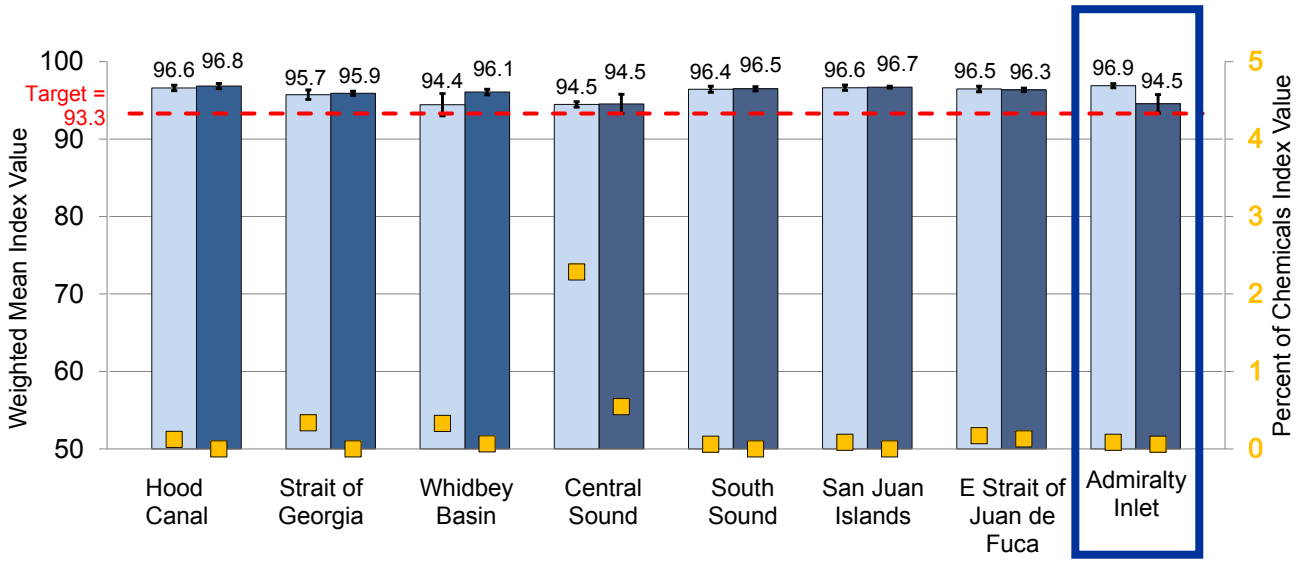


Figure 7. Change over time in Chemistry Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. The PSP's 2020 target value of 93.3 is shown as a dashed red line. Gold squares illustrate the percentages of chemicals with concentrations exceeding (not meeting) SCO criteria, PSP target of 0.

Overall sediment quality, as measured by the Triad Index, for Admiralty Inlet significantly declined from the Baseline to 2014. However the PSP target value of 81 was still met (Figure 8). The target value corresponds to the minimum value in the *unimpacted* Triad category.

When compared to other Puget Sound regions, the Triad Index values for Admiralty Inlet were among the highest and were comparable with those of the Strait of Georgia and Central Puget Sound.

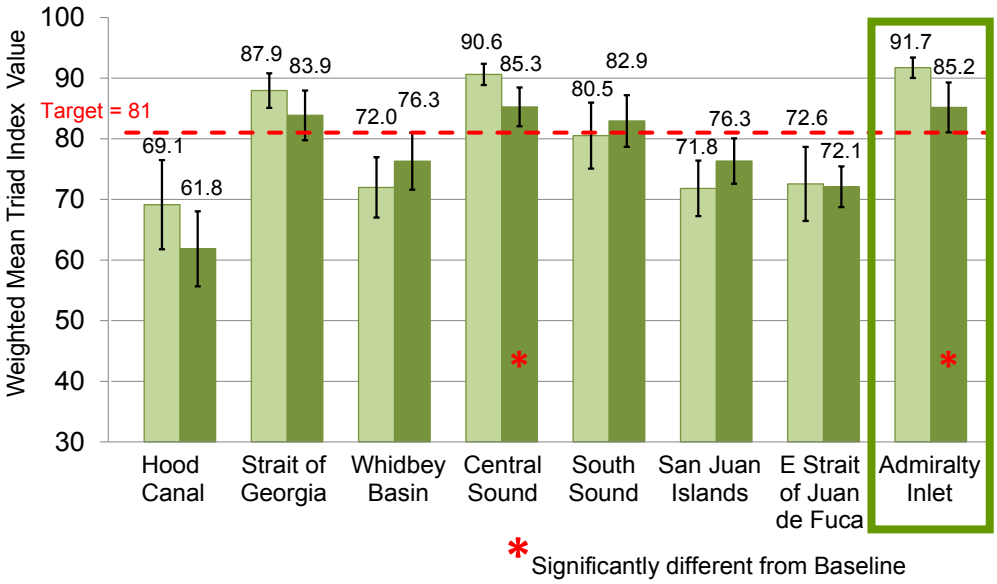


Figure 8. Change over time in Triad Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. Also shown is the PSP's 2020 target value of 81 (dashed red line).

Summary, Conclusions, Future Directions

Sediment quality in the Admiralty Inlet sampling region was *unimpacted* or *likely unimpacted* in the majority of the 2014 study area. Overall sediment quality declined significantly from the previous surveys (1998; 2002-2003) of the region.

Exposure to chemical contaminants measured was not a factor in classifying sediments as *possibly impacted*. Declining sediment quality was driven by the presence of *adversely affected* benthic assemblages. All sites in the Admiralty Inlet monitoring region had benthic assemblages that included at least one species known or suspected to be tolerant of stressful conditions in the top 10 most-abundant species at a particular site. Most sites in the region had several tolerant species in the top 10 most-abundant species. In addition, average values for calculated benthic community measures decreased from the previous surveys. This indicates that the benthic communities in the region are under pressure.

To determine what is adversely affecting the benthic community, further investigation and additional parameters may need to be monitored.

References

Bay, S.M. and S.B. Weisberg. 2012. Framework for interpreting sediment quality triad data. Integrated Environmental Assessment and Management 8:589-596. http://onlinelibrary.wiley.com/doi/10.1002/ieam.118/full (Erratum: http://onlinelibrary.wiley.com/doi/10.1002/ieam.1335/full).

Dutch, M., E. Long, S. Aasen, K. Welch, and V. Partridge. 2008. Sediment Quality in the Bays and Inlets of the San Juan Islands, Eastern Strait of Juan de Fuca, and Admiralty Inlet (2002-2003). Washington State Department of Ecology Publication 08-03-031. https://fortress.wa.gov/ecy/publications/SummaryPages/0803031.html.

Dutch, M., V. Partridge, S. Weakland, K. Welch, and E. Long. 2009. Quality Assurance Project Plan: The Puget Sound Assessment and Monitoring Program[1]: Sediment Monitoring Component. Washington State Department of Ecology, Olympia, WA. Publication 09-03-121. https://fortress.wa.gov/ecy/publications/summarypages/0903121.html.

Dutch, M., V. Partridge, S. Weakland, K. Welch, and E. Long. 2012. 2013 Addendum to Quality Assurance Project Plan: The Puget Sound Ecosystem Monitoring Program[1]/Urban Waters Initiative: Sediment Monitoring in the Eastern Strait of Juan de Fuca and Elliott Bay. Washington State Department of Ecology Publication 12-03-129. https://fortress.wa.gov/ecy/publications/SummaryPages/1203129.html.

Dutch, M., E.R. Long, S. Weakland, V. Partridge, and K. Welch. 2014. Sediment Quality Indicators for Puget Sound: Indicator Definitions, Derivations, and Graphic Displays. Unpublished report. www.ecy.wa.gov/programs/eap/sediment.

Ecology (Washington State Department of Ecology). 2013. Sediment Management Standards. Chapter 173-204, WAC. Washington State Department of Ecology, Olympia, WA. Publication No. 13-09-055. http://apps.leg.wa.gov/WAC/default.aspx?cite=173-204.

Kincaid, T. 2015. User Guide for spsurvey, version 3.0 Probability Survey Design and Analysis Functions. U.S. Environmental Protection Agency, Office of Research and Development, Corvallis, OR. Available from the Comprehensive R Archive Network at https://cran.r-project.org/web/packages/spsurvey/index.html.

Long, E.R. and P.M. Chapman. 1985. A sediment quality triad-measures of sediment contamination, toxicity, and infaunal community composition in Puget Sound. Marine Pollution Bulletin 16:405-415.

Long, E., S. Aasen, M. Dutch, K. Welch, and V. Partridge. 2008. Sediment Quality Assessment of the Bays and Inlets of the San Juan Islands, Eastern Strait of Juan de Fuca, and Admiralty Inlet, 2002-2003. Washington State Department of Ecology Publication 08-03-030. https://fortress.wa.gov/ecy/publications/SummaryPages/0803030.html.

Long, E.R., M. Dutch, V. Partridge, S. Weakland, and K. Welch. 2013. Revision of sediment quality triad indicators in Puget Sound (Washington, USA): I. A sediment chemistry index and targets for mixtures of toxicants. Integrated Environmental Assessment and Management 9(1):31-49. http://onlinelibrary.wiley.com/doi/10.1002/ieam.1309/full.

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

Department of Ecology Contacts

Authors: Sandra Weakland, Valerie Partridge, and Margaret Dutch
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
Eastern Regional Office, Spokane	(509) 329-3400

This report is available on the Department of Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1603008.html.

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search Study ID, PSAMP_SP.

If you need this document in a format for the visually impaired, call 360-407-6764.

Persons with hearing loss can call 711 for Washington Relay Service.

Persons with a speech disability can call 877-833-6341.