Urban Bays Monitoring 2015:
Sediment Quality in the Bainbridge Basin

November 2017

DEPARTMENT OF ECOLOGY
State of Washington

Signs of Declining Quality

Overall sediment quality in the Bainbridge Basin has declined since first evaluated by the Sediment Monitoring Program in 1998. Three of the four calculated indices measuring sediment condition significantly declined over the 17-year period, 1998-2015 (Figure 1). Only the Chemistry Index stayed the same and surpassed ecosystem recovery target values.

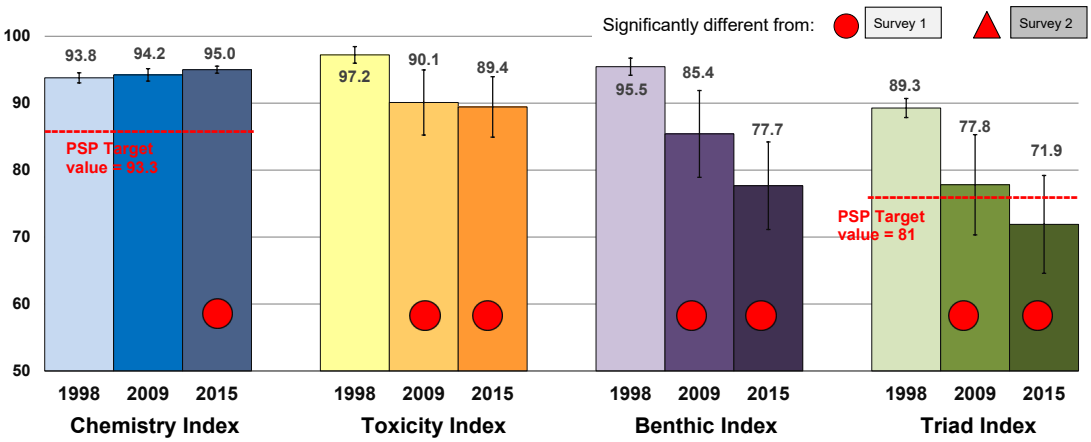
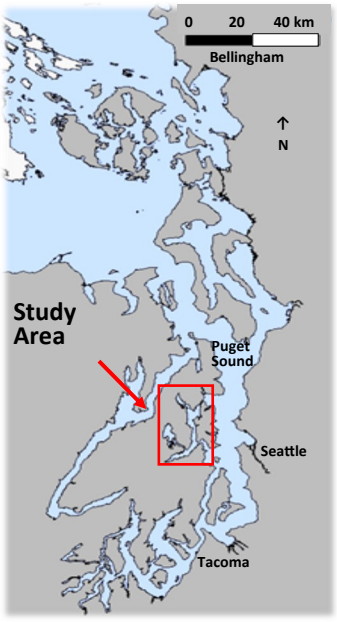


Figure 1. A comparison of weighted mean index values for Bainbridge Basin over three surveys (1998, 2009, and 2015), with 95% confidence intervals. The Puget Sound Partnership (PSP) target values for the Chemistry and Triad Indices are shown in red. Numerical values of the indices range from 0 (poor) to 100 (highest quality).



Bainbridge Basin study area outlined in red.

Monitoring Sediment Quality

As part of the Washington State Department of Ecology's (Ecology's) Urban Bays Monitoring Program, Bainbridge Basin surface sediments were sampled in 1998, 2009, and again in 2015. Sediment condition was evaluated with calculated indices based on laboratory analyses, including:

- Chemistry - concentrations of potentially toxic chemicals
- Toxicity - sediment and porewater toxicity to test organisms
- Benthic - presence of sediment-dwelling organisms
- Triad - overall sediment quality; a combination of the chemistry, toxicity, and benthic indices

The program is designed to evaluate and compare results over multiple surveys by using a survey design that weights sample results by area.

Want more information?

This report covers the primary results of the 2015 survey.
Reports from previous surveys are available on Ecology's website:
www.ecy.wa.gov/programs/eap/sediment.

Methods are in Dutch et al., 2009.

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Physical Condition

The Bainbridge Basin study area is relatively shallow, with station depths ranging from 3 to 47 meters. Shallower stations were located in the terminal inlets and bays, with deeper stations in the passages and near Port Madison. Depth is depicted in the maps of results, where darker blue indicates deeper stations.

Silt, clay, and total organic carbon (TOC) concentrations are spatially distributed at higher values in the terminal inlets and heads of bays, and lower values in the passages and near Port Madison. Neither depth, sediment composition, nor TOC changed significantly in the study area over the 17-year monitoring period.

Chemical Contamination

Individual chemicals that were most often qualified as undetected included pharmaceuticals and personal care products (PPCPs), perfluoroalkyl substances, and base/neutral/acid organic compounds. Chemical classes that were most often detected included metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Concentrations of several of these chemicals did not meet their respective Sediment Cleanup Objectives (SCO) (Ecology, 2013). SCOs were not met at 8 locations, representing 14% of the Bainbridge Basin study area. Six locations, all in Sinclair Inlet, exceeded (met) the SCO for mercury. One location in Liberty Bay exceeded the SCO for zinc.

When compared to the previous surveys of the area, concentrations of the individually measured chemicals had statistically significant declines or stayed the same, with the exception of cadmium and acenaphthene, for which concentrations increased over the 17-year period.

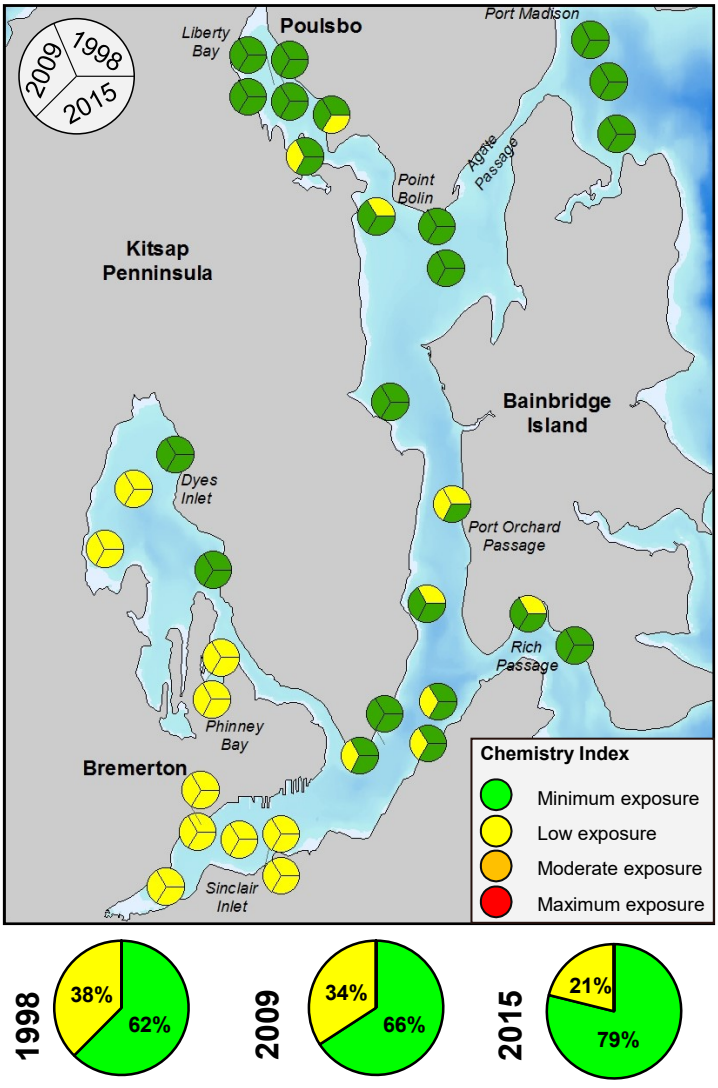


Figure 2. Chemistry Index categories calculated for Bainbridge Basin sediments. Spatial and temporal patterns shown on the map are summarized as percent area in the pie charts below the map.

Chemistry Index

The Sediment Chemistry Index (Long et al., 2013) indicated that in 2015 the majority (79%) of the Bainbridge Basin study area had *minimum exposure* to chemical contaminants (Figure 2). Sediments with *low exposure* to contaminants were limited to Sinclair Inlet, Dyes Inlet, and one site in Liberty Bay. These stations represented 21% of the 2015 study area. None of the study area was classified as having *moderate* or *maximum exposure*.

Exposure to potentially harmful chemicals has gradually decreased in the Bainbridge Basin since first evaluated in 1998. The area with *minimum exposure* to chemicals increased slightly, with a concurrent significant decrease in the area with *low exposure* (Figure 2). Individual sites all showed improvement or stayed the same, with the exception of one site in Liberty Bay. Overall chemical exposure as measured with the weighted mean Sediment Chemistry Index improved significantly.

Toxicity Index

In the 2015 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.
(2) percent fertilization of sea urchin gametes exposed to sediment porewater.

Results for each test are characterized into four toxicity ranges, from *non-toxic* to *high toxicity* (Table 1).

The amphipod survival test designated the entire study area as *non-toxic,* whereas the urchin fertilization test indicated toxicity in 22% of the study area.

Test results were then combined, characterized according to the four toxicity categories, mapped, and the spatial extent calculated for the study area (Figure 3).

The Toxicity Index indicated that 74% of the 2015 study area had *non-toxic* sediments. *Low toxicity* sediments were found at one location in Port Orchard Passage, representing 8% of the total study area. Sediments with *moderate toxicity* were found at several locations in Liberty Bay, Dyes Inlet, Phinney Bay, and Sinclair Inlet, representing 18% of the area.

The weighted mean Toxicity Index value for 2015 was significantly lower than for the initial 1998 survey of the Bainbridge Basin, indicating greater overall toxicity (Figure 1). Toxicity remained relatively the same over time in the high-current passages, but increased in the inner portions of the bays and inlets of the Bainbridge Basin.

Table 1. Toxicity Index category descriptions (Dutch et al., 2014).

Category	Description
Non-Toxic	Mean control-adjusted test results were not significantly lower than the controls **or** were ≥90% of controls
Low Toxicity	Mean control-adjusted test results were not significantly lower than the controls **and** between <90-80% of controls
Moderate Toxicity	Mean control-adjusted test results were not significantly lower than the controls **and** between <80-50% of controls
High Toxicity	Mean control-adjusted test results were not significantly lower than the controls **and** between <50% of controls

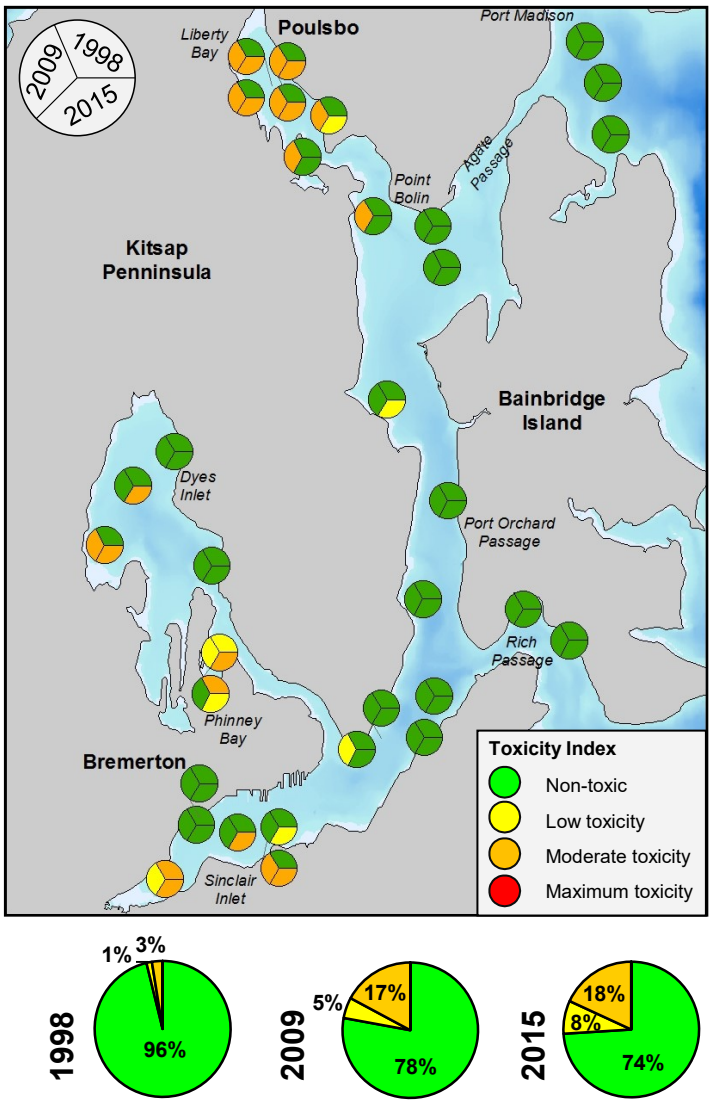


Figure 3. Toxicity Index categories calculated for Bainbridge Basin sediments. Spatial and temporal patterns shown on the map are summarized as percent area in the pie charts below the map.

Benthic Invertebrates

Sediment-dwelling invertebrates (benthos) were identified and counted for all 33 locations sampled in 2015. Annelids (marine worms) were numerically dominant in the Bainbridge Basin, followed by molluscs and arthropods (Figure 4). Echinodermata and miscellaneous taxa were the least-represented groups. Total abundance and taxa richness were low in Liberty Bay and gradually increased southward to Rich Passage, then declined again in Sinclair Inlet and inner Dyes Inlet.

Significant declines in total abundance occurred in the Bainbridge Basin since first evaluated in 1998. Total abundance in 2015 was approximately one-half of that measured in 1998 (Figure 4).

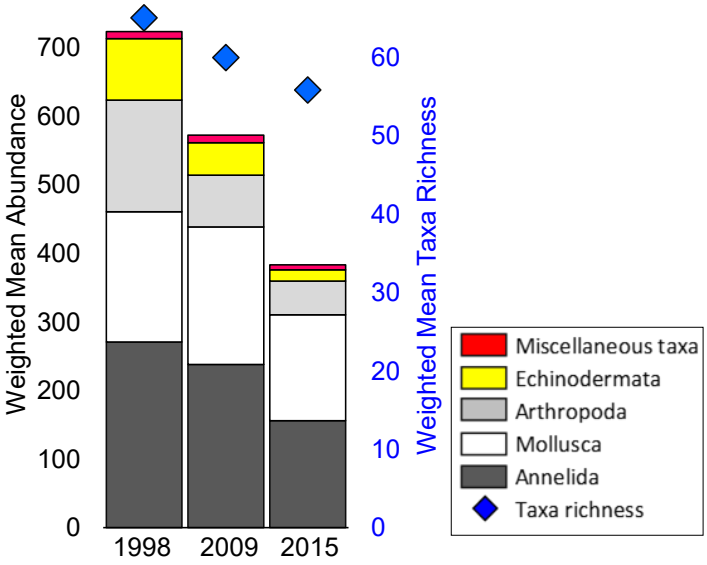


Figure 4. Weighted mean total abundance and taxa richness (number of unique species).

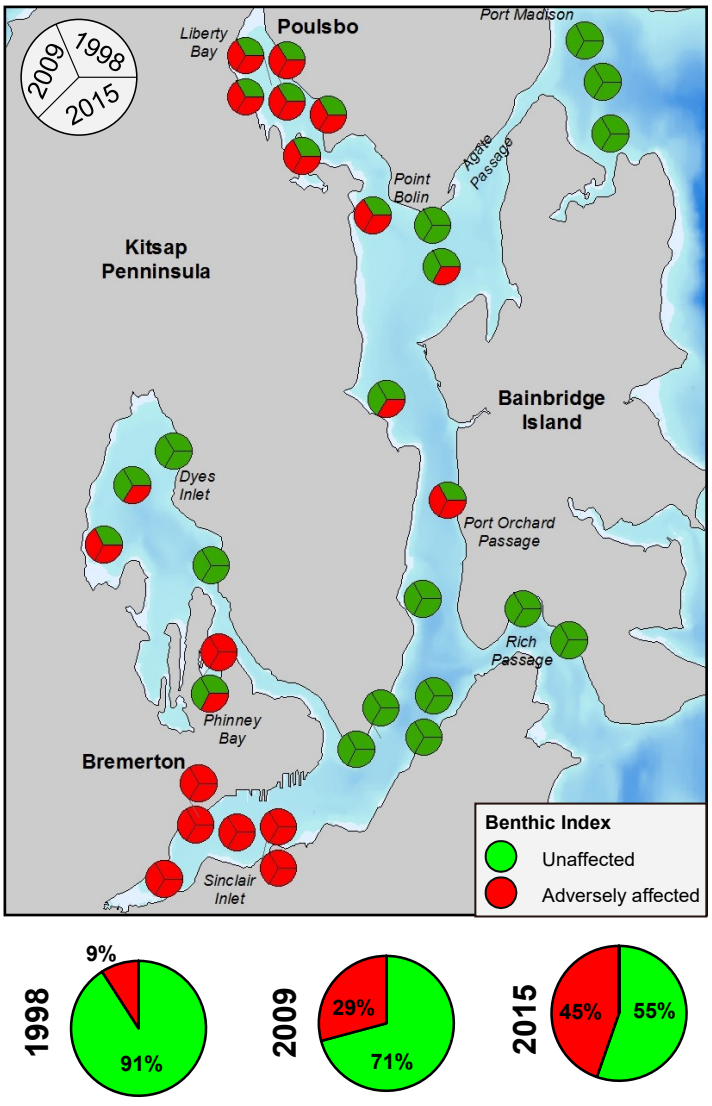


Figure 5. Benthic Index categories calculated for Bainbridge Basin sediments. Spatial and temporal patterns shown on the map are summarized as percent area in the pie charts below the map.

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 based on a suite of calculated indices including total abundance, major taxa abundances, taxa richness, evenness, and species dominance, and 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 2015 Bainbridge Basin survey were judged to be *adversely affected* for 45% of the study area (Figure 5). The remainder of the study area had *unaffected* benthos. The area represented by *adversely affected* benthic assemblages in 2015 was significantly higher than that found in the previous surveys. None of the sampling locations in the study area improved over time.

The condition of the benthic assemblages in Liberty Bay and Dyes Inlet have deteriorated since 1998, and assemblages in Sinclair Inlet remained *adversely affected* over time. Port Madison and most of the sites located in the passages of the basin remained in good condition over the three surveys.

Community Function

Functional feeding guilds (Macdonald et al., 2012) that integrate information on how, where, and what Salish Sea benthos eat were applied to Puget Sound benthos. Although total abundance and taxa richness declined over time in the Bainbridge Basin, percent abundance in the functional feeding guilds remained relatively constant over the three surveys (Figure 6).

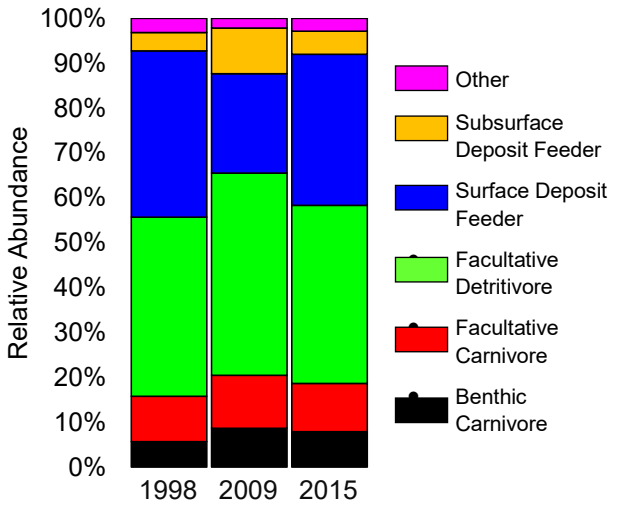


Figure 6. Relative abundance by functional feeding guild.

Triad Index

The sediment triad concept of characterizing sediment condition is an empirical weight-of-evidence approach (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 2015, 55% of the study area was classified as *unimpacted* (Figure 7). *Unimpacted* sediments were found in the passages of Bainbridge Basin, along the northeastern shoreline of Dyes Inlet, and in Port Madison. *Possibly* and *likely impacted* sediments were found in the inner portions of Liberty Bay, Dyes Inlet, Phinney Bay, and Sinclair Inlet, representing 7% and 15% of the study area, respectively. One site in Port Orchard Passage was classified as *inconclusive*, with conflicting Chemistry, Toxicity, and Benthic Index results, representing 4% of the study area. None of the Bainbridge Basin sediments were classified as *clearly impacted*.

Since 1998, overall sediment quality in the Bainbridge Basin declined significantly (Figure 1). The area with *unimpacted* sediments decreased significantly between 1998 and 2009, and again in 2015. Concurrent increases occurred in areas with *likely impacted* sediments between all three years. Two stations west of Point Bolin had improvements in sediment quality; all others remained the same or declined over time.

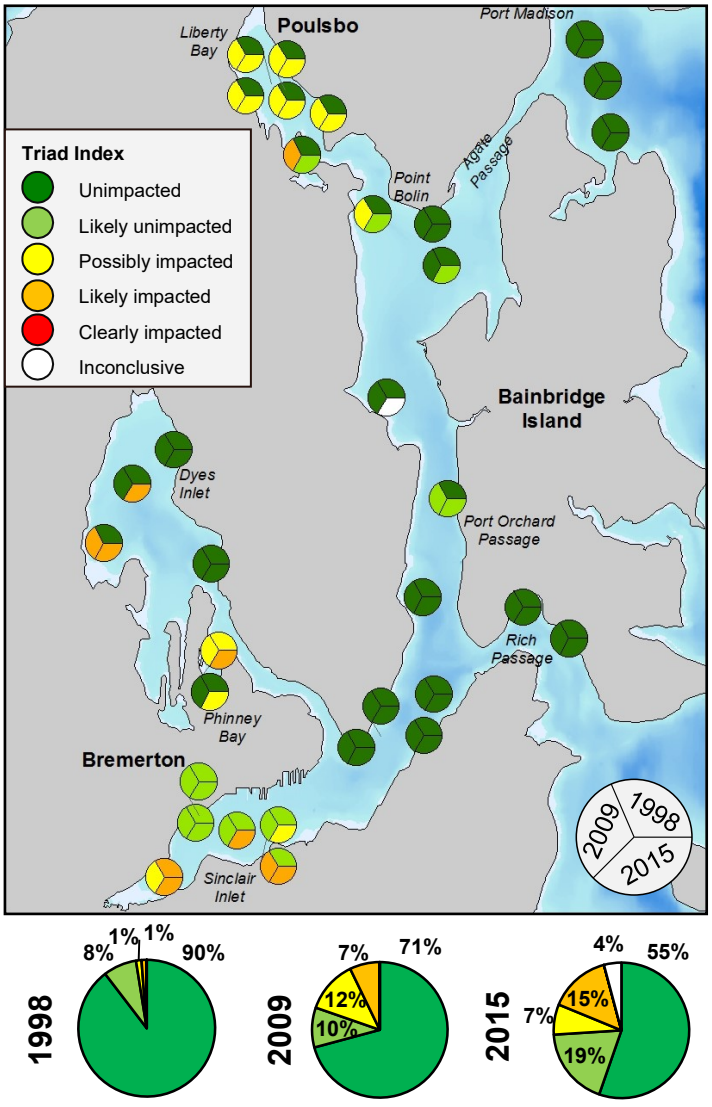
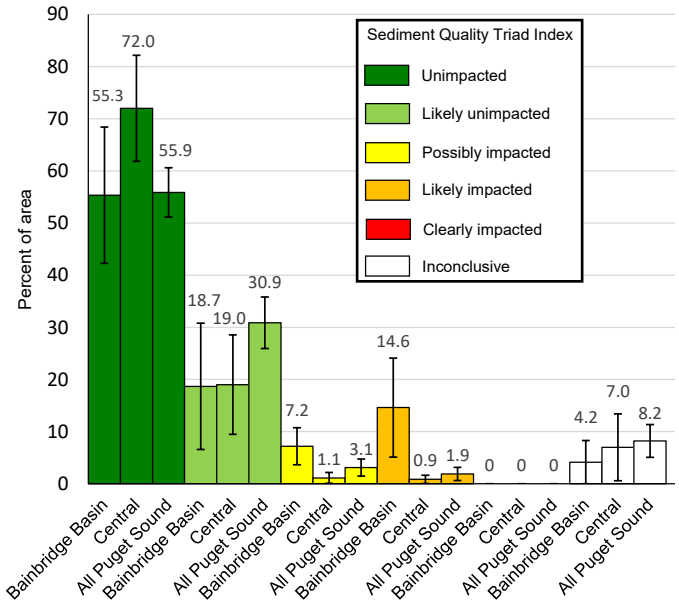


Figure 7. Triad Index categories calculated for Bainbridge Basin sediments. Spatial and temporal patterns shown on the map are summarized as percent area in the pie charts below the map.



Bainbridge Basin Compared to Central Puget Sound and all of Puget Sound

The area with unimpacted sediments in the 2015 Bainbridge Basin survey was statistically similar to that of the encompassing Central Puget Sound region and the 2004-2014 Puget Sound Survey as a whole (Figure 8). The Bainbridge Basin did have higher percentages of impacted sediment than either Central Puget Sound or all of Puget Sound.

Figure 8. Percent of area for the Triad Index categories for Bainbridge Basin compared to Central Puget Sound and to all of Puget Sound.

Puget Sound Partnership "Vital Signs" Chemistry and Triad Indices

Ecology's Chemistry and Triad Indices, and also the percent of chemicals exceeding (not meeting) the Washington State Sediment Cleanup Objective (SCO) chemical criteria (Ecology, 2013), were adopted by the Puget Sound Partnership (PSP) to serve as one of the "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 2020 target values for highest quality sediment, adopted by the PSP.

The weighted mean Chemistry Index value for Bainbridge Basin was above the target value of 93.3 in all three surveys (Figure 9a). The Bainbridge Basin study area was similar to the other recently surveyed urban bays except Elliott Bay, which was below the target.

The percent of chemicals in Bainbridge Basin in 2015 exceeding SCO chemical criteria did not meet the PSP target of zero (Figure 9b).

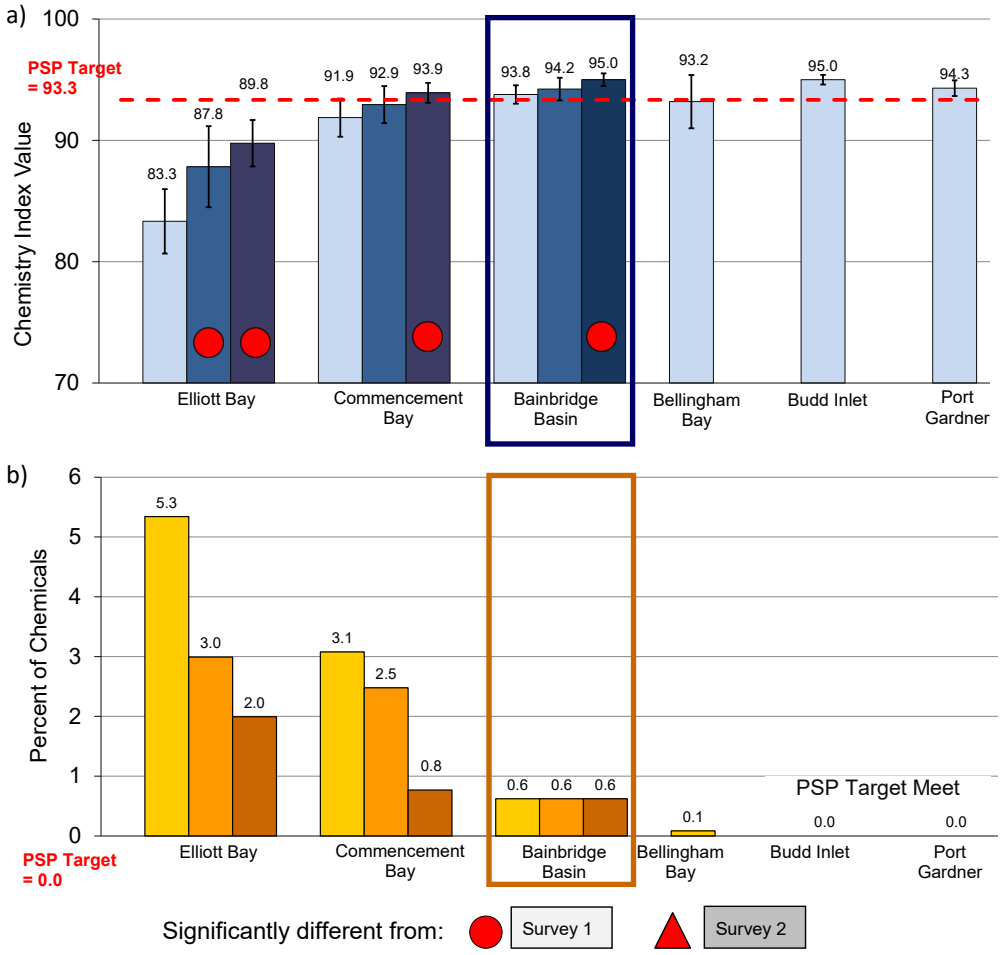


Figure 9. a) Change over time in Chemistry Index values (upper) and b) percent of chemicals not meeting Sediment Cleanup Objectives (lower) for urban bays in Puget Sound. Darker colored bars indicate later surveys (1998, 2009, 2015).

The weighted mean Triad Index value for the 2015 Bainbridge Basin survey did not meet the PSP target value of 81 and was statistically lower than in the first Urban Bays survey of the basin (Figure 10). The PSP target value corresponds to the minimum value in the *unimpacted* Triad Index category.

Sediment quality in the Bainbridge Basin was statistically similar to Elliott Bay and Commencement Bay, and better than sediment quality in Bellingham Bay or Budd Inlet.

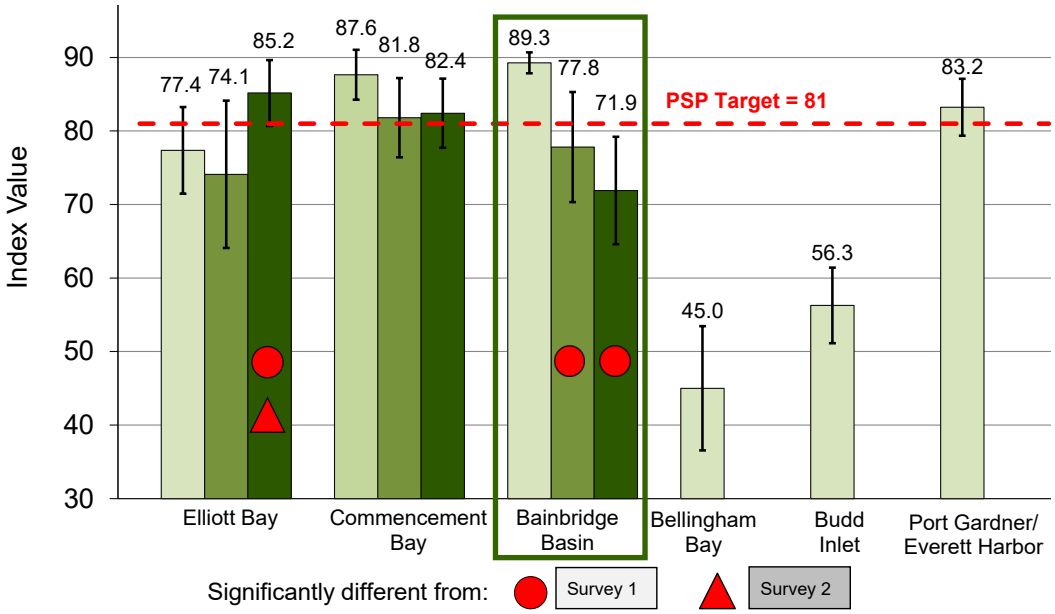


Figure 10. Change over time in weighted Triad Index values for urban bays in Puget Sound, with 95% confidence intervals. Darker colored bars indicate later surveys (1998, 2009, 2015).

Summary

The combined evidence from the triad measures of chemistry, toxicity, and benthos indicates that sediment quality in the Bainbridge Basin has significantly declined over time, with *unimpaired* sediment representing 90% of the study area in 1998 and dropping to 55% in 2015. Overall, exposure to measured chemical contaminants improved over the decade and contributed little to the overall decline in sediment quality. Increases in sediment toxicity contributed to the decline, in part, but the largest contribution was from the amount of area with *adversely affected* benthic communities. The Toxicity and Benthic Indices identified several co-located sites with impairment, yet no significant correlations between sediment toxicity and the benthic community could be established in these surveys.

Although it is not possible to state why the benthic community declined with the parameters measured by the Urban Bays Program, the physical and oceanographic environment in the Bainbridge Basin may be affected by large-scale climatic drivers that, in turn, affect the benthic community. Additional parameters will need to be monitored to determine what is adversely affecting the benthic community.

Note

It is important to distinguish between Ecology's ambient sediment monitoring activities, such as this Urban Bays study, and Ecology's Toxic Cleanup Program (TCP) Remedial Investigations and Feasibility Studies (RI/FS). This ambient study characterizes current conditions for large geographic areas rather than targeted locations. The TCP is concerned primarily with the toxic legacy from past industrial practices and how those practices have impacted Puget Sound. The RI/FS process examines sediment contamination in the entire biologically active zone, whereas the Urban Bay Monitoring assesses the most recently deposited sediments. The two programs use different sampling and analysis procedures. As a result, these differences in approach could potentially lead to differing conclusions, even at similar locations. Results from this publication are not intended to supersede, revise, or replace the State's regulatory criteria under the Sediment Management Standards.

References

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

Department of Ecology Contacts

Authors: Sandra Weakland, Valerie Partridge, Margaret Dutch, Dany Burgess, and Angela Eagleston

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, Union Gap	(509) 575-2490
Eastern Regional Office, Spokane	(509) 329-3400

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Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search Study ID, UWI2015.

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