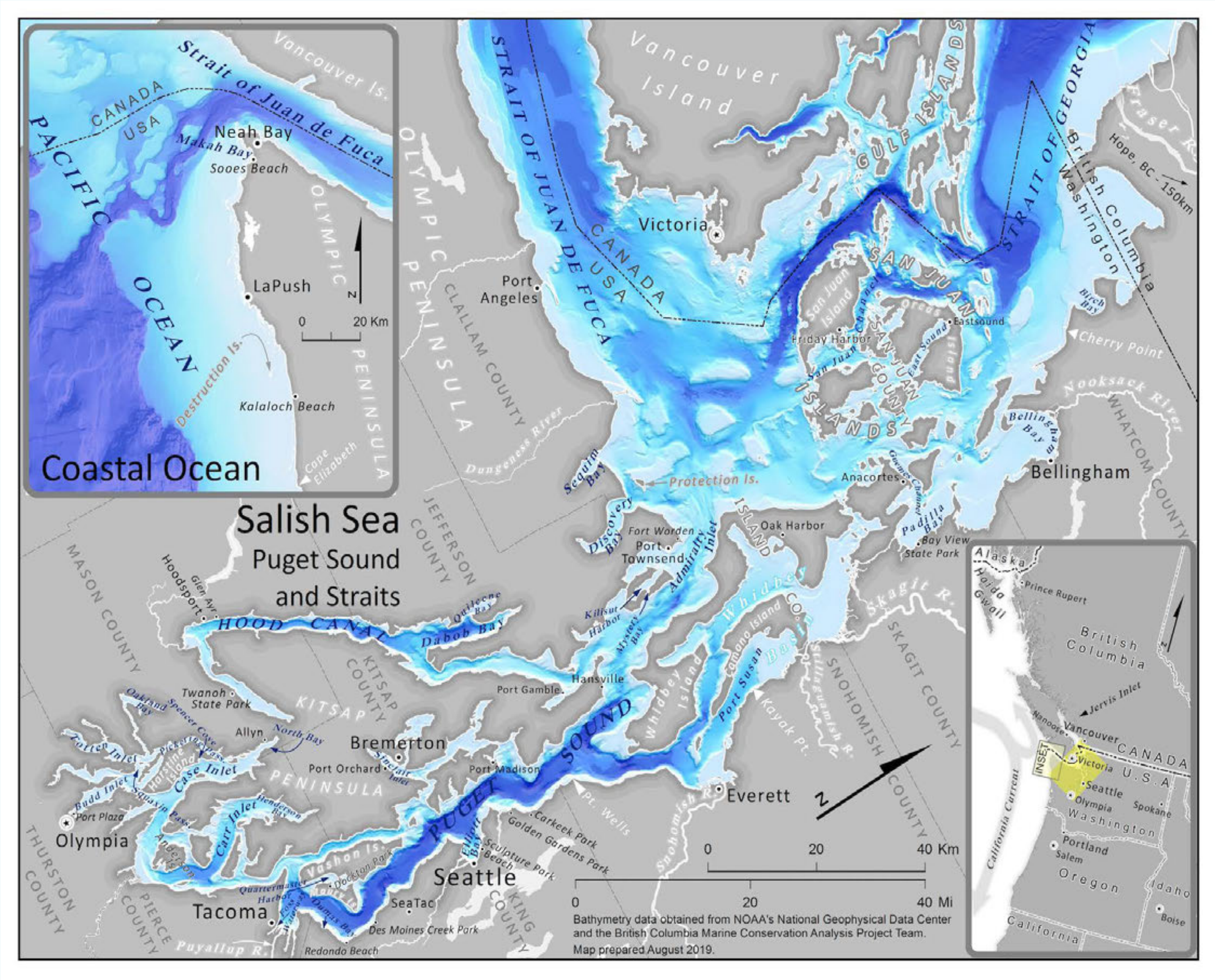
puget sound marine waters

2025 overview



Map: Damon Holzer

Produced by: The Puget Sound Ecosystem Monitoring Program Marine Waters Workgroup with support from the University of Washington Puget Sound Institute.

PSEMP
PUGET SOUND ECOSYSTEM MONITORING PROGRAM

PUGET SOUND INSTITUTE
UNIVERSITY of WASHINGTON

Cover: Kukutali Preserve State Park Heritage Site. Photo: Sylvia Kantor/PSI

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About PSEMP

The Puget Sound Ecosystem Monitoring Program (PSEMP) is a collaboration of monitoring professionals, researchers, and data users from federal, tribal, state, and local government agencies, universities, nongovernmental organizations, watershed groups, businesses, and private and volunteer groups.

The objective of PSEMP is to create and support a collaborative, inclusive, and transparent approach to regional monitoring and assessment that builds upon and facilitates communication among the many monitoring programs and efforts operating in Puget Sound. PSEMP's fundamental goal is to assess progress toward the recovery of the health of Puget Sound.

The Marine Waters Workgroup is one of several technical workgroups operating under the PSEMP umbrella, with a specific focus on the inland marine waters of Puget Sound and the greater Salish Sea, including the oceanic, atmospheric, and terrestrial influences and drivers affecting the Sound. For more information about PSEMP and the Marine Waters Workgroup, please visit the PSEMP website.

Introduction

This Marine Waters Overview provides a perspective of 2025 Puget Sound marine water quality and conditions and associated biota from comprehensive monitoring and observing programs. While the report focuses on the marine waters of greater Puget Sound, additional selected conditions are also included due to their influence on Puget Sound waters. These include large-scale climate indices and conditions along the Washington coast. It is important to document and understand regional drivers of variability and patterns on various timescales so that water quality data may be interpreted with these variations in mind, to better attribute human effects versus natural variations and change. This is the fifteenth annual report produced by the PSEMP Marine Waters Workgroup. Our message to decision makers, policy makers, managers, scientists, and the public who are interested in the health of Puget Sound follows.

From the editors

Our objective is to collate and distribute the valuable physical, chemical, and biological information obtained from various marine monitoring and observing programs in Puget Sound. Based on mandate, need, opportunity, and expertise, these efforts employ different approaches and tools that cover various temporal and spatial scales—including but not limited to surface and water column surveys, fixed depth and profiling high temporal resolution moorings, and continuous monitoring platforms. Collectively, these methods provide information representing various temporal and spatial scales and can be used to connect the status, trends, and drivers of ecological variability in Puget Sound / Salish Sea marine waters. In this report, the terms Puget Sound and Salish Sea are used interchangeably. By identifying and connecting trends, anomalies, and processes from each monitoring program, this report adds significant and timely value to the individual datasets and enhances our understanding of this complex ecosystem. We present here that collective view for the year 2025.

This report is the proceedings of an annual effort by the PSEMP Marine Waters Workgroup to compile observations collected across the marine waters of Washington State during the previous year. As always, data quality assurance and documentation remain the primary responsibility of the authors submitting technical summaries, whose names, contact information, and links to data are provided with each submission. Due to the lack of any funding available for production of the Overview report this year, the typical editorial review of all submissions, and description of Vital Sign linkages could not be completed. The Summary section is based on the individual contributions and seeks to provide a high-level description of the overall trends in variability and change in marine waters during 2025.

This report helps the PSEMP Marine Waters Workgroup address important priorities, including 1) maintaining an inventory of active monitoring programs in Puget Sound and other marine waters and 2) improving dissemination, transparency, data sharing, and communication of monitoring results and efforts across the marine waters monitoring network.

Integral to this data sharing is the Northwest Association of Networked Ocean Observing Systems (NANOOS), which is the regional arm of the U.S. Integrated Ocean Observing System (IOOS) for the Pacific Northwest and is working to improve regional access to marine monitoring data. Much of the marine data presented in the report, as well as an inventory of monitoring assets, can be found through the NANOOS web portal.

Summary of What Happened in 2025

In general, the year 2025 was warmer, drier, saltier, with less abundant biota.

Both large-scale climate indices (El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) were in their negative or cooler phase, which is typically associated with cooler air and sea temperatures. Weak to moderate La Niña conditions prevailed during the winters of 2024-25 and 2025-26. The PDO remained negative in 2025 for the fifth year in a row, with particularly extreme values from summer into fall 2025 and the most negative value (July) since the mid-1800s. However, Puget Sound's average air temperature was 0.6 °C above normal for 2025, tying as the 5th warmest year since records began in 1895. Summer temperatures were also warmer than normal with June through September ranking as the 2nd warmest on record, making 2025 the 5th consecutive summer with above normal temperatures.

Warmer than average waters were common. Pacific Northwest coast offshore waters warmed significantly over the summer, leading to the development of a marine heat wave that peaked in September. Puget Sound was also warmer than usual, with warm temperature anomalies in all basins likely driven by surface heat fluxes. Central Basin waters set record highs in fall and winter 2025. The Padilla Bay annual water temperature anomaly was the highest since the 2015-16 marine heat wave. Water temperatures in Whidbey Basin and San Juan Channel (deep and surface) also were warmer than average.

An exception to warmer than average waters was along the Washington coast where particularly strong upwelling influenced conditions, with cool and salty water anomalies on the shelf. 2025 saw an early onset of the most sustained and strongest upwelling wind conditions on the northwest Washington shelf going back more than a decade. Like in 2024, waters were generally cooler and saltier than climatology over the upwelling season.

The region not only saw warmer than average air temperatures but drier also, with the annual Puget Sound precipitation below normal during 2025. January received 33% of normal precipitation, ranking as the 3rd driest January since records began in 1895. Spring and summer were also drier than normal, with April through July ranking as the 5th driest such period on record. The exception was December, which received 146% of normal precipitation, ranking as the 9th wettest December on record, causing major flooding.

Puget Sound was saltier than normal throughout the year, likely due to the reduced rainfall and river input, continuing a multi-year trend. Low freshwater inputs persisted through 2025 until the heavy rainfall in December. Salinity in the Central Basin was high throughout the year leading to relatively weak stratification. While Whidbey Basin stations were stratified throughout the year, surface waters were saltier in the summer and fall. San Juan Channel had saltier surface and deep waters.

Pathogens and bacteria appeared to respond to the temperature and precipitation anomalies, for better or worse. Fecal indicator bacteria concentrations, typically correlated with runoff, were generally low compared to the historical record, except in December after the heavy rains and flooding. Twelve confirmed *Vibrio parahaemolyticus* illnesses in September 2025 were twice as high as the prior five years and may have been related to the higher than normal seawater temperatures.

The weaker stratification may have resulted in less phytoplankton, as indicated by generally low chlorophyll values, since sunlight and nutrients were not lacking. Chlorophyll a in the Central Basin was the lowest since 2008 (except for Elliott Bay, with the highest summer value on record). Chlorophyll anomalies at East Passage were negative for all of 2025, a substantial departure from the prior three years. Whidbey Basin chlorophyll was lower in 2025 compared to prior years. Surface waters nitrate was higher than previous years during the growing season, consistent with lower productivity and lack of uptake compared to prior years. The weaker stratification may have prevented blooms from accumulating. Central Basin microplankton biovolume was 45.7% lower than the previous 10-year average and the second lowest year on record.

Heading up the food web, consumers also showed lower abundance in general. Zooplankton biomass was generally lower than in the past decade. Peak zooplankton biomass occurred later than the historical regional average. Zooplankton abundances in Padilla Bay were generally less than the long-term average. Dungeness crab megalopae (late larval stage) abundances were generally low relative to previous years, with the highest catches recorded at sites in Hood Canal.

Higher trophic levels were a mix, but with generally lower numbers. Puget Sound herring declined again with the 6th lowest estimate on record, with two positive exceptions: herring spawning was observed at Cherry Point for the first time in three years and was confirmed in Oro Bay for the first time. Early marine survival of Puget Sound-origin juvenile Chinook salmon has remained low since 2014. The San Juan Channel fall survey found the 2nd lowest marine mammal density on record, but the 4th highest seabird density. Unprecedented numbers of short-tailed shearwaters, a pelagic seabird associated with open ocean waters, were observed throughout Puget Sound during fall.

Overall, the abundances of many key ecosystem components were lower than average. Whether continued positive seawater temperature anomalies are involved is yet to be understood. Whether 2025 was a blip or part of a pattern will have to wait to unfold with our Marine Waters Overview next year.

By Jan Newton, with input from the Editorial Team

Highlights from 2025 Monitoring

Large-scale climate variability and wind patterns

- Weak to moderate La Niña conditions prevailed during the winters of 2024-25 and 2025-26.
- The Pacific Decadal Oscillation (PDO) in 2025 remained negative for over the fifth year in a row, with particularly extreme values from summer into fall 2025. July had the most negative value since the mid 1800s.

Local climate and weather

- Puget Sound's average air temperature was 0.6 °C above normal for 2025, tying as the 5th warmest year since records began in 1895.
- Puget Sound total precipitation was below normal for 2025. January only received 33% of normal precipitation, ranking as the 3rd driest January since records began in 1895.
- In contrast to January, December was much wetter than normal with the Puget Sound region receiving 146% of normal precipitation and ranking as the 9th wettest December on record. A long duration atmospheric river in December 2025 caused major flooding throughout the region.
- The Puget Sound region experienced a drier than normal spring and summer. April through July ranked as the 5th driest such period on record. Summer temperatures were also warmer than normal with June through September ranking as the 2nd warmest on record, making 2025 the 5th consecutive summer with above normal temperatures.

Coastal ocean and Puget Sound boundary conditions

- Waters off the Pacific Northwest coast warmed significantly over the summer, leading to the development of a marine heatwave (MHW) that peaked in September.
- Like in 2024, waters were generally cooler and saltier than climatology over the upwelling season.
- The early onset of strong, sustained upwelling-favorable wind appears to have caused cool and salty water anomalies. 2025 had the most sustained and strongest seasonally-averaged upwelling wind conditions on the northwest Washington shelf going back more than a decade.
- Like in 2024, dissolved oxygen (DO) at depth was lower than normal with sustained hypoxic (<2 mg/L) events in late summer.

Water quality

Temperature

- In 2025, Puget Sound was warmer than usual throughout the year. Remarkably warm water temperatures were observed in December 2025, which rivaled anomalies recorded during the marine heatwave years of 2014-2016.
- The warm temperature anomalies in all basins were likely driven by surface heat fluxes.
- Warm water temperature anomalies present since mid-2023 continued in the Central Basin, with record highs in fall and winter 2025.
- Elliott Bay water temperatures were near the maximum of the data record that culminated in record high temperatures in November and December at both the surface and 10 meters.
- Starting in late spring, surface water temperatures in Padilla Bay were warmer than normal through the remainder of the year.
- The annual water temperature anomaly in Padilla Bay for 2025 was the highest recorded since the 2015-16 marine heatwave.
- Northern stations in the northern Whidbey Basin showed more mixing and less variability compared to stations in the south that are more heavily influenced by the Skagit River. Overall, ranges and trends measured in 2025 were similar to those in 2023 and 2024.
- Water temperatures in the central and southern Whidbey Basin were warm and similar to 2022–2024, with temperature inversions (colder at the surface than deep) at the beginning and end of the year.
- In the San Juan Channel, warmer than average surface and deep water temperatures in the fall were observed at stations North and South.

Salinity and water column structure

- In 2025, Puget Sound was saltier than normal throughout the year, likely due to reduced river and rainfall input, continuing a multi-year trend.
- Salinity in the Central Basin was high throughout the year leading to relatively weak stratification. Low freshwater inputs persisted through most of 2025 until heavy rainfall in December.
- The water column in the northern Whidbey Basin was well-mixed near Deception Pass, with increased stratification and

greater variability observed at stations near the Skagit River in the south.

- All stations in the central and southern Whidbey Basin were stratified throughout the year, but surface waters were saltier in the summer and fall.
- In the San Juan Channel, saltier surface and deep waters were observed at stations North and South in the fall.

Dissolved oxygen

- Modest dissolved oxygen (DO) anomalies were observed in most basins, alternating between positive and negative periods. However, DO had significant regional and temporal variability during 2025, with relatively modest anomalies of less than ±1 mg/L for most of the year in the Main Basin, and generally stronger anomalies (>±1mg/L) in Hood Canal.
- Strongly negative DO anomalies during some months were observed in Puget Sound, which exceeded changes in solubility associated with temperature and salinity anomalies.
- Hypoxia was observed at Twanoh (southern Hood Canal) in summer-fall, before modulating but staying low to the end the year. Relative to prior years, 2025 had a stronger and more prolonged period of hypoxia.
- Dissolved oxygen was anomalously low for most of the year in the Central Basin, especially during the phytoplankton growing season, likely due to lower productivity.
- Dissolved oxygen in the central and southern Whidbey Basin was slightly lower than previous years. Port Susan intermittently experienced low DO (~2 mg/L) near the bottom throughout the year, in contrast to continuous lows observed in winter–spring 2024.

Ocean and atmospheric CO_2

- Monthly average 2025 atmospheric carbon dioxide (CO_2) levels on the coast were 2-8 ppm higher than globally averaged marine surface air during October-June; however, they were 0-4 ppm lower during the other months, likely reflecting regional forest production.
- Monthly coastal surface seawater xCO2 averages were ~30-90 ppm higher than normal during January-April.
- Atmospheric CO_2 in Hood Canal during fall-winter averaged 15–21 ppm higher than the globally averaged marine surface air, with smaller differences in summer (7–14 ppm) when regional primary production reduces the offset.
- Surface seawater xCO_2 averages were mostly within historical ranges at both Hood Canal sites, but were substantially lower than long-term means at Twanoh in January and September, suggesting early and late phytoplankton productivity in Hood Canal, and substantially higher-than-normal at both sites in October, suggesting early storm mixing.

Nutrients

- August and September dissolved silica values in the Central Basin were atypically high throughout the water column and did not correspond with freshwater inputs.
- Average monthly dissolved nitrate+nitrite and silica in Central Basin deep waters was higher than normal for most of 2025.
- Whidbey Basin dissolved nitrate+nitrite in surface waters was higher than previous years during the growing season, consistent with lower productivity and lack of uptake compared to prior years.

Chlorophyll

- Chlorophyll a in the Central Basin was low in 2025 and was the lowest at many sites since 2008.
- Chlorophyll a in the Central Basin indicated the spring bloom was evident in early April, a lack of sustained blooms during the growing season, and was low by mid-August at most sites. Chlorophyll a anomalies at East Passage were negative for all of 2025, a substantial departure from the prior three years.
- Elliott Bay had atypically high chlorophyll a for most of the growing season, including the highest summer value on record.
- Chlorophyll in the central and southern Whidbey Basin was lower in 2025 compared to prior years.

Plankton

Phytoplankton

- Total microplankton biovolume in 2025 in the Central Basin was 45.7% lower than the previous 10-year average. It was the second lowest biovolume year on record, with 2018 being the lowest.
- The 2025 growing season was short, with the majority of microplankton biovolume in the Central Basin observed by the end of June.
- The diatom *Coscinodiscus* bloomed in record high biovolumes throughout the Central Basin in late April, with the highest biovolume observed at East Passage.

Highlights from 2025 Monitoring (cont.)

- The central and southern Whidbey Basin microplankton growing season spanned April to November, with a small February diatom bloom observed at most stations.
- A *Thalassiosira punctigera* (diatom) bloom was observed in the central and southern Whidbey Basin from October to November. While common, this species had not contributed significantly to biovolume during this period in prior years.
- Elevated detritus particle concentrations were observed at Port Susan and Saratoga Passage following heavy December rainfall and river discharge.

Zooplankton

- In 2025, total mesozooplankton biomass in Puget Sound was generally below the past decade's monthly averages.
- At most stations in Puget Sound, peak zooplankton biomass occurred later than the historical regional average, with isolated early, high peaks driven by blooms of specific taxa (e.g., larval invertebrates and *Noctiluca*).
- Monthly zooplankton abundances in Padilla Bay were less than the long-term average except in August when abundance was higher.
- In Padilla Bay, monthly zooplankton community composition was similar to previous years though some months showed more similarity to each other than is typical.
- Dungeness crab megalopae (late larval stage) abundances were generally low relative to previous years, with the highest catches recorded at sites in Hood Canal.
- Larval Dungeness crab monitoring indicated a shift in peak larval delivery timing, with Pacific coast sites peaking in May, central Salish Sea sites in June, and South Puget Sound sites in July.

Harmful algae and biotoxins

- Marine biotoxins resulted in 28 recreational shellfish harvest closures and 7 commercial shellfish harvest closures in 2025.
- Paralytic Shellfish Poisoning (PSP) closures began later than usual, with isolated lethal levels (≥1,000 µg/100 g) restricted to Discovery and Sequim Bays.
- Diarrhetic Shellfish Poisoning (DSP) toxins caused shellfish closures in Discovery Bay and Sequim Bay in June. DSP reached the maximum level ever recorded for the coast (33 µg/100 g) in September.
- 2025 marked the second year in a row with no Amnesic Shellfish Poisoning (ASP; domoic acid) closures.
- In 2025, the diatom to dinoflagellate ratio peaked in February, about one month earlier than the 10-year median.
- Frequently reported blooms and the presence of the target harmful algal bloom (HAB) genera were typical in 2025 based on previous years of SoundToxins data.

Bacteria and pathogens

- Fecal indicator bacteria concentrations at Central Basin beach stations were generally low compared to the historical record, except in December after heavy rains and flooding.
- Fecal indicator bacteria concentrations in offshore waters in the Central Basin were low like in previous years.
- In 2025 there were a total of 67 laboratory confirmed *Vibrio parahaemolyticus* (*Vp*) illnesses from commercially harvested oysters.
- The 12 confirmed *Vp* illnesses in September 2025 was twice as high as the prior five years and may have been related to the higher than normal water temperatures.

Forage fish and juvenile salmon

- Estimated Spawning Biomass (ESB) of Puget Sound herring declined again from 11,404 metric tons (mt) in 2024 to 8,862 mt in 2025, the 6th lowest estimate on record.
- Herring spawning was observed at Cherry Point for the first time in three years.
- Herring spawning was confirmed for the first time in Oro Bay. The spawning observed at this location was the latest observed anywhere in Puget Sound during the 2025 season.
- Early marine survival of Puget Sound-origin juvenile Chinook salmon has remained low since 2014.
- Puget Sound-origin juvenile Chinook salmon have been eating fewer Pacific sand lance, but about the same amount of Pacific herring. This may indicate a decrease in sand lance populations.

Marine mammals and birds

- In the San Juan Channel fall months, 2025 had the 4th highest seabird density but the 2nd lowest marine mammal density on record.
- Unprecedented numbers of short-tailed shearwaters, a pelagic seabird associated with open ocean waters, were observed throughout Puget Sound during fall 2025.

Technical Summaries

Sediment collection. Photo: Christopher Krembs

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Large-scale climate variability and wind patterns

Golden Gardens. Photo: Rachel Wold

ENSO and PDO

Authors: Nicholas Bond (UW Washington State Climate Office, nab3met@uw.edu); Karin Bumbaco (UW Washington State Climate Office)
Edited by: Jacob Genuise
Website: www.climate.washington.edu; **Additional website for data**: www.cpc.ncep.noaa.gov/products/GODAS/multiora/index/mnth.ersstv5.clim19912020.pdo_current.txt

Highlights

- Weak-moderate La Niña conditions prevailed during the winters of 2024-25 and 2025-26.
- The PDO remained negative, with particularly extreme values from summer into fall 2025.

Narrative

ENSO

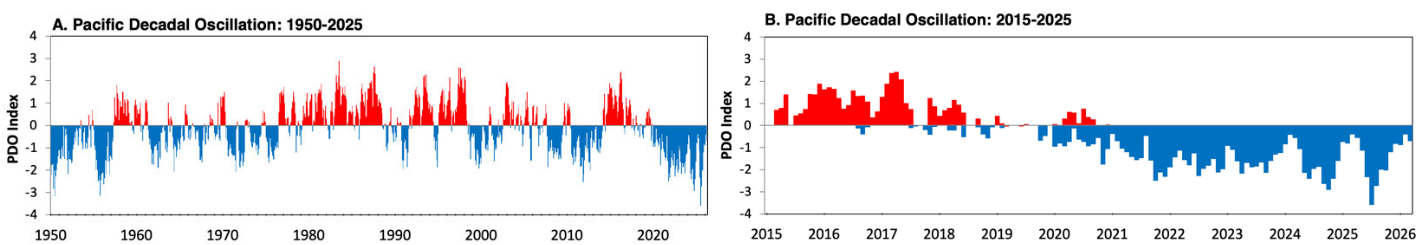
Sea surface temperatures (SSTs) were cooler than normal in early 2025 in association with the weak-moderate La Niña of the winter of 2024-25. Near-surface temperatures moderated as a neutral state of El Niño-Southern Oscillation (ENSO) developed by June 2025. Cooling relative to seasonal norms resumed in late summer 2025 with the Relative Oceanic Nino Index (RONI) reaching a three-month minimum of -1.0 during the period of November 2025 through January 2026, indicating the 2nd winter in a row of a weak-moderate La Niña. That period included a weaker than normal Aleutian Low, which commonly occurs with La Niña, but the sea level pressure (SLP) anomaly was centered over the Bering Sea well to the northwest of its typical location. Note that NOAA began officially using RONI in place of the Oceanic Niño Index (ONI) in February 2026 and has reclassified historical ENSO events based on RONI. This switch was made to reduce the impact of long-term warming on ocean temperatures and more accurately reflect year-to-year variability.

PDO

The PDO was negative during 2025, decreasing from approximately -0.8 early in the year to a minimum in July of about -3.6 before increasing to values of about -1 near the end of the year. The July 2025 value represents the most negative state for the PDO since the mid 1800s. The PDO was negative primarily due to a large area of persistent SST anomalies of 1-2°C between roughly 30° and 50°N extending from the east coast of Asia across the dateline into the eastern North Pacific with regional peaks exceeding 4°C ; temperatures along the west coast of North America were mostly near normal (with an exception noted below), implying those waters had mostly a negligible contribution to the PDO.

Pacific NW Offshore Waters

SSTs of near normal values were present off the Pacific NW coast during the first half of 2025 (relative to 1991-2020 averages). These waters warmed significantly over the summer, leading to the development of a marine heat wave (MHW) that peaked in September. Cooling occurred with the onset of fall storms, resulting in just slightly warmer than normal SSTs by the end of 2025.



Monthly values of the Pacific Decadal Oscillation (PDO) Index from a) 1950 through 2025 and b) 2015 through 2025.

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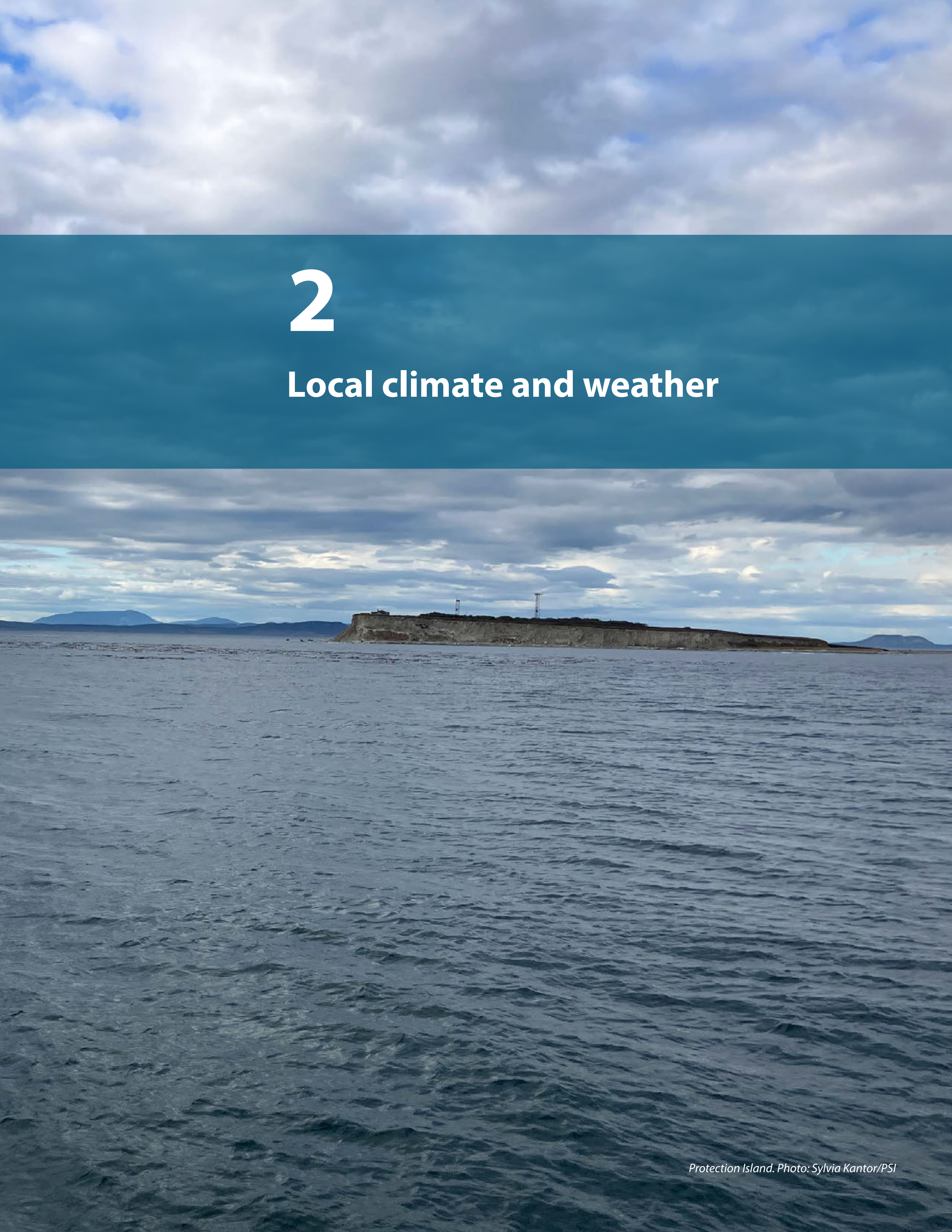
Local climate and weather



Protection Island. Photo: Sylvia Kantor/PSI

Regional air temperature and precipitation

Authors: Karin Bumbaco (Washington State Climate Office, University of Washington, kbumbaco@uw.edu), Nicholas Bond (Washington State Climate Office, University of Washington)
Edited by: Jacob Genuise, Washington State Climate Office, University of Washington
Website: www.climate.uw.edu; **Additional website for data**: https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/divisional/time-series

Highlights
- Puget Sound's average air temperature was 0.6°C above normal for 2025, tying as the 5th warmest year since records began in 1895.
- Puget Sound total precipitation was below normal for 2025.

Overview

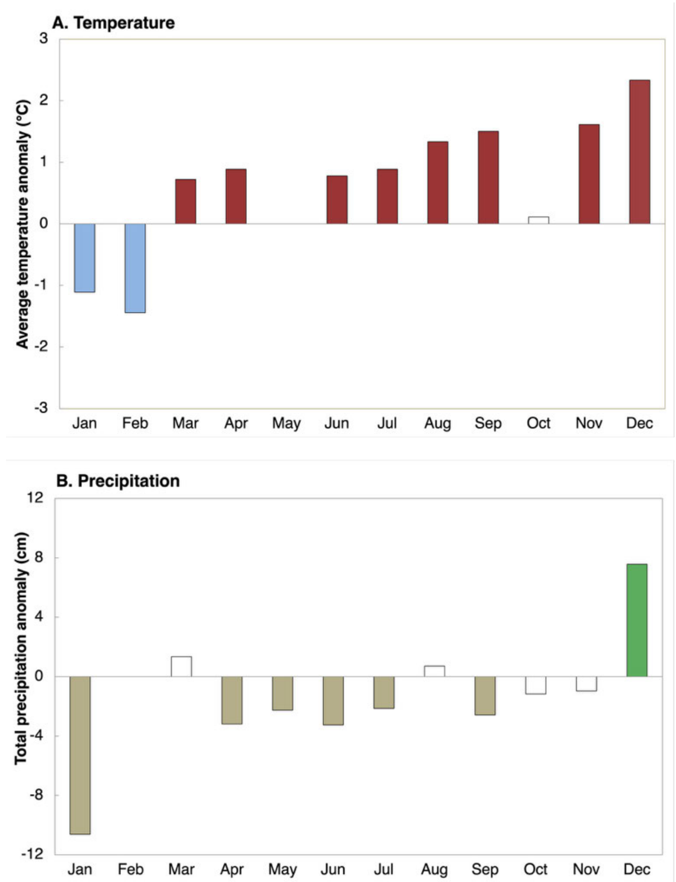
Washington is divided into 10 separate climate divisions based on similar average weather conditions. The following summary uses data from the Puget Sound Lowlands division that encompasses most of Puget Sound.

Narrative

The 2025 Puget Sound annual average air temperature (11.3°C; 52.4°F) was above the 1991-2020 normal (+0.6°C), warmer than the last eight years, and tied with 2014, 1992, and 1934 as the 5th warmest year since records began in 1895. The recent years of 2015 and 2016 were both warmer than 2025. Total annual precipitation (98.86 cm; 38.92") was 86% of normal, and 2025 was the driest year of the last 11, with the exceptions of the even drier years of 2019 and 2023.

Monthly values are used to illustrate the variability in the weather during the year. Figure 1 shows monthly temperature and precipitation anomalies for the Puget Sound region relative to the 1991-2020 normal.

January and February were the only two months of the 2025 calendar year with cooler than normal temperatures. January only received 33% of normal precipitation, ranking as the 3rd driest January since records began in 1895. These dry January conditions were detrimental to statewide snowpack. February and March received near-normal precipitation, but not enough mountain snowfall to recover from the drier than normal January. By April 1, Washington statewide average snowpack was 87% of median and the average Puget Sound snowpack was only 78% of median. The Puget Sound region then experienced a drier than normal spring and summer. April through July ranked as the 5th driest such period on record. Summer temperatures were also warmer than normal with June through September ranking as the 2nd warmest on record and the 5th consecutive summer with above normal temperatures. Finally, it was warmer than normal for the 3rd December in a row; 2025 ranked as 3rd warmest December since records began in 1895. December was also much wetter than normal, with the Puget Sound region receiving 146% of normal precipitation, and a ranking as the 9th wettest December on record. A long duration atmospheric river in December 2025 caused major flooding throughout the region.



Monthly anomalies relative to the 1991-2020 climate normal for (A) temperature (Celsius) and (B) precipitation (centimeters) for the Puget Sound Lowlands climate division in Washington State during the 2025 calendar year. Temperature anomalies (A) are colored red for above normal and blue for below normal. Temperature anomalies within 0.5°C are classified as near normal and are colored white. Precipitation anomalies (B) are colored green for above normal and brown for below normal. Precipitation anomalies within 2 cm are classified as near normal and are colored white.

CALLOUT 1 | Thirteen years of Marine Waters Overview reports

The Marine Waters Overview Reports annually cover numerous aspects of the Puget Sound Ecosystem for a given year. What has been lacking, however, is comparison between and over the years. PSEMP's Marine Waters Work Group identified this as an unmet need. Utilizing effort from a University of Washington EarthLab summer intern (SS), we undertook to conduct such an interannual analysis of reports from 2011 through 2023.

Each Marine Waters Overview Report was reviewed for the ecosystem aspects shown in Figure 1. Various metrics about each aspect were assessed, including annual averages, minima/maxima, timing, and exceptional anomalies. We present only a fraction of the information synthesized, focusing on relative values to compare the years. Results are best analyzed in topical groupings; for each, hypotheses were made based on known mechanisms and connections. Note that although there are often substantial differences among basins, this effort reflects Puget Sound overall patterns.

The top panel includes climate system drivers, such as El Niño-Southern Oscillation and the Pacific Decadal Oscillation. When these are in the positive or warm phase (deep red), we would expect warmer air and water temperatures (deep red) and vice versa (blue). This pattern largely held, however there are some years where it did not. Notably, in 2017 following the strong 2014-2016 Marine Heat Wave and El Niño, Puget Sound water temperatures stayed warm. This likely reflects the retentive nature of Puget Sound circulation and/or regional heating. 2021 also showed cool climate forcings but warmer sea temperatures. The analysis presented here gives insight into where more analysis is needed to understand the patterns, such as whether local weather or river input could offer a mechanism to explain the 2021 result.

The second panel shows hydrological forcings and salinity. The hypothesis is when either precipitation or river flows are high (turquoise), salinity will be low (turquoise), and vice versa (tan). Again, the pattern largely holds but there are exceptions, and much more variation within a given year. Because major river flows contributing to the Puget Sound are highly dependent on snow-pack in the Cascades, tracking how temperatures and storm intensity effect the total and pulse snow runoff volumes may clarify discrepancies in this section.

The third panel contains ecosystem attributes relevant to phytoplankton production. We hypothesize that when solar radiation and nutrients are high, that phytoplankton will be more plentiful. However, phytoplankton in the presence of sunlight will drive down nutrients. While phytoplankton production would increase the dissolved oxygen in surface waters it would decrease it at depth, potentially leading to hypoxia. Our color coding is to show when these consistent patterns went together: sunlight high, nutrients low, phytoplankton high, and deep oxygen low (orange) and vice versa (green). We see some consistencies but many times where that pattern does not hold, likely due to time lags and the issue of sampling these attributes on time scales longer (e.g., monthly) than they change (e.g., days-weeks) in nature and other key factors like mixing and stratification not represented here. Again, the patterns shown can be used to inform further detailed investigation.

The bottom panel shows various Puget Sound biota: zooplankton, fish, marine birds, and marine mammals. Making a hypothesis here is not possible, since this represents several trophic levels, confounding prey and predators. We do notice that there is some interannual cohesivity, meaning that sometimes all abundances are high (mint green) or all low (red), though this breaks down in the later years. We also see that the lower biota abundances tend to be in the higher temperature years, though 2013 preceded the 2014 Marine Heat Wave. Data collection timing issues may confound, but this also could relate to the migration patterns of the species being tracked coinciding with the start of the Marine Heat Wave in offshore waters, which started prior to the warming that occurred in the Puget Sound.

We hope that these high-level patterns will inspire further research.

Authors: Jan Newton, Sabrina Sandberg, Hana Busse (UW); Reviewer: Kim Stark (King County)

CALLOUT 1 (cont.)

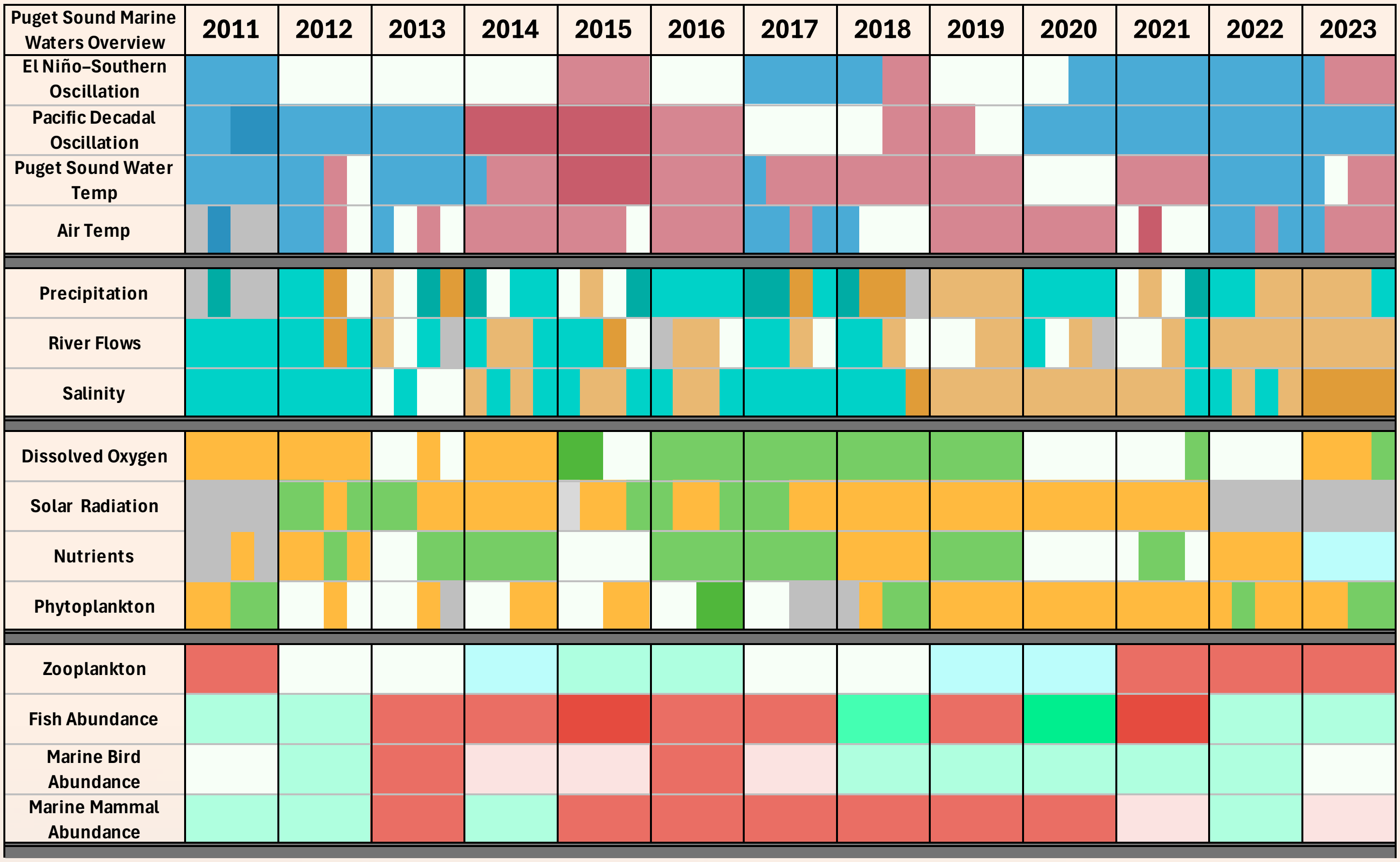


Figure 1. Ecosystem component anomalies from Marine Waters Overview data, color coded by their relative conditions over the years 2011-2023. Within year seasonal differences are indicated. Color intensity indicates strength of anomaly. Colors: top panel: blues = cooler, deep reds = warmer; second panel: turquoises = high precipitation/flow and lower salinity, tans = converse; third panel: orange = higher solar and phytoplankton with lower nutrient and deep oxygen, green = converse; bottom panel: mint greens = higher abundances, reds = lower abundances. Grey indicates data insufficient; white = no anomaly.

3

Coastal ocean and Puget Sound boundary conditions

C̓háʔba· in the water. Photo: John Mickett

NW Washington Coast water properties

Authors: John Mickett (Applied Physics Laboratory, University of Washington (UW-APL),mickett@uw.edu); Jan Newton (UW-APL and UW School of Oceanography), Seth Travis (UW-APL)
Edited by: Christopher Krembs
Website www.nanoos.org; **Data website**: www.nwem.apl.uw.edu/erddap

Highlights

- Like in 2024, over the upwelling season waters were generally cooler and fresher than climatology.
- The early onset of strong, sustained upwelling-favorable wind appears to have caused cool and salty anomalies.
- Like in 2024, deep DO was lower than normal with sustained hypoxic (<2 mg/L) events in late summer.

Overview

A large surface mooring, Čháʔba·, and an adjacent subsurface profiling mooring, NEMO-subsurface, maintained by the Northwest Association of Networked Ocean Observing Systems (NANOOS) and the University of Washington (UW), collect oceanographic and meteorological measurements on the Northwest Washington shelf since 2010. These observations give insight into boundary condition changes for Puget Sound.

Narrative

On the northwest Washington shelf, a general pattern of cooler (~0.5 °C) and saltier (~0.1-0.3 PSU) water properties from spring to fall that began in 2024 continued in 2025. The primary driver for these anomalous conditions appears to be wind, with upwelling-favorable winds starting about a month earlier than typical in 2025 (early April vs. early May) and remaining fairly strong and sustained through the end of September (Figure 1).

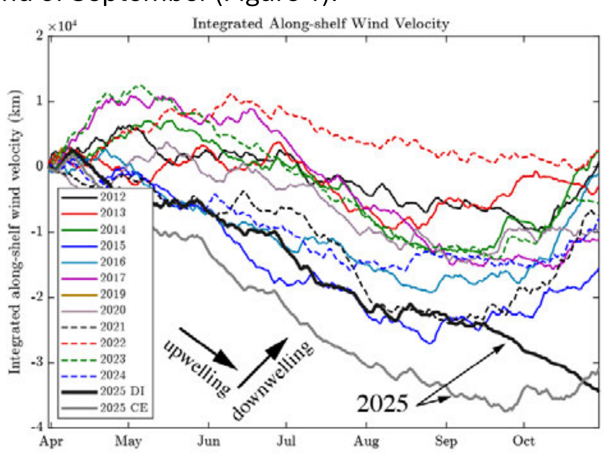


Figure 1. Cumulative upwelling winds from April to November at the Cape Elizabeth NDBC Buoy and Destruction Island.

In fact, 2025 had the most-sustained and strongest seasonally-averaged upwelling wind conditions on the northwest Washington shelf going back more than a decade. These upwelling-favorable, northerly winds drive southward, geostrophically-balanced flow that advects cooler water from the Canadian shelf and force a sustained Ekman-driven inshore flow of saltier, and cooler water at depth, which can be upwelled to shallower waters. Both effects likely combined in 2025 to cause the cool and salty anomalies at depth (Figure 2) and at the near surface (Figure3). It is worth noting that similar to other strong upwelling years (e.g., 2015), cooler conditions on the shelf tend to contrast with elevated SST in offshore waters during upwelling periods. With the transition to storms, south winds and downwelling conditions in late September, as is typically observed the water column rapidly warmed and freshened, with some of the warmest temperatures in the record for November (Figure 2).

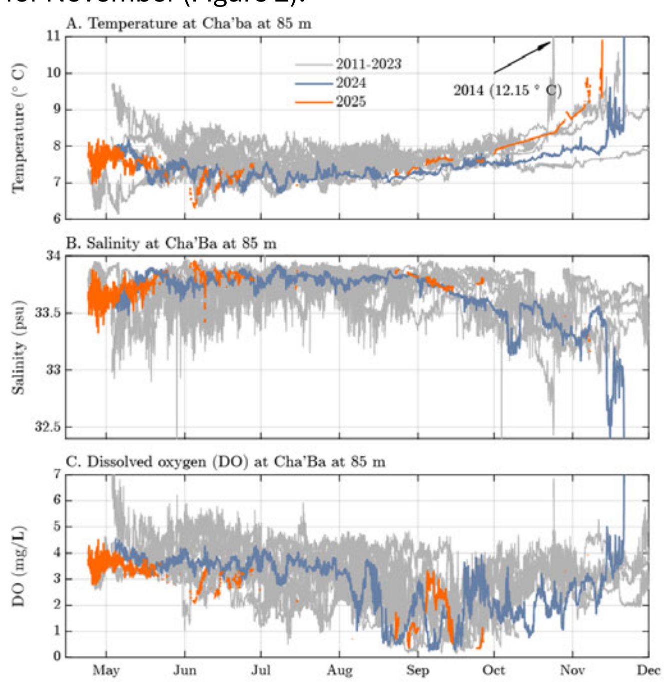


Figure 2. Interannual comparison of near-bottom properties (85 m). (A) temperature, (B) salinity, (C) dissolved oxygen.

Although observations are somewhat limited in 2025 due to instrumentation problems, as observed in 2024, dissolved oxygen levels at depth appear to be lower than average over the upwelling period in 2025

Title: NW Washington Coast water properties
Authors: Mickett, J., J. Newton and S. Travis

(Figure 2), which is consistent with the enhanced flow of colder, less oxygenated upwelled waters onto the shelf. Surface chlorophyll appeared to be largely higher than average, but maxima were consistent with those seen in other years (Figure 3).

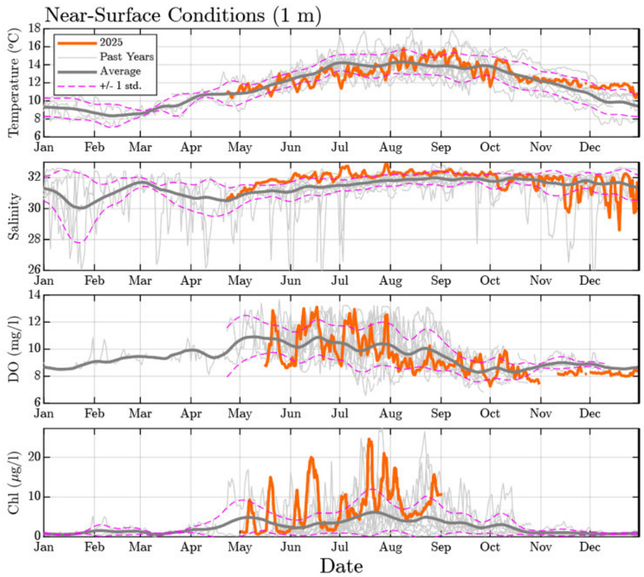


Figure 3. Interannual comparison of near-surface properties (1 m). (A) temperature, (B) salinity, (C) dissolved oxygen and (D) chlorophyll concentration.

Čháʔba· being prepared for deployment aboard the R/V Jack

Ocean and atmospheric CO_2 from Washington coastal moorings

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Edited by: Brendan Carter

Website: Cape Elizabeth Ćháʔba· **Additional website for data**: Cape Elizabeth Ćháʔba·

Highlights

- Monthly average 2025 atmospheric CO_2 levels on the coast were 2–8 ppm higher than globally averaged marine surface air during October–June; however, they were 0–4 ppm lower during the other months, likely reflecting regional forest production.
- Monthly coastal surface seawater xCO_2 averages were ~30–90 ppm higher than normal during January–April.

Overview

Carbon dioxide (CO_2) sensors have measured atmospheric and surface seawater mole fraction of CO_2 (xCO_2) on the Ćháʔba· mooring off La Push since 2010 and on the National Data Buoy Center mooring 46041 off Cape Elizabeth since 2006. These moored CO_2 time-series observations are part of a 40-site global network that measures CO_2 every three hours across seasons and provides estimates of surface ocean carbon cycle variability, ocean acidification rates, and air-sea flux. Upwelling, river inputs, and primary production drive strong surface CO_2 variability across seasons and years in the northern California Current System, resulting in long "times of emergence" for the anthropogenic acidification signal in Washington coastal surface waters (2029–2037; Sutton et al. 2019). Funding to support these observations and their analysis (2006–2026) has come from NOAA Global Carbon Cycle Program, Murdock Charitable Trust, NANOOS-IOOS, NOAA Ocean Acidification Program, NOAA/PMEL, and the Washington Ocean Acidification Center.

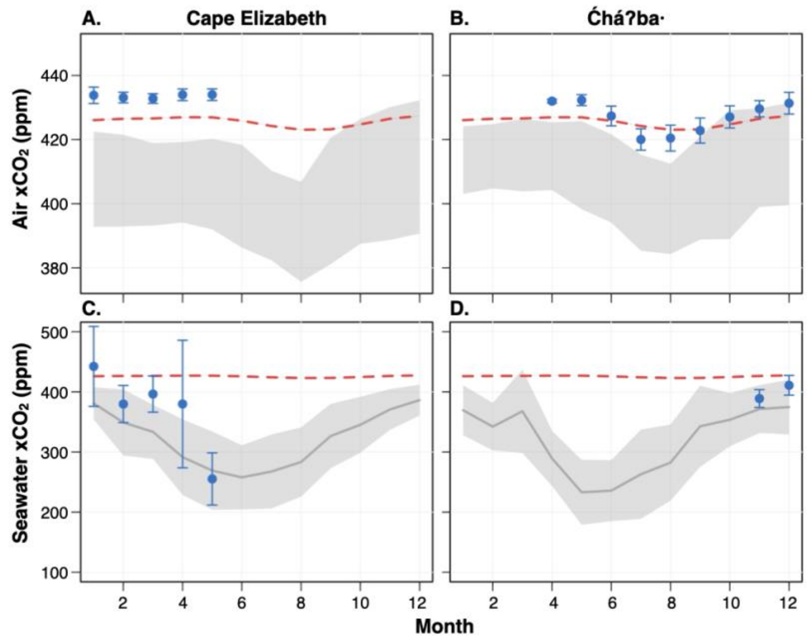

Figure 1. xCO_2 in air at 1.5 m above seawater (A, B) and in surface seawater at 0.5 m depth (C, D) on the Cape Elizabeth (A, C) and Ćháʔba· (B, D) moorings. Because atmospheric CO_2 increases year after year, comparisons provided for the current year (2025) are the minimum and maximum monthly means observed across 2006–2024 at Cape Elizabeth and 2010–2024 at Ćháʔba·; thus, the lower bound of the gray shading represents earlier years and the upper bound more recent years at each site. For seawater, the gray line reflects the monthly mean value for each month across all measurements through 2023, with the gray shading representing natural variability as one standard deviation (1SD) around the mean. Means ± 1SD for 2025 months with ≥50% data return are shown in blue. The dashed red line in each panel represents monthly mean atmospheric xCO_2 values for globally averaged marine surface air in 2025 (NOAA/GML 2026).

Narrative

In 2025 at Ćháʔba·, preliminary data returns for seawater and atmospheric xCO_2 spanned November 11–December 31 (13%) and April 23–December 31 (69%), respectively (Figure 1, Table 1). At Cape Elizabeth, both parameters had initial data return January–May and sporadically thereafter (44%). The atmospheric xCO_2 range was 412–465 parts per million (ppm) at Ćháʔba· and 414–457 ppm at Cape Elizabeth in 2025. Monthly average atmospheric xCO_2 values for months with ≥50% of data return across both sites were 0.4–4.2 ppm lower in July–September and 1.5–7.8 ppm higher during January–June and October–December than the monthly globally averaged marine surface air values (NOAA Global Monitoring Laboratory, NOAA/GML, 2026). The lowest annual values are observed during July–September each year and likely reflect summertime productivity of regional forests. Atmospheric xCO_2 variability within months, reflected in one standard deviation (1SD) bars, was ±0.6–4 ppm across 2025 months.

Surface seawater xCO_2 measurements spanned 334–457 ppm at Ćháʔba· and 113–649 ppm at Cape Elizabeth during 2025. Across both sites, all 2025 monthly means except May at Cape Elizabeth were above average, with January and April having significantly higher means and wider 1SD bars than normal, respectively, perhaps reflecting mixing (Figure 1).

	Ćháʔba·				Cape Elizabeth			
	Air		Seawater		Air		Seawater	
Month	2025	2010–2024	2025	2010–2024	2025	2006–2024	2025	2006–2024
Jan.	n.a.	403–424	n.a.	369 ± 41	434 ± 3	393–422	442 ± 66	381 ± 27
Feb.	n.a.	405–425	n.a.	342 ± 40	433 ± 2	393–421	380 ± 31	349 ± 55
Mar.	n.a.	404–426	n.a.	368 ± 69	433 ± 1	393–419	396 ± 30	333 ± 45
Apr.	432 ± 1	398–425	n.a.	289 ± 46	434 ± 2	394–419	380 ± 106	291 ± 63
May	432 ± 2	394–426	n.a.	233 ± 54	434 ± 2	392–420	255 ± 43	269 ± 65
Jun.	427 ± 3	385–422	n.a.	236 ± 51	n.a.	386–418	n.a.	258 ± 53
Jul.	420 ± 3	384–415	n.a.	263 ± 74	n.a.	382–410	n.a.	267 ± 61
Aug.	420 ± 4	389–412	n.a.	282 ± 63	n.a.	376–407	n.a.	283 ± 58
Sep.	423 ± 4	389–421	n.a.	343 ± 67	n.a.	381–421	n.a.	327 ± 54
Oct.	427 ± 3	389–429	n.a.	354 ± 44	n.a.	387–426	n.a.	345 ± 46
Nov.	430 ± 3	399–430	389 ± 15	371 ± 40	n.a.	389–430	n.a.	371 ± 34
Dec.	431 ± 3	400–431	411 ± 16	375 ± 45	n.a.	391–432	n.a.	386 ± 26

Table 1: Atmospheric and surface seawater xCO_2 at the coastal Ćháʔba· and Cape Elizabeth moorings (in ppm). Monthly means ± 1SD for 2025 are compared to monthly statistics for the historical time series at each location (noting that winter observations began in 2013 at Ćháʔba·). As in Figure 1, past air xCO_2 statistics used for comparison to the current year are the minimum and maximum monthly means observed across the time series through 2024. For seawater measurements, the historical range used for comparison is monthly means ± 1SD, because the variability at Washington mooring sites is sufficiently high as to obscure long-term trends at the present time (Sutton et al. 2019). Months lacking ≥50% 2025 data coverage show "n.a." (not available) in each cell.

Across the historical record, air xCO_2 monthly averages have typically been higher than seawater across seasons at both coastal sites, making these marine surface waters a sink for atmospheric CO_2. Depending on the season, seawater CO_2 levels below atmospheric values may reflect local marine primary production and/or seasonal cooling of regional surface waters. In past years, the monthly average air-seawater xCO_2 difference at these sites has been larger during April–August (106–185 ppm) than fall and winter months (20–71 ppm). Because most monthly seawater means were higher-than-normal, reducing the air-sea xCO_2 gradient, the strength of the surface water sink was weaker than normal during 2025. In fact, average seawater xCO_2 was high enough in January 2025 that surface seawater at Cape Elizabeth was a CO_2 source to the atmosphere (Figure 1C, Table 1).

References and contribution number

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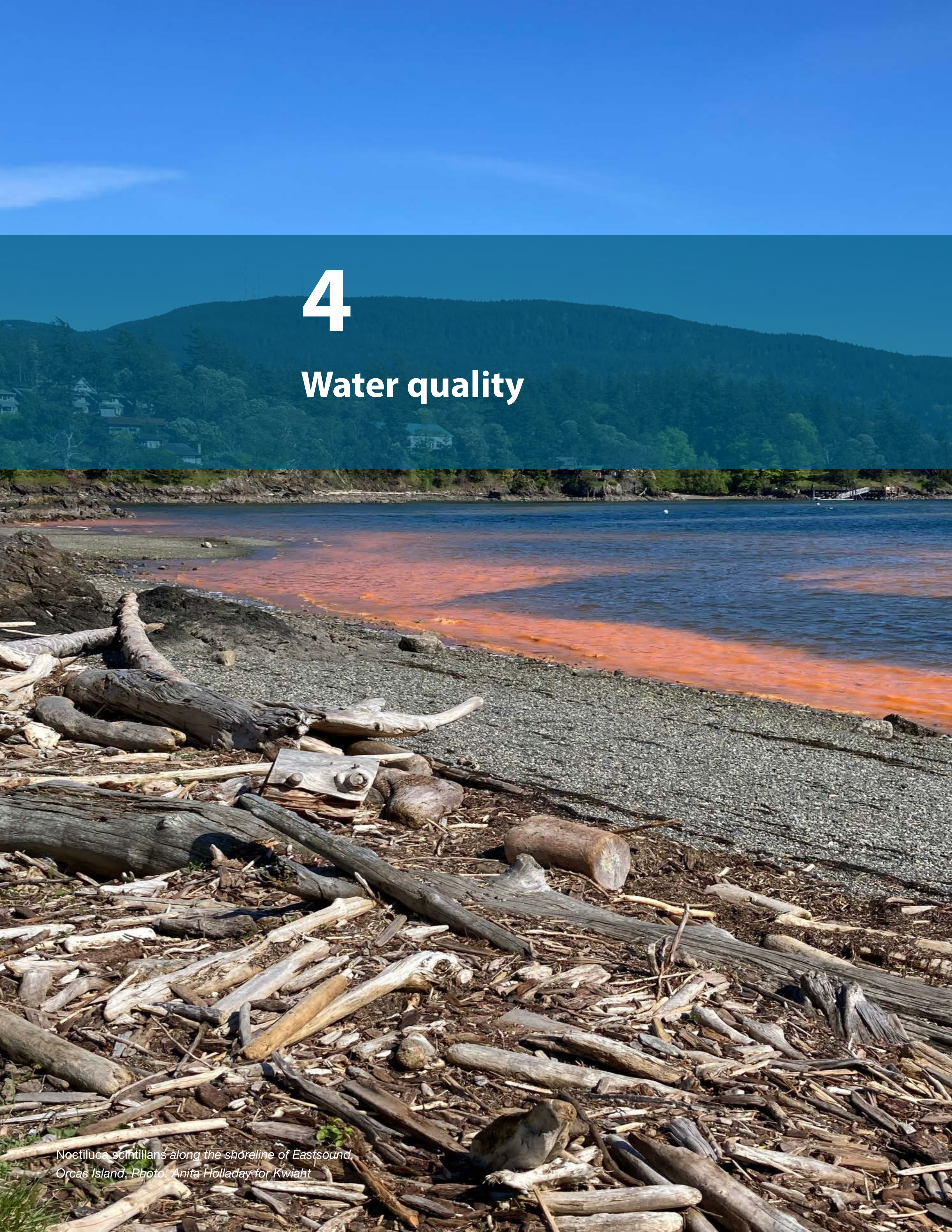

4

Water quality

Noctiluca scintillans along the shoreline of Eastsound, Orcas Island. Photo: Anita Holladay for Kwiaht

Temperature, Salinity, and Dissolved Oxygen Anomalies

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Edited by: Seth Travis (Applied Physics Laboratory, University of Washington)
Website: https://ecology.wa.gov/research-data/monitoring-assessment/puget-sound-and-marine-monitoring
Additional website for data: https://apps.ecology.wa.gov/eim/search/Default.aspx

Highlights

- In 2025, Puget Sound was warmer and saltier than usual with lower-than-normal DO conditions present throughout the year.
- Strongly negative DO anomalies were observed, which exceeded changes in solubility associated with temperature and salinity anomalies.
- Remarkably warm water temperatures were observed in December 2025, which rivaled anomalies recorded during "the Blob" years of 2014-2016.

Overview

The Marine Monitoring Unit at the Washington State Department of Ecology collects vertical water column profile data on a year-round, monthly basis at 31 stations within greater Puget Sound that includes measurements of temperature, salinity, and dissolved oxygen (DO). Here, we present a summary of 2025 temperature, salinity, and dissolved oxygen anomalies relative to a 1999-2023 baseline. Due to persistent vessel issues, sampling attainment across Ecology's station network was much lower than usual in 2025. Northern stations (Whidbey Basin, Strait of Juan de Fuca, San Juan Islands, and Admiralty Reach) were sampled consistently throughout the year, while sampling within Central Basin, South Sound, and Hood Canal was limited.

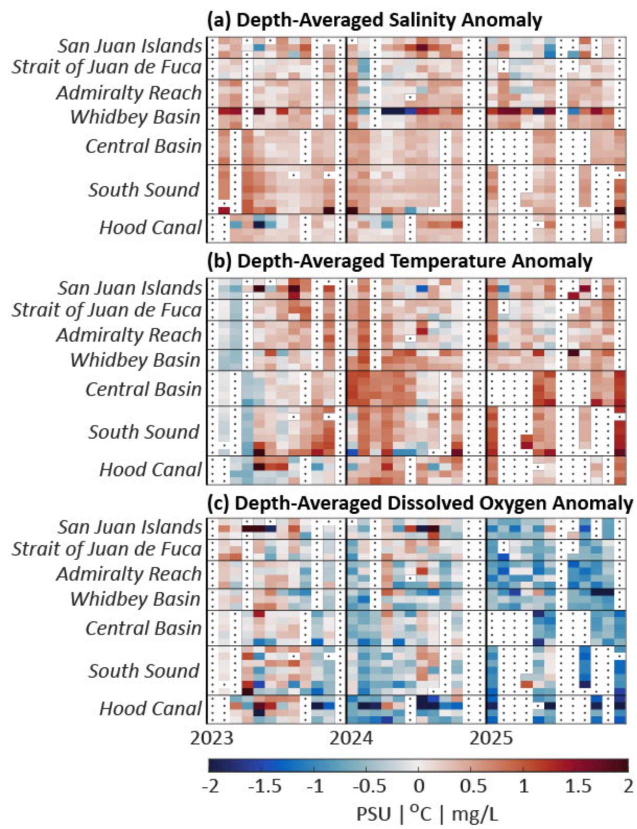

Figure 1: Depth-averaged anomalies of (a) salinity [PSU], (b) temperature [°C], and (c) dissolved oxygen mass concentration [mg/L] across WA Ecology's long-term sampling network. Anomalies are calculated relative to a 1999-2023 baseline.

Narrative

Salinity

Throughout 2025, available measurements indicate that Puget Sound waters were warmer and saltier than historical averages (Figure 1). Depth-averaged positive salinity anomalies ranged from near normal in early 2025 to >0.4 PSU in late summer at northern stations. Within Puget Sound, depth-averaged salinity anomalies were slightly higher on average and ranged between 0.4 and 0.5 PSU above normal throughout much of the year. From January to June, isolated negative anomalies were briefly observed at northern stations following discharge events in the Fraser, Skagit, and Nooksack watersheds. These observations mark the continuation of high salinities that began in late 2022, which have persisted over the last 3 years driven primarily by extended periods of low river flows in the region. (Figure 1).

Temperature

Water temperatures within greater Puget Sound were above normal throughout 2025 with depth-averaged anomalies ranging from 0.2 to >1°C above normal. Surface waters (<20m deep) exhibited a more pronounced warming signal, particularly during periods of high summer insolation, with depth-averaged temperature anomalies in the upper water column being 0.2-0.3°C warmer than deep waters. Measured temperatures throughout the water column in December 2025 were among the warmest recorded since 1999 and exceeded >1°C at many stations within Puget Sound. When taken in aggregate, these measurements exceed the 95th percentile of estuary-

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wide temperature anomalies for the month of December and were comparable to anomalies observed during "the Blob" years of 2014-2016. Anomalous surface heat fluxes likely played a key role in driving the evolution of the remarkably warm water temperatures observed within the Salish Sea and along the Washington coast in late 2025.

Dissolved Oxygen

Widespread negative dissolved oxygen (DO) anomalies, which in some locations were less than -2 mg/L in a depth-averaged sense, were observed throughout greater Puget Sound in 2025. Much larger deficits were observed at individual station-depths, including <-4 mg/L anomalies in the upper 10m in Hood Canal in June and October. Concentrations which comprised new monthly minima within Ecology's historical record were observed every month and ranged from 15% to 70% of total observations. Hypoxia (< 2mg/L) was observed in Hood Canal in January, May, June, October, and December. Anoxic conditions (< 0.2 mg/L) were observed in Lynch Cove in October.

Increased water temperatures and salinity likely contributed to low DO levels by decreasing the solubility of oxygen in seawater. However, when expressed as saturation state rather than mass concentration, these observations indicate that observed oxygen deficit(s) greatly exceeded changes in solubility alone (Figure 2). Furthermore, these results suggest that DO concentrations within greater Puget Sound have been decreasing since 2023 and that the median DO saturation state of the estuary was among the lowest measured since 1999 (~10% below normal).

In addition to changes in solubility, other physical controls may have played a role in shaping the observed DO trend. Persistent drought conditions within Washington and British Columbia resulted in low freshwater discharge that may have impacted the physical functioning of the estuary by reducing the estuarine exchange flow; thereby increasing the exposure of Puget Sound waters to local atmospheric warming trends and biological respiration processes via changes in residence time and stratification. Additionally, higher cumulative upwelling off the Washington coast in 2025 may have played a role in reducing oxygen availability near the mouth of the Strait of Juan de Fuca thereby influencing observed DO anomalies through a change in the oceanic boundary condition.

Methods

Using a fixed 25-year baseline period spanning 1999-2023, anomalies were calculated relative to bootstrapped monthly median profiles of temperature, salinity, and dissolved oxygen for each station using 1000 bootstrapped samples with replacement. To quantify the uncertainty associated with baseline median profiles, the spread in bootstrapped estimates was quantified via standard deviation. Depth-averaging was performed over the full extent of the water column.

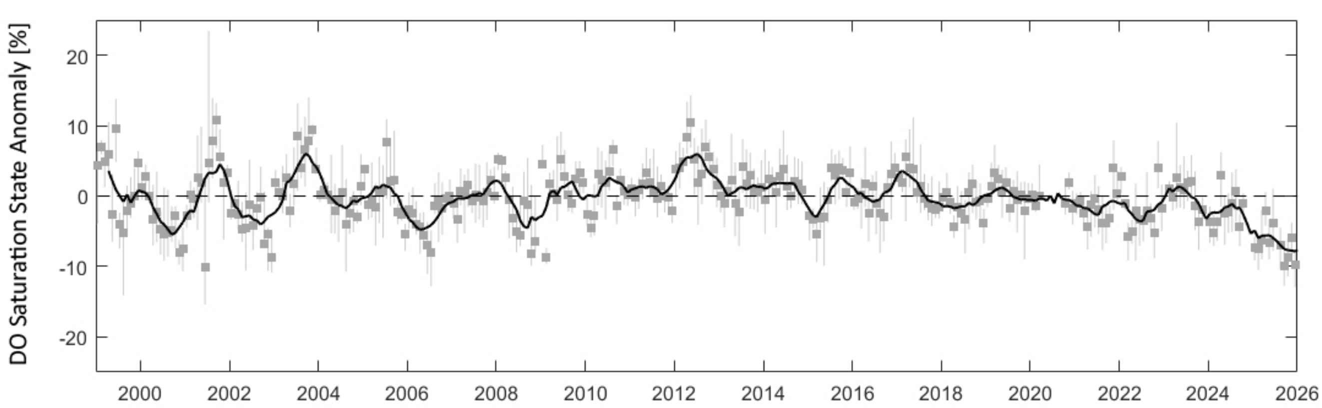

Figure 2 Time series of DO saturation state anomalies measured across WA Ecology's long-term station network from 1999 to 2025. Grey markers indicate monthly median values and are shown with error bars that indicate the interquartile range. A smoothed time series calculated using a 6-month moving average is shown as a solid black line.

Nutrients and chlorophyll

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Website: https://ecology.wa.gov/research-data/monitoring-assessment/puget-sound-and-marine-monitoring

Highlights

- Several nutrient concentrations and ratios in Puget Sound (including nitrate, phosphate, DIN:P, and SiOH:DIN) exhibit predictable interdecadal variability.
- Chlorophyll-a concentrations during the fall bloom (September) show a decline until 2013 and since then remained lower.
- Many of the interdecadal patterns appear to be predictable, although future observations will be needed to substantiate this current conclusion.

Overview

Understanding, quantifying, and accounting for natural variability is critical for assessing the status and trends of water quality in Puget Sound. Ecology's marine water monitoring program spans a large geographic area (Pool et al., 2025), enabling the detection of long-term, large-scale patterns across the southern Salish Sea.

A key step is removing variability associated with depth, region, and season using site-specific monthly baselines and anomalies. The data are processed as follows:

1. Monthly samples (at target depths of 0 m, 10 m, and 30 m) are reduced to medians to eliminate vertical variability.
2. Regional and seasonal variability is removed by subtracting site-specific monthly baselines (1999–2024), (Krembs, 2012).
3. Annual medians of all anomalies (with 25th and 75th percentiles) across the station network are generated and shown in Figure 1.

Chlorophyll-a naturally exhibits high variability. Therefore, we implemented an additional non-parametric method using a Quantile Regression Forest (QRF) approach following Meinshausen (2006).

To quantify natural cycles, we applied a weighted harmonic regression, using sample counts as weights. The model estimates harmonic coefficients via weighted least squares. Model performance metrics, including R^2, period, residuals, and best fit.

Narrative

We examined whether macronutrient species and their ratios exhibit quantifiable interdecadal variability in Puget Sound and identified interdecadal cycles for nitrate (15 years), phosphate (18 years), the (Dissolved Inorganic Nitrogen, DIN) to Phosphate ratio (12 years). In contrast, chlorophyll-a showed little evidence of predictable long-term patterns, except for September (Fig. 1, E) where concentrations decreased until 2013 suggesting physical processes preventing the formation of fall blooms.

While most variables follow the long-term patterns observed across the station network (N = 27) in 2025, it is notable that NO_3 (Fig. 1 A) was unusually high and chlorophyll-a was lower (data not shown), although station attainment in 2025 was very low in some regions. The long-term decline in the SiOH:DIN ratio observed from 1999 to 2023 appears to be recovering in the past two years.

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Title: Nutrients and chlorophyll

Authors: Christopher Krembs (Ecology, christopher.krembs@ecy.wa.gov); Alex Fisher; Holly Young; Natalie Coleman; Suzan Pool, Christopher Jendrey

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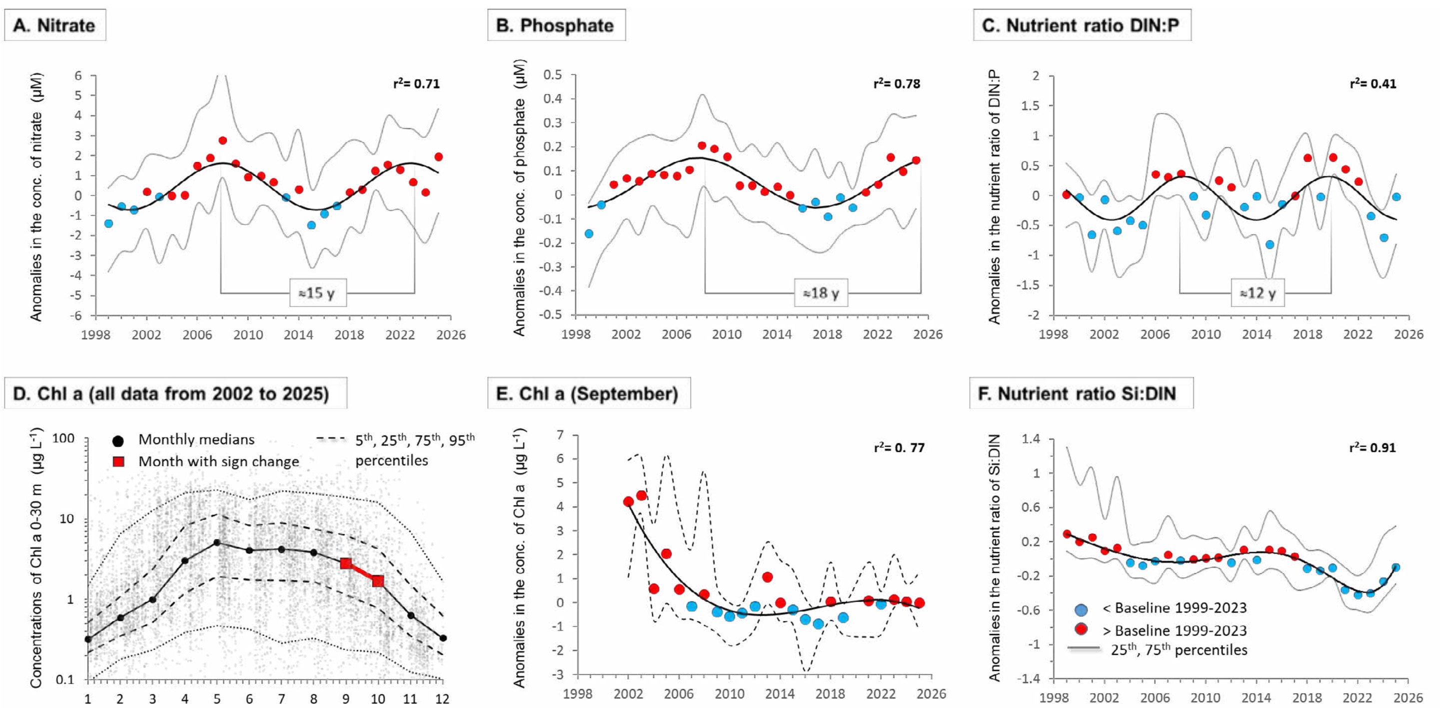

Figure 1. Interdecadal variability and trends in nutrient concentrations and ratios in surface waters of Puget Sound. Anomalies of, (A) Nitrate, (B) Phosphate, (C) DIN:P ratio, (D) Seasonal discrete Chlorophyll a values (2002 to 2025), and (E) Anomalies of discrete Chlorophyll a values (September), (F) Silicate to dissolved inorganic nitrogen ratio (SiOH:DIN). Harmonic fit applied to A-C, and third order polynomial applied to D and E.

Puget Sound profiling buoys and environmental metrics

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Website: https://www.nanoos.org **Additional website for data**: https://nwem.apl.washington.edu

Highlights

- Warm temperature anomalies were observed in all basins for most of the year, likely driven by surface heat fluxes.
- Salinity remained higher than normal across all basins, likely due to reduced river and rainfall input, continuing a multi-year trend.
- Modest dissolved oxygen anomalies were observed in most basins, alternating between positive and negative periods.
- Hypoxia was observed at Twanoh in summer-fall, before modulating, but staying low to end the year.

Overview

University of Washington profiling buoys collect full water column data 1–4 times daily, enabling analysis of both short- and long-term processes such as deep-water renewal, river runoff influence, and water mass tracking. There are currently six ORCA (Oceanic Remote Chemical Analyzer) moorings in Puget Sound supported primarily by NANOOS and the Washington Ocean Acidification Center: South Hood Canal (Twanoh), central Hood Canal (Hoodsport), Dabob Bay, Admiralty Inlet (Hansville), Main Basin (Point Wells), and Southern Puget Sound (Carr Inlet). Data for Hansville were not available for 2025, and is not discussed. Climatologies are based upon the data record available at all buoy sites, with 16 years of data available, being the years of 2010-2025.

Narrative

i) Temperature

ORCA mooring observations indicate warmer-than-normal temperatures across all basins in 2025, with ~1°C warm anomalies observed at most sites for much of the year, despite some site-specific variability (Figure 1).

In Hood Canal, the upper 15 m showed strong, rapid variability in the summer, suggesting a shallow mixed layer and surface-confined forcing on short time scales. At Hoodsport, the annual late-summer/fall deep-water intrusion appeared as a warm anomaly that intensified in mid-to-late September.

The warmer waters shoaled through the fall and remained warmer than average throughout the rest of the year (Figure 1B). The timing of this event was roughly typical with previous observations and indicates that the intrusion was warmer than normal.

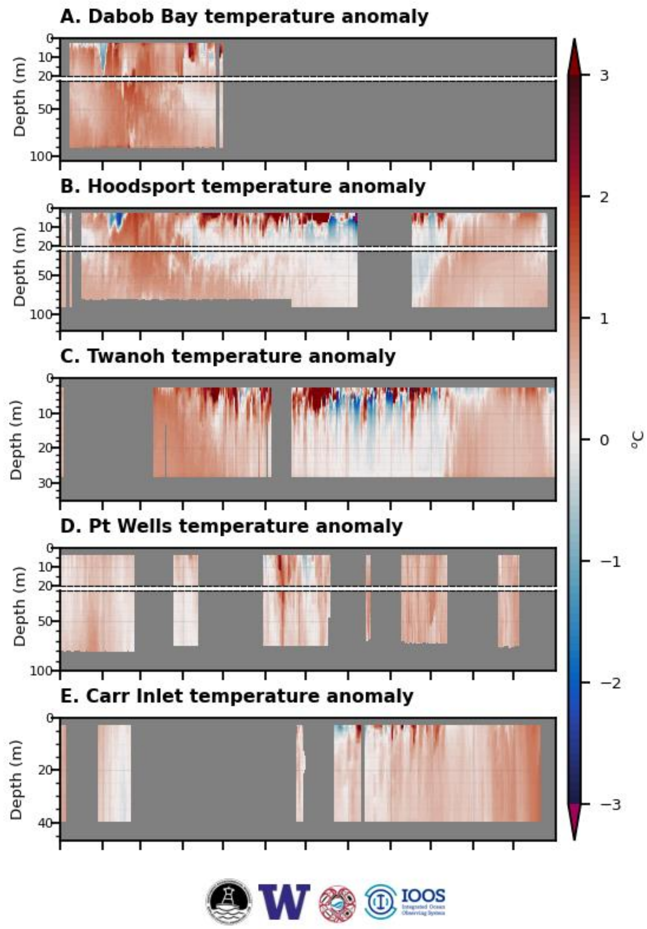

Figure 1. Depth-time color maps of water temperature anomalies in 2025 relative to the climatological averages (years included in the climatologies: 2010–2025) at six ORCA mooring sites: Dabob Bay in north Hood Canal (A), Hoodsport in mid–Hood Canal (B) and Twanoh in South Hood Canal (C), Point Wells in Main Basin (D), Carr Inlet in South Sound (E). No data is available for Hansville.

Title: Puget Sound profiling buoys and environmental metrics
Authors: Seth Travis, John Mickett, Jan Newton, Anna Boyar

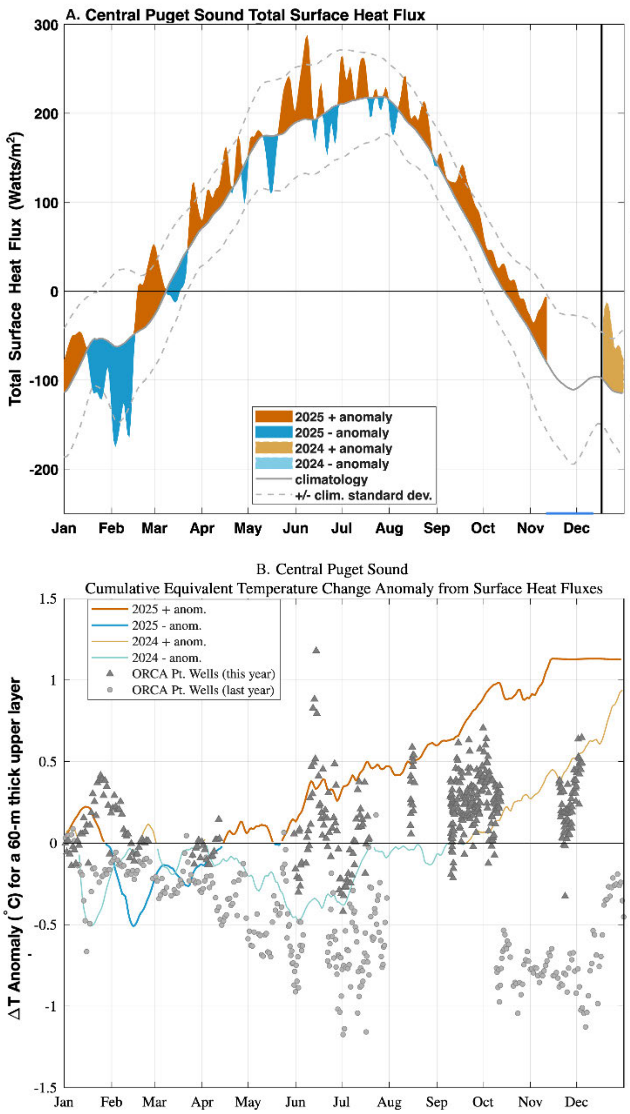

Figure 2. Impact of surface heat flux on temperature anomalies. (A) Total heat fluxes in 2025 relative to climatological averages with positive anomalies shown in orange and negative anomalies in blue. (B) Central Sound equivalent change in temperature from accumulated heat gain or loss over a fixed 60 m water depth since the start of the year. The line shows the heat-flux derived anomaly while the asterisks show the observed anomaly at Point Wells.

In the Main Basin (Figure 1E-F), waters were modestly warmer than average early in the year, cooled to near-normal (~0°C anomalies) from March through June, and then gradually strengthened the warm anomalies toward year's end (~1°C anomalies). Surface heat flux forcing had an extended period of cooling during late January to March, corresponding to ~0.5°C cooling in the upper 60 m and consistent with Point Wells observations (Figure 2B). Through the spring and early summer, heat flux forcing was alternately stronger and weaker than normal, consistent with weak-to-neutral temperature anomalies observed at Pt Wells. In contrast, elevated surface heat fluxes in the second half of the year suggest ~1°C net warming compared to the start of the year. However, observations show only depth-averaged temperature anomalies of ~0.5°C warmer than normal (Figure 2B). One possible cause for the discrepancy could be weaker vertical stratification allowing any anomalous heat to mix deeper, effectively heating a larger pool of water. An additional possibility is the effect of the advection of cooler-than-normal coastal waters into Puget Sound. For more information, refer to the section on Northwest Washington shelf water properties.

ii) Salinity

Mooring observations showed consistently saltier than average conditions across all sites in 2025 (Figure 3), except for brief periods of fresher surface waters (<10 m) in Hood Canal. Salinity anomalies were weakly positive (<+0.5 psu), then intensified at all observed sites. In the Main Basin and South Sound (Figures 3 E-F), anomalies reached ~0.5-1.0 psu, while in Hood Canal (Figures 3 A-C), the anomalies exceeded 1.0 psu. There was a brief weakening of these salty anomalies in Hood Canal in April and May, when anomalies at mid-depths (15-50 m) returned to near normal (i.e., <± 0.5 psu). This weakening was short-lived, and salinity anomalies returned to +0.5-1.0 psu at all observed sites for most of the rest of the year. In the second half of December, there is a rapid freshening of Puget Sound waters, as seen in the observations at Twanoh and Carr Inlet. Surface salinity anomalies were generally more intense, particularly in Hood Canal, where anomalies regularly exceeded +1.0 psu, with some extreme events recorded at Hoodsport and Twanoh where salinity anomalies exceeded +2 psu.

A freshwater-conserving box-model, used as a metric to understand drivers of salinity changes in different regions of Puget Sound, attributed the 2025 positive salinity anomalies primarily to reduced freshwater input

(Figure 4), and is a continuation of the signal observed in 2022-2024. River flow remained below average throughout 2025, except for a few large events in the spring and an extreme event in late December (Figure 4A). The model closely mirrored depth-averaged ORCA buoy observations, particularly at Carr Inlet, with both showing elevated salinities for the whole year, as well as the rapid freshening associated with the late-December event (Figure 4B). The changes in salinity are a dominant driver of changes in water density, and can reduce stratification, promote mixing, and may impact bloom timing and basin residence times.

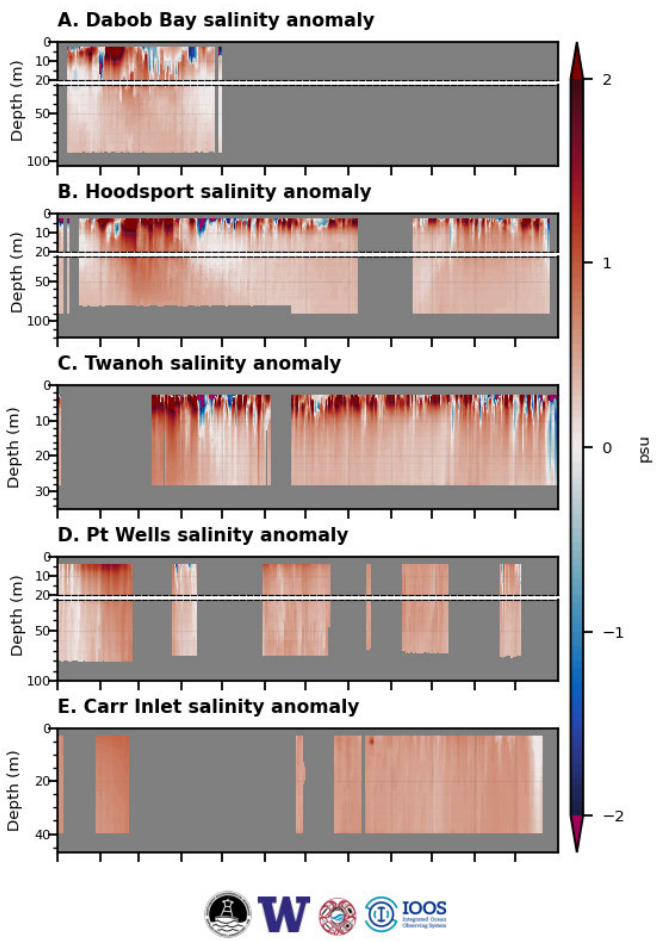

Figure 3. Depth-time color maps of salinity anomalies in 2025 relative to the climatological averages (years included in the climatologies: 2010–2025) at six ORCA mooring sites: Dabob Bay in north Hood Canal (A), Hoodsport in mid–Hood Canal (B) and Twanoh in South Hood Canal (C), Point Wells in Main Basin (D), Carr Inlet in South Sound (E). No data is available for Hansville.

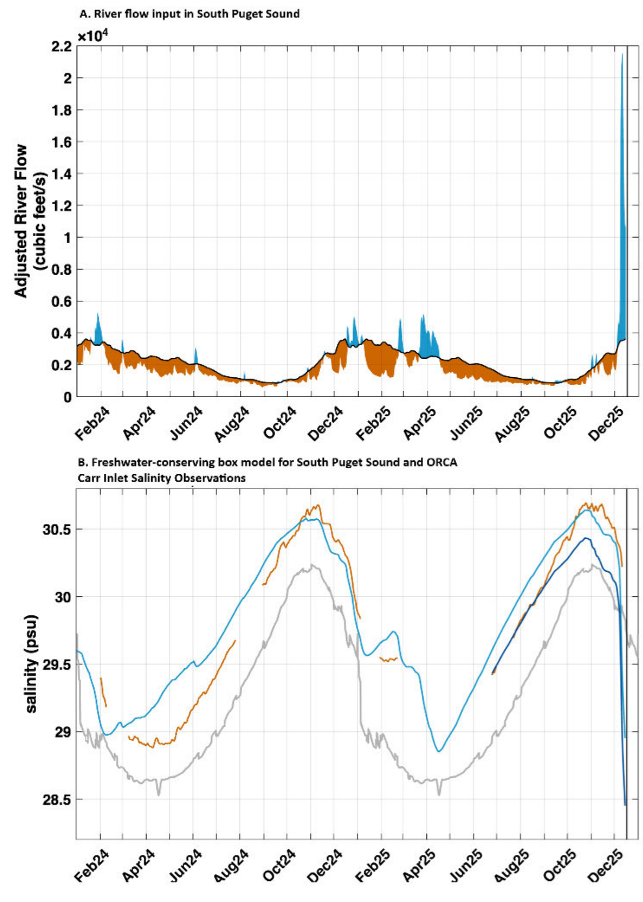

Figure 4. Top panel: Adjusted river flow anomalies for the Main Basin for the two-year period from January 2024 through December 2025. Bottom panel: depth-averaged salinity climatology (gray), ORCA Carr Inlet measurements (orange) and freshwater box-model estimates (blue). Near-surface values are excluded to reduce transient, short-timescale variability in the observations. Correlation between the model and ORCA observations (blue and orange) indicates salinity changes are mostly due to changes in freshwater input to Puget Sound.

iii) Dissolved Oxygen

Dissolved oxygen (DO) had significant regional and temporal variability during 2025, with relatively modest anomalies of less than ±1 mg/L for most of the year in the Main Basin, and generally stronger anomalies (>±1 mg/L) in Hood Canal. Intermittent, localized events exceeded these thresholds in both regions (Figure 5). The Main Basin and South Sound (Figures 5 E-F) began the year with neutral anomalies before transitioning to modestly-positive anomalies through the spring and summer. Brief events occurred during this time where

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DO levels exceeded 2 mg/L above normal concentrations. From late summer to the end of the year, the region alternated between periods of weakly-positive and weakly-negative anomalies.

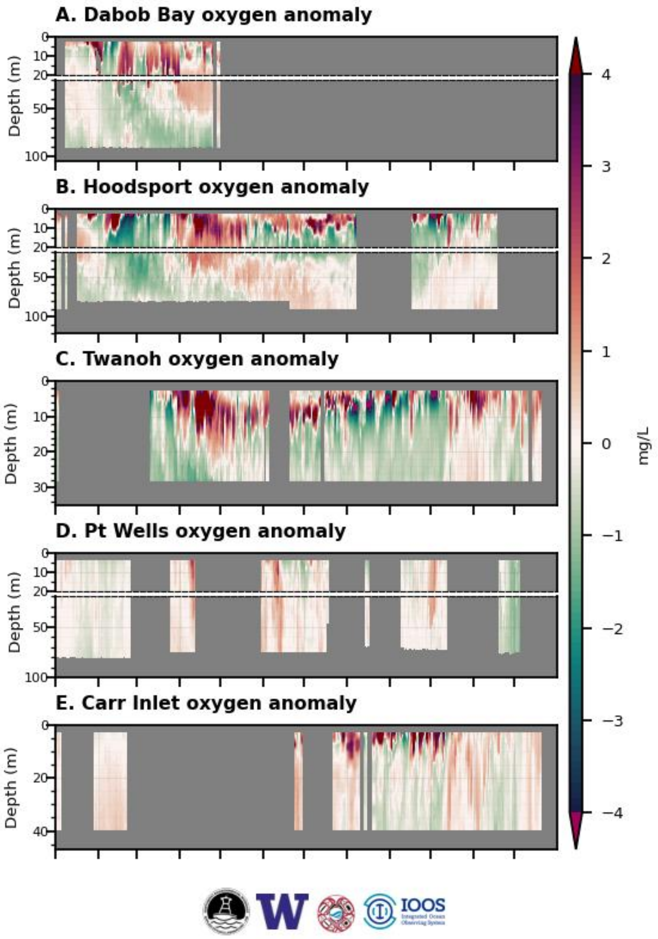

Figure 5. Depth-time color maps of dissolved oxygen anomalies in 2025 relative to the climatological averages (years included in the climatologies: 2010–2025) at six ORCA mooring sites: Dabob Bay in north Hood Canal (A), Hoodsport in mid–Hood Canal (B) and Twanoh in South Hood Canal (C), Point Wells in Main Basin (D), Carr Inlet in South Sound (E). No data is available for Hansville.

In Hood Canal (Figures 5 A-C), stronger variability was observed. Strong positive anomalies (>2 mg/L) were regularly seen in the upper 10-15 m. Negative oxygen anomalies (1-2 mg/L below normal) developed below the surface layer in late spring. A strong positive anomaly developed in surface waters in April and can be seen at depth in the summer months. As seen at Hoodsport and Twanoh, this resulted in a period with negative anomalies at mid-depths (15-50 m), but positive anomalies in the deep waters. This persisted until the annual deep-water intrusion event, when low DO waters were displaced, and led to weakly-positive anomalies which persisted through the rest of the year.

At Twanoh, hypoxic waters during 2025, indicated in purple in Figure 6, were observed beginning in late June. DO concentrations were between 1-2 mg/L and dropped below 1 mg/L for August and September. Hypoxic waters may have outcropped to the surface in early October, although there were no reports of fish kills during this time. Following this, DO concentrations modulated to ~2 mg/L, and remained near this level for the remainder of the year. Relative to other years in our observational record at Twanoh, 2025 had a stronger and more prolonged period of hypoxia.

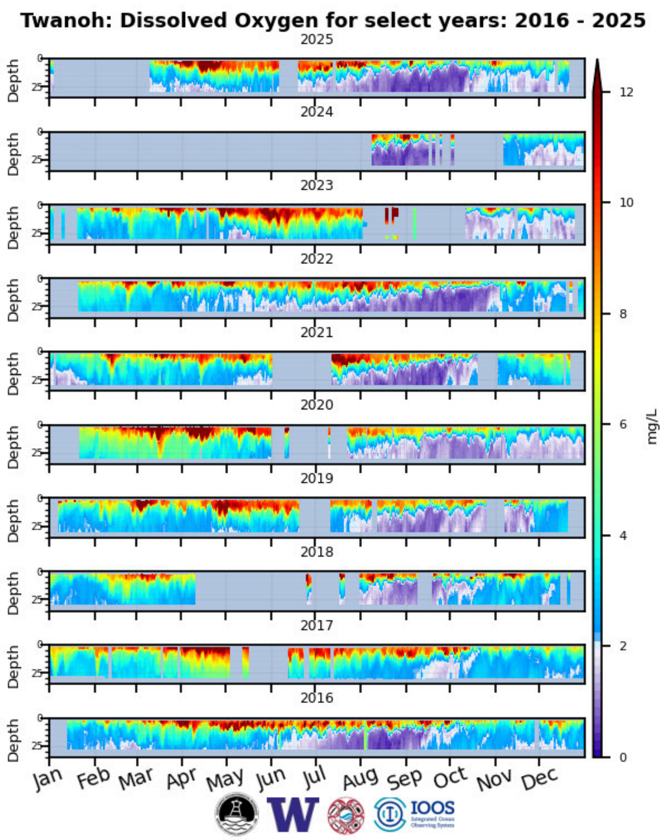

Figure 6. Time series of water column dissolved oxygen concentrations at the Twanoh mooring between 2016 and 2025 (not the full record, selected years to fit). Pressure (or depth) is shown on the y-axis and time in monthly increments on the x-axis between January and December.

Central basin temperature, salinity, and dissolved oxygen

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Highlights

- Warm water temperature anomalies present since mid-2023 continued in Central Basin, with record highs in fall and winter 2025.
- Salinity was high throughout the year leading to relatively weak stratification. Low freshwater inputs persisted through most of 2025 until heavy rainfall in December.
- Dissolved oxygen was anomalously low for most of the year, especially during the growing season, likely due to lower productivity.

Overview

King County conducts routine full water column sampling at 14 sites in Puget Sound's Central Basin. CTD casts and bottle data are collected monthly in December and January, and twice a month for the rest of the year. Additionally, four moorings collect real-time data at 15-minute intervals.

Anomalies presented here are calculated using a static baseline from 1997 to 2013.

Narrative

Conditions in Central Basin continued the warm, salty, and low dissolved oxygen (DO) conditions observed in 2024. Warmer waters that began in mid-2023 were sustained throughout the water column, and 2025 marked the third year in a row of consistently high salinity anomalies. Furthermore, DO was below baseline throughout most of the year, with few positive anomalies during the growing season.

Water Temperature: Following consistently warm conditions that have persisted since mid-2023, subsurface temperature in Central Basin dropped to near baseline in spring and early summer in 2025, though surface temperature stayed warm of baseline (Figure 1A). However, column-wide temperature increased in fall and winter, leading to anomalies among the highest observed, with the average temperature anomaly in December over 1.5 °C above baseline. The Seattle Aquarium mooring in Elliott Bay recorded water temperature near the maximum of the data record that culminated in record high temperatures in November and December at both the surface and at 10 meters (Figure1D).

Salinity and density: Most of the year was saltier than baseline conditions, with a short period of lower than typical salinity in spring (Figure 1B). Reduced freshwater inputs from rivers and rainfall throughout the year resulted in high surface salinity anomalies throughout late spring and summer, until high rainfall in December ended the year with a significant decrease in surface salinity.

We observed stratified waters April–May, though the strength of stratification was weaker than typical conditions. Stratification was strongest in Elliott Bay and northern Central Basin, as is typical.

Dissolved Oxygen: DO was below baseline for most of the year throughout the water column (Figure 1C). Increases in surface DO during spring and early summer were shorter than prior years, likely due to the compressed and lower productivity growing season.

CTD profiler and Niskin bottles.

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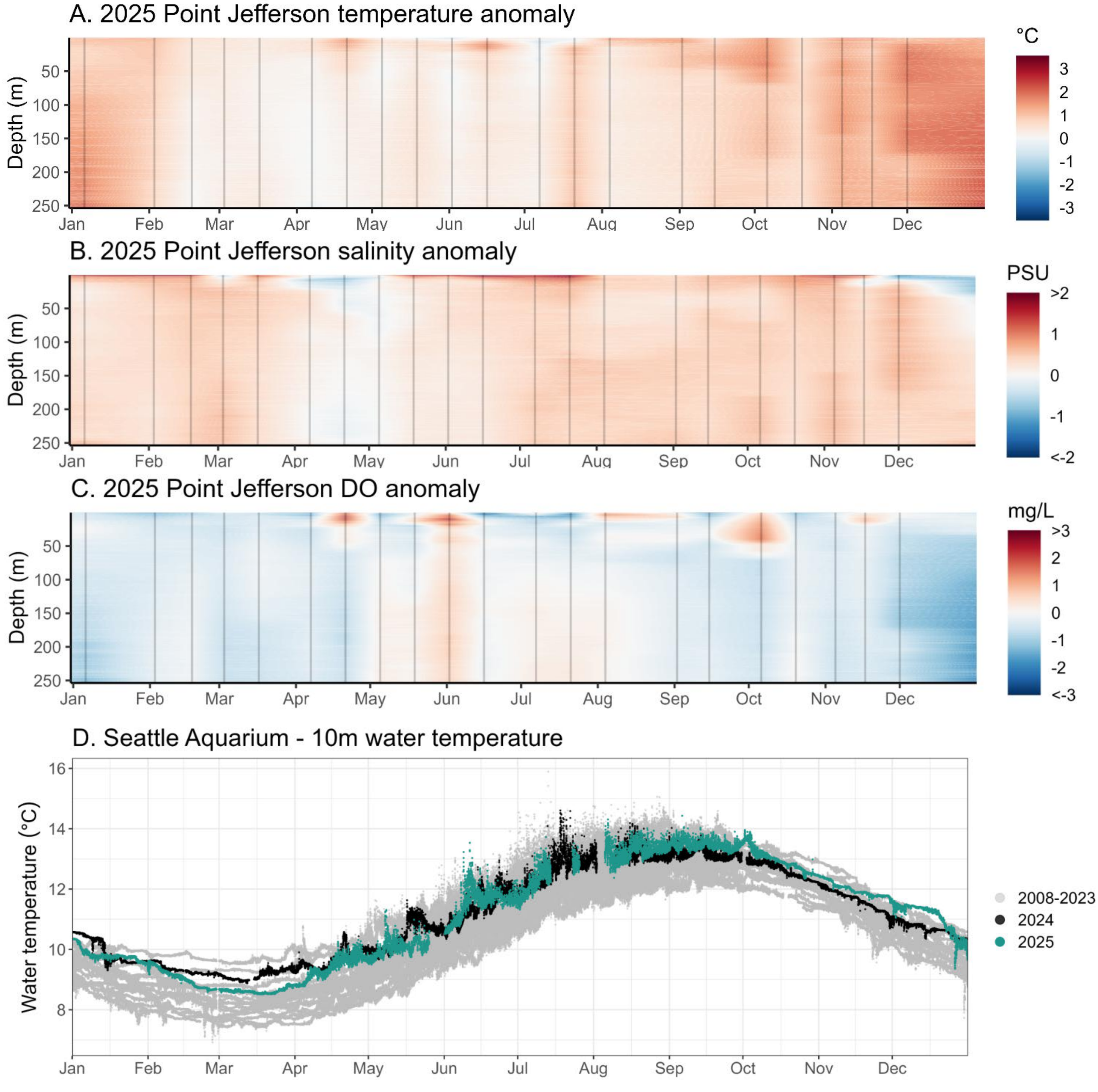

Figure 1 – Anomaly contour plots of (A) temperature, (B) salinity, and (C) dissolved oxygen at Point Jefferson. The black vertical lines indicate sampling casts. (D) A time series of water temperature at the Seattle Aquarium 10 meter mooring in Elliott Bay showing 2025 compared to data going back to 2008.

Central Basin chlorophyll and nutrients

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Highlights

- Chlorophyll (productivity proxy) was low in 2025 and was lowest at many sites since 2008
- Elliott Bay had atypically high chlorophyll for most of the growing season, including highest summer value on record
- August and September silica values were atypically high throughout the water column

Overview

King County collects water data twice monthly at 12 mainstem sites in the Central Basin and 2 in Quartermaster Harbor. Dissolved nutrients (nitrate+nitrite-N, ammonia-N, silica, and orthophosphate-P) are analyzed from up to seven discrete depths and chlorophyll *a* is analyzed at five depths (two depths in Quartermaster Harbor). Full water column profiles for chlorophyll fluorescence and nitrate are also collected at the 12 mainstem sites. Moorings at four locations collect surface chlorophyll fluorescence data at 15-minute intervals.

Narrative

Central Basin chlorophyll *a* data indicated the 2025 spring phytoplankton bloom began in early April (evident on April 7th), similar to 2024. The spring bloom was atypically low in the northern basin but higher than prior years in the mid-basin. Overall in 2025, chlorophyll *a* was lower at all sites (except in Elliott Bay) than prior years. Some of the lowest annual averages since 2008 were noted at many sites. Sustained blooms were not seen during the growing season and chlorophyll *a* was low by mid-August at most sites, by mid-September at southern sites (Figure 1). Chlorophyll *a* surface anomalies (2003-2025 baseline) at East Passage were negative for all of 2025 and were strongly negative in the fall (Figure 2A). This was a substantial difference from the three preceding years.

The Elliott Bay site typically has lower chlorophyll than other sites due to proximity and turbidity from the outflow of the Duwamish River. However, in 2025 all growing season months except June had the highest monthly averages for the period of record (1997-2025) and the early July value (37 µg/L) was the highest summer value on record.

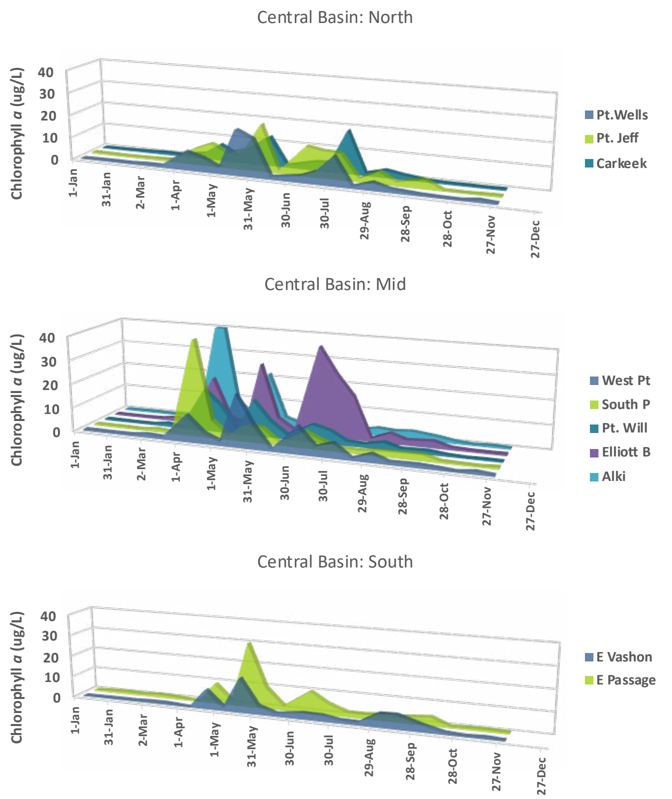

Figure 1. Surface (< 2m) chlorophyll a at 10 Central Basin sites in 2025. Note: early April sampling was missed for the two southern sites. Phytoplankton data indicate large bloom at these sites (see Lyndsey Swanson phytoplankton submission).

Dissolved nutrients in surface waters (<2 meters) corresponded with chlorophyll levels and phytoplankton uptake. For the second year in a row, nitrate+nitrite-N was never drawn down below detectable levels at any mainstem site. Average monthly nitrate+nitrite-N and silica in deep waters (>150 meters) shifted from mainly lower than the baseline (1997-2025 or 2003-2025) in 2024 to higher for most of 2025 (Figure 2B). Silica was higher than normal throughout the water column at all sites in August and September, but did not correspond with river flows.

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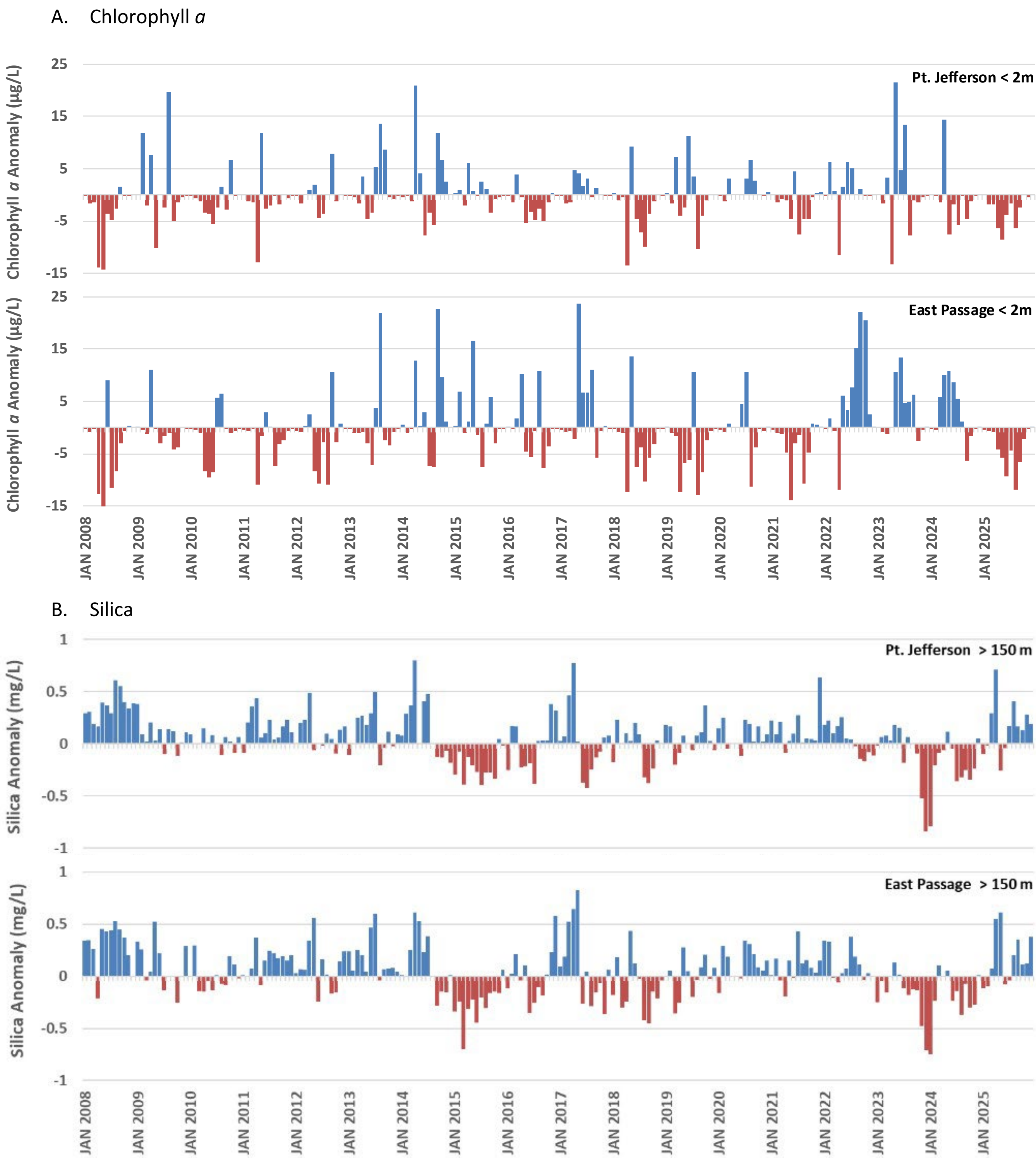

Figure 2. Pt. Jefferson and East Passage surface chlorophyll a monthly anomalies (A: top 2 panels) and deep water silica monthly anomalies (B: bottom 2 panels). Baseline is 1997-2025 for Pt. Jefferson and 2003-2025 for East Passage.

Whidbey Basin water quality

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Highlights

- Water temperatures were warm and similar to 2022–2024.
- All stations were stratified throughout the year, but surface waters were saltier in the summer and fall.
- Chlorophyll was low, and dissolved inorganic nitrogen was rarely depleted.

Overview

King County began water quality sampling in Whidbey Basin in February 2022. Water column CTD profiles were collected at 10 sites monthly (see website for map), and bottle samples at specific depths were collected at five of those sites. Autonomous moorings are deployed at three sites.

Narrative

Temperature (Figure 1A) and salinity were largely similar to 2022–2024 at all sites, with temperature inversions (colder at the surface than deep) at the beginning and end of the year; warm temperatures during the summer and fall (particularly in deep water); and relatively fresh water at the surface (though saltier than previous years in the summer and fall). All stations were consistently stratified, like in previous years. No big mixing events were observed that mixed the water column, unlike previous years. Deep water density was most like 2023: high to start the year, followed by a decrease in spring and a steady movement of equal density layers toward the surface into the fall, signaling ocean input.

Surface (<2 m) dissolved nitrate+nitrite concentrations remained higher than previous years during the growing season, with only one measurement below the detection limit (Figure 1B). Lack of nitrate drawdown is consistent with lower productivity compared to previous years, as estimated by chlorophyll *a* fluorescence (Figure 1D). Nitrate concentrations at all depths resembled previous years, except at the Port Susan buoy (PSUSANBUOY) where concentrations were high in October and low in December (measured on December 11, after the flooding began).

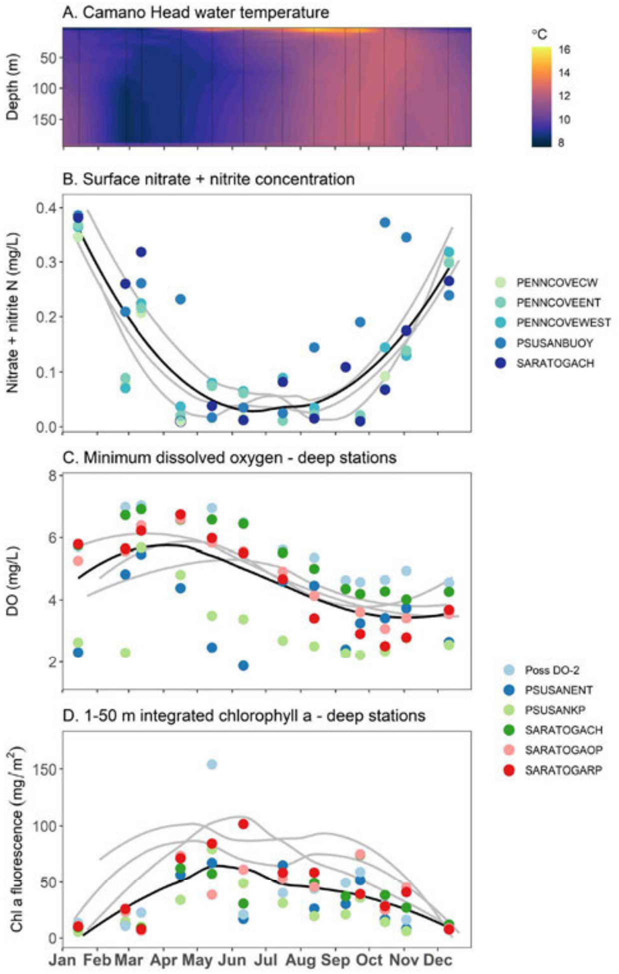

Figure 1. A) Temperature contour plot at Camano Head (SARATOGACH). Black lines indicate dates when casts were performed. Time series plots of B) surface nitrate+nitrite nitrogen, C) minimum dissolved oxygen, and D) 1–50 m integrated chlorophyll fluorescence. Open symbol indicates below the method detection limit. Black (2025) and gray (2022–2024) lines represent Loess-smoothed averages of B) five sites or C-D) six sites (max. depth >50 m).

Dissolved oxygen concentrations were slightly lower than previous years. Port Susan intermittently experienced low dissolved oxygen (~2 mg/L) near the bottom throughout the year, in contrast to the continuous lows observed in winter–spring 2024. Dissolved oxygen typically decreased from south to north along Possession Sound and Saratoga Passage.

Annual variability and long-term trends in Padilla Bay water temperatures

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Highlights

- Water temperatures in 2025 started similarly as in recent years but then was warmer the remainder of the year.
- The temperature anomaly for 2025 was highest recorded since the 2015-16 marine heatwave.

Overview

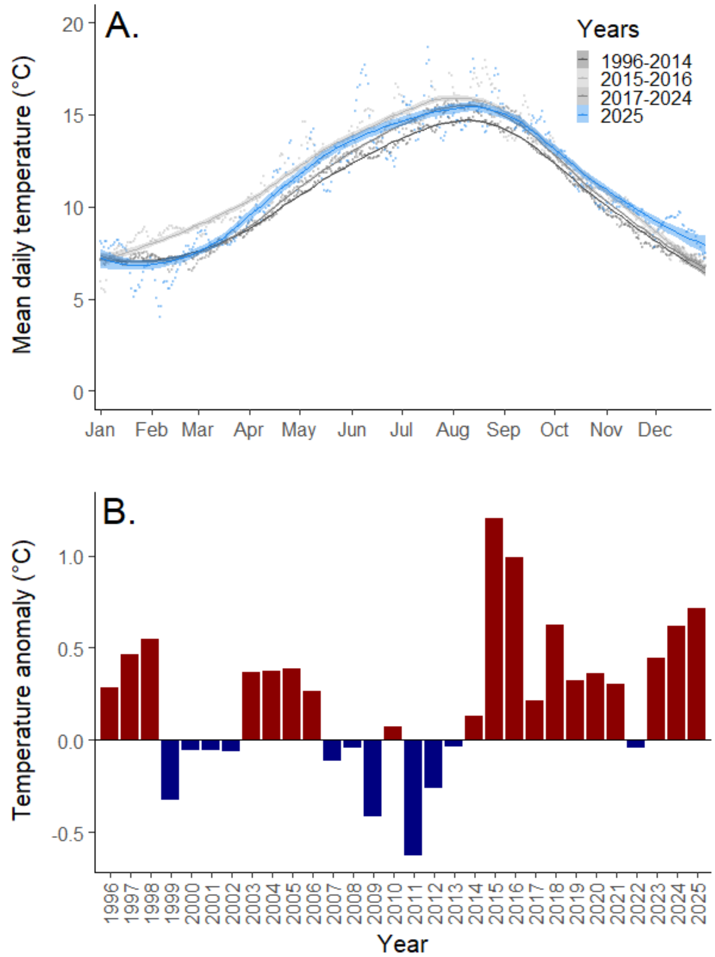
Padilla Bay is a tidally influenced shallow (<5 m) embayment north of Puget Sound and part of the National Estuarine Research Reserve System (NERRS). The Reserve maintains a long-term monitoring program (>20 years) at four stations throughout the bay that represent a range of conditions and nearshore habitats, including eelgrass meadows and deeper marine-dominated open water channels. High frequency (15-minute interval) monitoring data allow us to identify short-term variability and long-term trends in water quality parameters such as dissolved oxygen, pH, salinity, and temperature. Data from the longest running station (Bayview) is described here.

Narrative

Continuous monitoring of surface waters (0.5 m) in Padilla Bay throughout 2025 reveals mean daily temperatures ranging from 4.0 - 18.6 °C. Starting late Spring 2025, surface water temperatures were generally warmer than pre-2015 long-term daily means (1996-2014) and nearly as warm or warmer than the 2015-2016 'blob' heatwave years (Fig. A).

Average annual daily water temperature (±SE) in 2025 (11.2 ± 0.2 °C) was very similar to 2024 & 2018 (both 11.2 ± 0.2 °C) and was slightly lower (0.3-0.5 ° C) than 2015 (11.7 ± 0.2 °C) and 2016 (11.5 ± 0.2 °C).

The annual mean surface water temperature anomaly of +0.7 °C for 2025 was lower than that of the 'blob' years (+1.1 °C), but continued the pattern of positive anomalies occurring in recent years 2016-2024, with the exception of 2022 (Fig. B).



(A) Long-term seasonal patterns in temperature in Padilla Bay, including comparison of daily mean temperatures in 2015-2016, 2025, and long-term (1996-2014 & 2017-2024). LOESS fit (line) ± SE (shaded) is shown. (B) long-term annual temperature anomalies (1996-2014 mean as baseline).

Temperature, salinity, and dissolved oxygen in northern Whidbey Basin

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Highlights

- 2025 represents the second full year of data collected for this monitoring program.
- Northern stations show more mixing and less variability compared to stations in the south that are more heavily influenced by the Skagit River.

Overview

North Whidbey Basin is influenced by marine waters from the Strait of Juan de Fuca through Deception Pass in the north and from Saratoga Passage to the southwest, and substantial freshwater input from the Skagit River in the southeast. Depths in the area range from shallow mudflats in Skagit Bay to basins reaching ~40m depth near Skagit and Hope Islands to a deep channel (~100m) opening to Saratoga Passage at the southern extent of the area (Fig. 1 A-B).

The Swinomish Indian Tribal Community initiated a long-term monitoring program in northern Whidbey Basin in June 2023. Collected data include a 15-minute time-series of surface-water conditions at Little Hope Buoy, a mooring in Kiket Bay, and monthly depth profiles at seven stations between Deception Pass and Polnell Point. Profiles were collected as near as possible to neap high tides across months. 2025 represents the second full calendar year of measurements for these data sets.

Narrative

Conditions at the buoy site varied seasonally and were affected by freshwater inputs from the nearby Skagit River and storm events. Surface-water temperature ranged from 7.1 to 14.8°C with larger diurnal spreads in summer months (Fig. 1 C). Salinity ranged from 4.3 – 30.1 with prolonged periods of freshening attributable to storm events (Fig. 1 G). Dissolved oxygen (DO) (Fig. 1 K) concentrations increased during storm events and otherwise generally varied with chlorophyll *a* abundance (data not shown). Overall ranges and trends of properties measured in 2025 were similar to those observed in 2023 and 2024 (Fig. 1 C, G, and K).

Water column properties were well mixed near Deception Pass with increased stratification and greater variability observed in stations near the Skagit River in the south. Generally, except at Deception Pass station, a mixed layer in the upper 2 – 3m of the water column overlayed a pycnocline extending to between 8 and 30m (depending on station and time of year). A temperature inversion was evident at all stations except Deception Pass in the winter months (Fig. 1 D-F). Dissolved oxygen maxima were located in the upper 6.5m of the water column (Fig. 1 L-N), and values as low as 3.5mg/L were observed at depth in late fall and winter. Mixing, induced by tidal flow through Deception Pass, was influential at northern stations (e.g., Deception Pass and Little Hope Buoy), while Skagit River inputs had a greater influence on stations to the south (e.g., Polnell Point). Southern stations showed greater variability in properties both daily, in individual profiles, and over the course of the year.

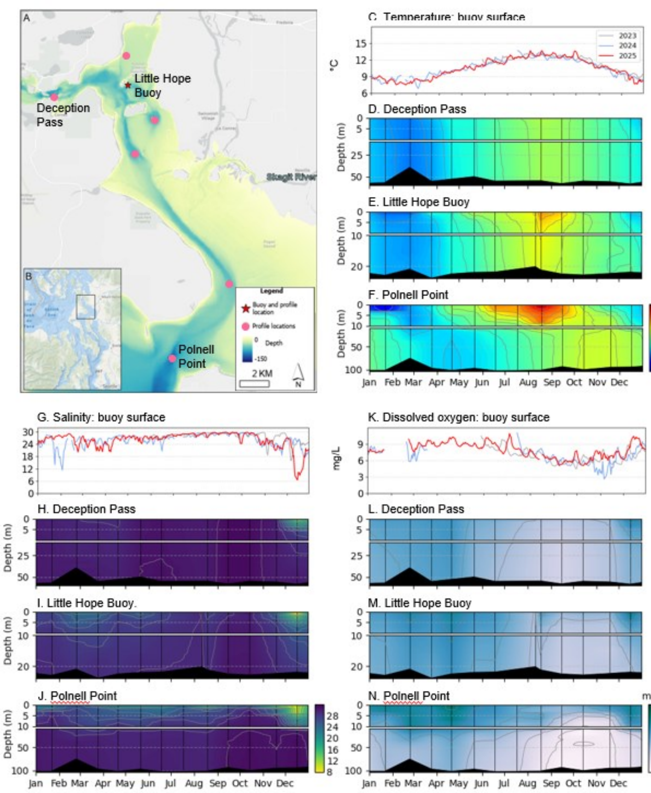

Figure 1: A: Observation locations in North Whidbey Basin. B: Study area extent. C, G, and K: daily means of continuous (15-minute interval) mooring data collected at the surface (0.7m) from June 2023 through 2025 at Little Hope Buoy. D-F, H-J, and L-N: water column profiles for multiple parameters collected at Deception Pass, Little Hope Buoy, and Polnell Point, respectively. The upper 10m are represented in equal scale in the upper section of each plot, with the remaining depth at each station shown at different scales in the lower section. Vertical black lines indicate dates when casts were taken.

Ocean and atmospheric CO_2 from Hood Canal moorings

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Edited by: Brendan Carter
Website: Dabob Twanoh **Additional website for data**: Dabob Twanoh

Highlights

- Atmospheric CO_2 in Hood Canal averaged15–21 ppm in fall–winter higher than the globally averaged marine surface air, with smaller differences in summer (7–14 ppm) when regional primary production reduces the offset.
- Surface seawater xCO_2 averages were mostly within historical ranges at both sites, but were substantially lower than long-term means at Twanoh in January and September, suggesting early and late phytoplankton productivity in Hood Canal, and substantially higher-than-normal at both sites in October, suggesting early storm mixing.

Overview

Atmospheric (air) and surface seawater xCO_2 (mole fraction of CO_2) have been measured on surface ORCA moorings in Dabob Bay since 2011 and at Twanoh in southern Hood Canal since 2009. These moored CO_2 time-series observations are part of a 40-site global network that measures CO_2 every three hours across seasons and provides estimates of surface ocean carbon cycle variability, ocean acidification rates, and air-sea flux. Estuarine seasonal and interannual CO_2 variability is high, driven by the input of many rivers, upwelled marine waters, extreme events, and strong primary productivity and respiration signals. As a result, xCO_2 ranges are exceptionally wide, with the longest "time of emergence" for anthropogenic acidification across this global network (2044–2056; Sutton et al. 2019). Funding to support these observations and their analysis (2009–2026) has come from NOAA Global Carbon Cycle Program, NANOOS-IOOS, NOAA/PMEL, and the Washington Ocean Acidification Center.

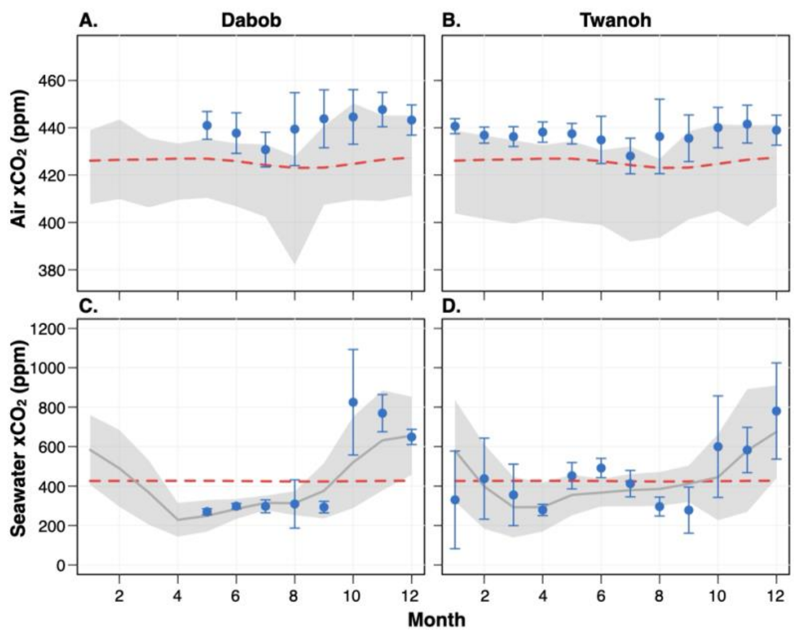

Figure 1. xCO_2 in air at 1.5 m above seawater (A, B) and in surface seawater at 0.5 m depth (C, D) on the Dabob Bay (A, C), and Twanoh (B, D) moorings. Because atmospheric CO_2 increases year after year, comparisons provided for the current year (2025) are the minimum and maximum monthly means observed across 2011–2024 at Dabob and 2009–2024 at Twanoh; thus, the lower bound of the gray shading represents earlier years and the upper bound more recent years at each site. For seawater, the gray line reflects the monthly mean value for each month across all measurements through 2023, with the gray shading representing natural variability as one standard deviation (1SD) around the mean. Means ± 1SD for 2025 months with ≥50% data return are shown in blue. The dashed red line in each panel represents monthly mean atmospheric xCO_2 values for globally averaged marine surface air in 2025 (NOAA/GML 2026).

Narrative

For both air and seawater xCO_2, preliminary 2025 data spanned the full year at Twanoh (100% data return!) and May 22–December 31 at Dabob (61%). The 2025 atmospheric xCO_2 range at Dabob was 406–523 ppm and 405–525 ppm at Twanoh. Monthly average atmospheric xCO_2 at both Hood Canal moorings was higher than the globally averaged marine surface air as a result of regional emissions (Figure 1). At both sites, the enrichment of regional air xCO_2 was lower in spring–summer (+7–14 ppm), and larger during winter and fall

(+15–21 ppm)[1]. The smaller offset between regional and global average atmospheric xCO_2 values likely reflects seasonal production of regional forests in spring–summer. Atmospheric xCO_2 variability (1SD bars) tends to be larger during summer–fall than winter–spring, with the widest 2025 ranges in August at both sites (Table 1).

During 2025, surface seawater xCO_2 measurements spanned 160–1792 ppm at Dabob Bay and 42–1764[1] ppm at Twanoh. At Dabob, mean ± 1SD seawater xCO_2 values for most months in 2025 were within the historical range (defined here as the time series mean ± 1SD through 2024), although the October mean was ~300 ppm higher than normal, and both August and October had higher than normal variability (Table 1). Monthly xCO_2 means at Twanoh were within the historical range for many months, but lower-than-normal in January (by 250 ppm) and August–September, and higher-than-normal in May–June, October, and December (Figure 1, Table 1).

	Dabob				Twanoh			
	Air		Seawater		Air		Seawater	
Month	2025	2011–2024	2025	2011–2024	2025	2009–2024	2025	2009–2024
Jan.	n.a.	408–439	n.a.	584 ± 176	441 ± 3	404–439	330 ± 247	579 ± 257
Feb.	n.a.	410–443	n.a.	490 ± 194	437 ± 3	402–437	438 ± 205	398 ± 215
Mar.	n.a.	406–436	n.a.	368 ± 163	436 ± 4	400–435	355 ± 156	293 ± 153
Apr.	n.a.	410–433	n.a.	229 ± 85	438 ± 4	402–433	279 ± 28	294 ± 124
May	441 ± 6	410–435	270 ± 15	249 ± 80	437 ± 4	400–434	453 ± 67	355 ± 103
Jun.	438 ± 9	407–433	298 ± 14	284 ± 50	435 ± 10	399–431	491 ± 49	367 ± 70
Jul.	431 ± 7	402–433	297 ± 33	315 ± 37	428 ± 8	392–432	413 ± 67	379 ± 82
Aug.	439 ± 15	382–428	309 ± 122	313 ± 61	436 ± 16	394–427	296 ± 48	385 ± 86
Sep.	444 ± 12	407–441	294 ± 29	376 ± 140	436 ± 10	401–439	278 ± 117	412 ± 92
Oct.	445 ± 12	409–450	825 ± 268	521 ± 232	440 ± 9	405–441	600 ± 257	445 ± 218
Nov.	448 ± 7	409–445	770 ± 94	632 ± 254	442 ± 8	398–441	583 ± 115	580 ± 311
Dec.	443 ± 6	411–445	649 ± 38	655 ± 198	439 ± 6	407–441	781 ± 244	675 ± 236

Table 1: Atmospheric and surface seawater xCO_2 (in ppm) at the Dabob Bay and Twanoh moorings. Monthly means ± 1SD for 2025 are compared to monthly statistics for the historical time series at each location. As in Figure 1, past air xCO_2 statistics used for comparison to the current year are the minimum and maximum monthly means observed through 2024. For seawater measurements, the historical range used for comparison is monthly means ± 1SD, because the variability at Washington mooring sites is sufficiently high as to obscure long-term trends at the present time (Sutton et al. 2019). Months lacking ≥50% 2024 data coverage show "n.a." (not available) in each cell.

Hood Canal surface xCO_2 typically falls below local atmospheric xCO_2 values in spring–summer, reflecting surface primary productivity and making surface waters a CO_2 sink during this time. Historically, seawater xCO_2 during March–June has averaged 128–194 ppm below atmospheric values. In 2025, notably low seawater xCO_2 in January and September at Twanoh and September at Dabob suggests stronger-than-normal early and late phytoplankton productivity. In December–February, seawater xCO_2 averages 156–248 ppm higher than air at both sites. In 2025, mean seawater xCO_2 was >320 ppm higher than air during October–November at Dabob and December at Twanoh (a 117–187 ppm larger air-sea difference than normal), indicating that Hood Canal surface waters were a stronger-than-normal source of CO_2 to the atmosphere in late 2025.

Footnote, references, and contribution number

NOAA Global Monitoring Laboratory (2026): Global Monthly Mean CO_2 data, https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_mm_gl.txt; accessed on April 8, 2026.

Sutton, A.J., and many others (2019): Autonomous seawater pCO_2 and pH time series from 40 surface buoys and the emergence of anthropogenic trends. *Earth System Science Data*, 11, 421–439, doi: 10.5194/essd-11-421-2019.

This is PMEL contribution number 5885.

[1] The preliminary Dabob 2025 monthly averages were 2.7–8.2 higher than at Twanoh in each month, due to a data processing issue. Both atmospheric and seawater xCO_2 values transmitted from the Twanoh MAPCO2 system were affected by a systematic offset during November 2024–early 2026. We estimated and applied a correction factor based on the field-transmitted data, but Twanoh seawater and air xCO_2 values from this period will be adjusted more accurately after the system is post-calibrated after its deployment. For the comparison between Hood Canal and global atmospheric xCO_2 in 2025, we used only Dabob data for months with measurements. For January–April, in this comparison only, we added the average offset observed during May–August (=3.0) to Twanoh average values to estimate the regional air xCO_2 enrichment for these months.

San Juan Channel - Strait of Juan de Fuca Fall Pelagic Ecosystem Surveys

Authors: Israel Marquez (University of Washington, imarquez@uw.edu); Rebecca Guenther (Friday Harbor Labs); Jan Newton (Applied Physics Laboratory, University of Washington)

Edited by: Greg Ikeda, King County

Website for data: https://www.nanoos.org/products/san_juan_pef/home.php

Highlights

- Warmer than average surface and deep water temperatures observed at stations North and South.
- Saltier surface and deep waters observed at stations North and South.
- 2025 had the 4th highest bird density but the 2nd lowest marine mammal density on record.

Overview

The Pelagic Ecosystem Function of the San Juan Archipelago apprenticeship program (PEF) has been collecting oceanographic data at stations North (north San Juan Channel) and South (Strait of Juan de Fuca) during the fall season since 2004. Stations are sampled approximately weekly from late September – early November. Additionally, seabird and marine mammal observations are conducted on a transect between stations. Animals are counted and recorded if they are within 200 m of the vessel's bow, starboard, or port side. Birds are recorded if they are flying or in the water and mammals are only recorded if they are in the water.

Narrative

Temperature and salinity anomalies were calculated from a running average (full data record 2004-2025) for both stations at the surface (0-5 m) and deep waters (10 m above seabed; North - 120 m, South - 90 m).

During fall 2025, surface seawater temperature anomalies were warmer than average at both North and South stations (Figure 1). The magnitude of the anomalies decreased as the fall season progressed but remained warmer than average. Notably, North station was nearly 2°C warmer than average in late September. Deep temperature anomalies (not shown) were ~1°C warmer than average at both stations.

Salinity was generally higher than average in surface waters at North and South stations during Fall 2025 (Figure 2). Salty surface anomalies at North station were observed on the first four cruises and then switched to a negative anomaly on the last cruise. Positive salinity anomalies were observed on each cruise at South station. Deep salinity anomalies (data not shown) were consistently salty at North station but oscillated between salty and fresh at South station. All surface and deep salinity anomalies for both stations were within 0.5 PSU.

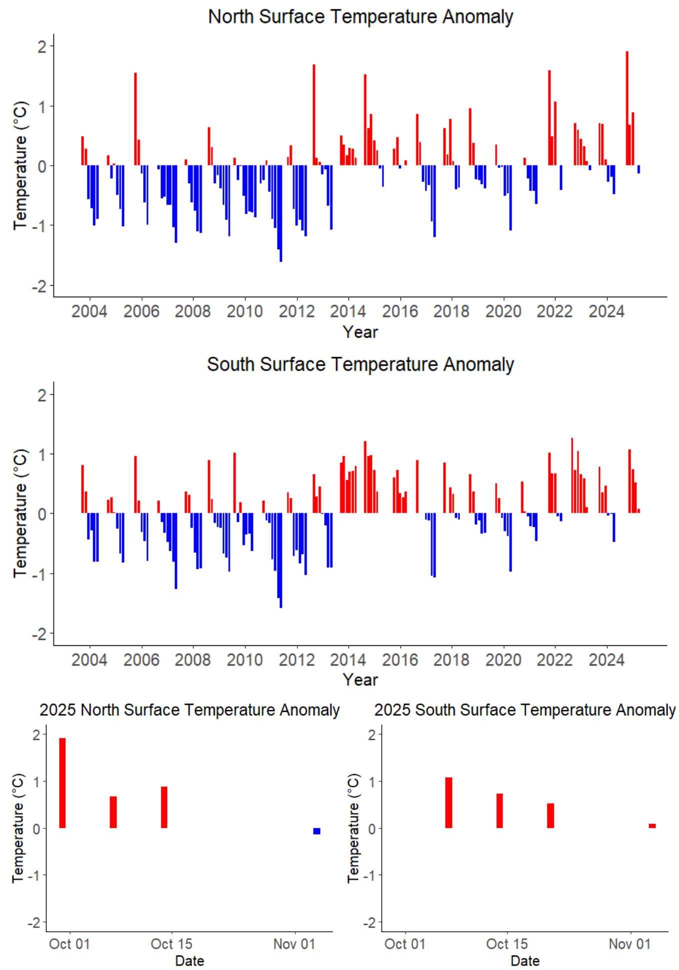

*Figure 1: Temperature anomalies at North and South stations during the fall from 2004-2025. Each bar represents an individual CTD cast. Red indicates warmer (positive) temperature anomalies and blue indicates cooler (negative) temperature anomalies. The mean and standard deviation for fall surface temperature were 10.32 ± 1.86 °C at North station and 10.10 ± 0.63 °C at South station. 2025 data shown below as an inset. *Note: North is missing one CTD cast and South station is missing two CTD casts during 2025 due to equipment and weather issues.*

Observations of seabirds and marine mammals from six transects during the fall continue to reveal contrasting interannual patterns. Seabird densities decreased from

Title: San Juan Channel – Strait of Juan de Fuca Fall Pelagic Ecosystem Surveys
Authors: I. Marquez, R. Guenther, J. Newton

record high observations in 2024, but were still the fourth highest on record. The observed decrease was due largely in part to reduced Common murre densities relative to 2024. In contrast, marine mammals continue to show relatively low and decreasing densities starting with the marine heatwave of 2014. Combined marine mammal densities have been especially low since 2021 and 2025 marks the second lowest density on record.

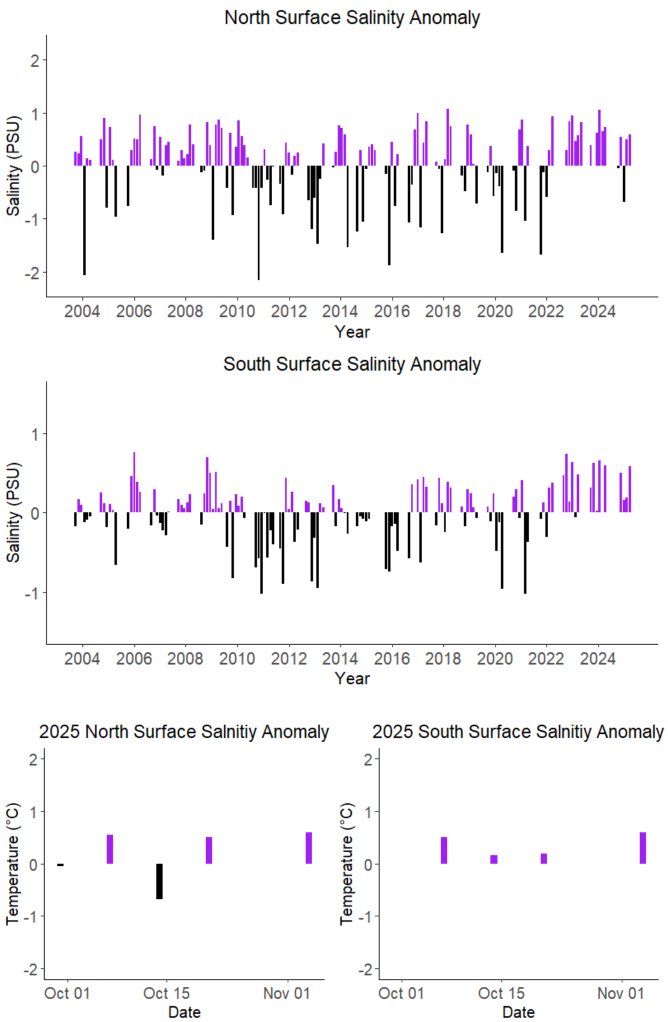

*Figure 2: Salinity anomalies at North and South stations during the fall from 2004-2025. Each bar represents an individual CTD cast. Purple indicates saltier (positive) salinity anomalies and black indicates fresher (negative) salinity anomalies. The mean and standard deviation for fall surface salinity were 30.12 ± 0.78 PSU at North and 30.84 ± 0.39 PSU at South. 2025 data shown below as an inset. *Note: North is missing one CTD cast and South station is missing two CTD casts due to equipment and weather issues. Different scales on the y-axis.*

In summary, while temperature and salinity anomalies were within the typical values measured during the time-series, ~10°C and ~30 PSU, 2025 marked the third consecutive year that water temperatures and salinity were consistently higher than average (~+0.5°C and ~+0.5 PSU) at the surface at both stations. While seabird densities decreased from their record high in 2024 this was largely due to one species. Marine mammal densities have continued to decrease since 2014, with the lowest five densities on record occurring since 2021. PEF continues to provide invaluable long-term regional data for these two oceanographic stations within the San Juan Archipelago.

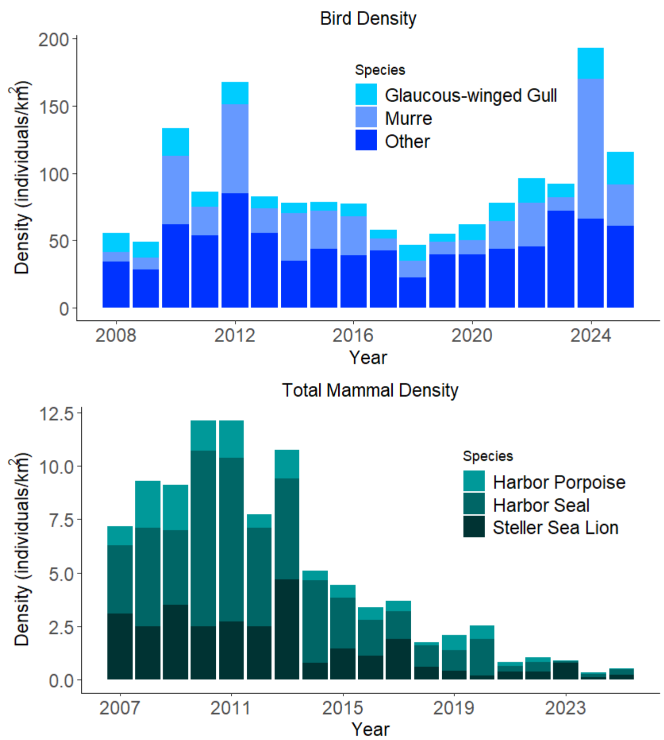

Figure 3: Bar plot displaying density (individuals/km^2) from fall surveys from 2007-2025 (note: different scales on the y-axis). Top panel shows total bird density: Glaucous-winged Gull (vivid sky blue), Murre (cornflower blue), Other (royal blue). Bottom panel shows mammal density: Harbor porpoise (turquoise), Harbor seal (bold teal), Steller sea lion (cyprus).

CALLOUT 2 | Shearwaters hold a surprise party

By Christopher Dunagan Puget Sound Institute
Excerpted from Salish Sea Currents magazine December 2025

It was mid-October 2025 when bird expert Peter Hodum launched his kayak at Owen Beach in Tacoma's Point Defiance Park. Hodum had heard that thousands of short-tailed shearwaters had appeared suddenly in Northern Puget Sound, to the amazement and delight of bird watchers throughout the region.

"I had seen short-tailed shearwaters from a distance in groups of three or four," said Hodum, a professor in conservation biology at the University of Puget Sound. The chance to see dozens or even hundreds at once was something he did not want to miss.

"It was a gorgeous sunny morning when I paddled out into the channel," Hodum recalled.

About 100 of the shearwaters were soaring on a light breeze across Dalco Passage. Some were floating on the water. One bird crossed his path, left to right, just off the bow of his kayak.

"It came within 10 or 15 feet," he said. "I could practically touch it with my paddle."

And yet Hodum had to face the fact that these short-tailed shearwaters were seemingly out of place in Puget Sound, where observers reported 1,800 near Tacoma, 2,300 near Anacortes and 1,100 near Port Townsend, with some birds counted more than once, according to the bird-watching site eBird.

"These birds near my home are hundreds of kilometers from where they should be," he added.

Reasons for the short-tailed shearwaters visiting Puget Sound might well be connected to a variety of unusual phenomena, with likely connections to weather, ocean conditions and long-term climate warming.

Avian ecologyist Peter Hodum sighted about 100 short-tailed shearwaters near Owen Beach in Tacoma in October 2025. Photo: Peter Hodum

Children of "The Blob"

The altered migration pattern of the short-tailed shearwaters is just one of the anomalies that could be related to the ecological effects of warm waters in the far north, experts say.

Some observers anticipated a major influx of this warm water into Puget Sound, with potentially devastating consequences, such as occurred in 2014, when conditions allowed warm water to rush in during September, raising the temperature of the Sound up to 2 degrees C (3.6 degrees F) within two weeks. But in 2025 there was no repeat performance. The difference appears to be a nearly steady and ongoing upwelling of deep, cold seawater along the coast. The upwelling, driven by winds out of the north, displaced and cooled the warmer incoming water, said Nick Bond, a longtime climatologist who first designated the 2014-16 heat wave as "the blob."

In late September, the winds shifted, resulting in a brief downwelling, somewhat on the normal schedule. But then the upwelling resumed and generally continued until late October. By the time the seasonal, more frequent downwelling began in mid-October, surface temperatures in the ocean had returned

Short-tailed shearwaters seen near Point No Point in Puget Sound, October 2025. Photo: Dennis Paulson

Each year, short-tailed shearwaters travel 9,000 miles from breeding grounds near Australia to their summer feeding grounds in the Gulf of Alaska and Arctic Ocean — but in fall 2025, thousands turned up in Puget Sound instead.
Photo: Dennis Paulson

to near-normal levels, thanks to cooler, windier weather. It seems that Puget Sound escaped the higher temperatures this time around, although the waterway still remains above the historical average temperature.

According to the National Oceanic and Atmospheric Administration, the 2025 heat wave will go down in the record books as the largest in size across the North Pacific, with higher temperatures than ever before. Warm water covered some 4 million square miles at its maximum, based on temperatures measured at the ocean's surface.

"But sea surface temperatures don't tell the whole story," Bond said, noting that maps of this year's marine heat wave showed it dissipating rather quickly in the Northeast Pacific Ocean, in part because the warm waters did not go very deep. In contrast, the blob of 2014 persisted because the warm waters created a moving mass of higher-temperature water that continued into the next year. For the past few years, a deep pool of warm water has been hanging off the Asian coast, reaching out to the middle of the North Pacific, where it could continue to play a role in ongoing heat waves as well as affecting weather in North America, Bond said.

"We should be expecting reorganizations in the marine food web," he said. "The variability in the climate brings changes in the community structure, so it makes sense that there will be winners and losers. There will also be surprises — some happy surprises and some unhappy surprises."

What happened with the birds?

While the 2025 marine heat wave was raging in the North Pacific, high temperatures were being measured up into the Gulf of Alaska and even into the Chukchi and Beaufort seas in the Arctic Ocean — all places where short-tailed shearwaters are known to spend their summers looking for food.

When one considers that these birds travel some 9,000 miles each year from their breeding grounds near Australia to reach their summer feeding grounds up north, it is no wonder that bird enthusiasts are awe-struck by their resilience. The birds generally make that trip in 10 to 15 days.

Unfortunately, summer heat waves up north have been playing havoc with their food supply, which includes shrimp-like crustaceans such as tiny krill and copepods. A new assessment of Arctic heatwaves by an international group of researchers shows a dramatic alteration in the food web, including a reduced size and fat content of the prey available to birds like the shearwaters.

Why the short-tailed shearwaters came to Puget Sound in large numbers may well be traced to their struggle to find enough nutritious food in their normal feeding grounds, according to speculation by several bird experts. All were surprised that so many birds would take a detour into Puget Sound, most apparently coming through the protected coastal waters east of Vancouver Island, sometimes called the Inside Passage.

While the deaths of marine birds have become associated with marine heat waves, the short-tailed shearwaters might survive hard times by looking for new places to forage, as suggested in a research paper by a group of Australian scientists. Perhaps this year the shearwaters were not in dire straits but were just running low on energy, so they dropped in to refuel.

Charlie Wright, who helps track seabird mortality for COASST, the Coastal Observation and Seabird Survey Team, says a shift in their migration pattern was first noted in 2021, when 2,000 short-tailed shearwaters showed up at the north end of Vancouver Island to the surprise and delight of bird enthusiasts who had never seen them there before. Other areas of British Columbia also saw increased numbers that year, as described in a report. Since then, the numbers have increased. This year, some 7,800 short-tailed shearwaters were spotted near the south end of Vancouver Island by the group Rocky Point Bird Observatory, which reported a similar number last year.

As for Puget Sound, the number of short-tailed shearwater sightings dwindled from mid-October to mid-November, when the last ones were reported in the Strait of Juan de Fuca.

"We were all following this event in real time," Wright said. "Now we are waiting for the fall of 2026. Will what happened this year become a new normal?" §

5

Plankton

Microscopic image of Ditrichocorycaeus anglicus. *Photo: Gabriela Hannach*

Marine Microplankton in Central Basin

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Highlights

- 2025 was the second lowest microplankton biovolume year on record in the Central Basin.
- The majority of microplankton biovolume in Central Basin was observed by the end of June.
- The diatom *Coscinodiscus* bloomed in record high biovolumes basin wide, with the highest biovolume observed at East Passage.

Overview

King County analyzes microplankton (microscopic marine plankton which includes diatoms, dinoflagellates, ciliates, and others) assemblages twice monthly in the Puget Sound Central Basin. A FlowCam® flow imaging microscope has been used since 2014 to assess abundance, biovolume, and taxonomic composition of all microplankton particles in the 10-300 µm range. Ten long-term monitoring stations were sampled for surface (1 m) microplankton in 2025, including nine open water sites and one shallow embayment (Dockton in outer Quartermaster Harbor; not reported here).

Narrative

Total microplankton biovolume in 2025 was 45.74% lower than the previous 10-year average (2015-2024; data not shown). It was the second lowest biovolume year on record, with 2018 being the lowest. Biovolume peaks tended to be transient and smaller in magnitude compared to other years (Fig. 1). The growing season was short compared to other years, with most of the total biovolume observed by the end of June. By July, biovolumes had decreased substantially at most stations and remained low through the end of the year, except for blooms in late July at Pt. Jefferson and Elliott Bay, late September at Vashon Outfall and East Passage, and early October at Pt. Jefferson and Elliott Bay. Diatoms were the dominant functional group in this basin, with chain-forming diatoms accounting for 8 of the top 15 biovolume contributing taxa (Fig. 2).

The season began in early April with mixed diatom blooms comprised primarily of *Chaetoceros*, *Thalassiosira*, and *Skeletonema* (Fig. 2). A record biovolume *Coscinodiscus* bloom was observed basin-wide in late April with the largest biovolume observed in East Passage (32.6 mm^3/L). *Coscinodiscus* cell diameters can exceed the 300 µm upper limit of the FlowCam, therefore total biovolume for this taxon may be underestimated. Biovolumes decreased abruptly in early May then rebounded in the second half of the month with a basin-wide *Chaetoceros* bloom through early June at most stations. A small *Pseudo-nitzschia* bloom at the two northernmost stations, Pt. Wells and Pt. Jefferson, was observed in early June, which coincided with a similar bloom in Whidbey Basin a week later. Biovolumes decreased again at the end of June, except for a small bloom of *Noctiluca* at Vashon Outfall. The small blooms observed in July consisted of *Noctiluca* and *Rhizosolenia (Sundstroemia)* at Pt. Jefferson and *Skeletonema* at Elliott Bay. *Coscinodiscus* was observed at Vashon Outfall and East Passage in September, but at biovolumes much lower than the bloom in late April. A late season bloom of *Noctiluca* was observed in October with the largest biovolumes observed at Pt. Jefferson and Elliott Bay.

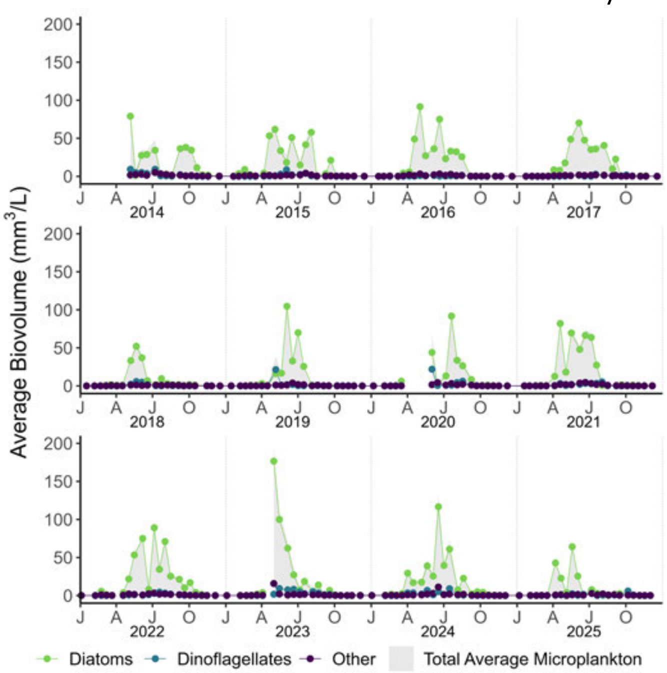

Figure 1. Average biovolume (mm^3/L) of microplankton groups from 2014 to 2025. Values are the average of nine Central Basin stations (Dockton excluded). Total Average Microplankton (gray shading) is the sum of the three microplankton groups. "Other" includes ciliates, flagellates, and zooplankton. No data collected April-May 2020, early April 2022, and late April 2023.

Title: Marine Microplankton in Central Basin
Authors: Swanson, Cain, Bos

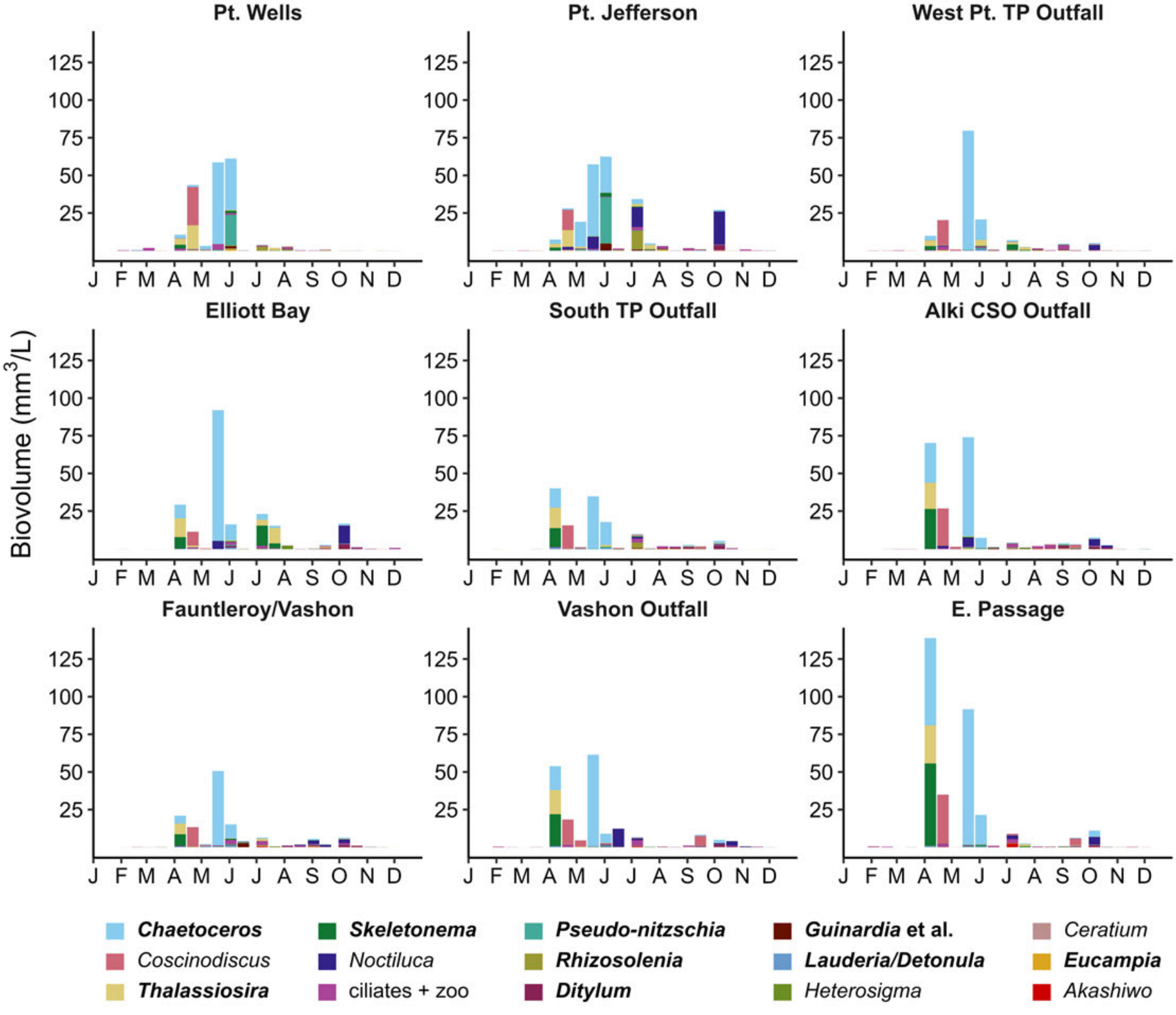

Figure 2. Biovolume (mm³/L) of the top 15 biovolume contributing taxa identified using FlowCam® in 2025 at each of the nine stations sampled in Central Basin (excludes Dockton). Bolded taxa indicate chain-forming diatoms.

Marine Microplankton in Whidbey Basin

Authors: Lyndsey Swanson (King County, Lyndsey.Swanson@kingcounty.gov); Kelsy Cain (King County), Julia Bos (King County)

Edited by: Kim Stark and Fran Sweeney (King County)

Website: https://kingcounty.gov/en/dept/dnrp/nature-recreation/environment-ecology-conservation/science-services/puget-sound-marine-monitoring/plankton/phytoplankton

Highlights

- Whidbey Basin microplankton growing season spanned April to November with a small February bloom observed at most stations.
- *Thalassiosira punctigera* bloom observed from October to November.
- Elevated detritus particle concentrations observed at Port Susan and Saratoga Passage following heavy December rainfall and river discharge.

Overview

In 2022, King County began analyzing microplankton (microscopic marine organisms that include diatoms, dinoflagellates, ciliates, and others) assemblages in Whidbey Basin twice monthly and was reduced to once monthly in 2024. A FlowCam® flow imaging microscope is used to assess abundance, biovolume, and taxonomic composition of all microplankton particles in the 10-300 µm range. Five monitoring stations were sampled for surface (1 m) microplankton in 2025, including an open water site (Saratoga Passage), a submerged delta site (Port Susan), and three shallow embayment sites (Penn Cove).

Narrative

The growing season in Whidbey Basin spanned April to November with a small, ephemeral bloom observed at all stations except Port Susan in February (Fig. 1). Biovolumes remained relatively steady throughout the growing season with peak biovolume observed in September. Biovolumes recorded at Port Susan were lower than the other stations, which has been consistently observed in previous years and is likely related to the nearby influence of the Stilliguamish River.

The small February bloom consisted mainly of the chain diatom, *Thalassiosira* (Fig. 1). Biovolume observations notably increased basin-wide in April with a mixed diatom bloom composed mainly of *Thalassiosira*, *Chaetoceros*, *Coscinodiscus*, and *Noctiluca*, a large-celled dinoflagellate. *Chaetoceros* biovolumes increased in May and maintained presence through October at most stations. *Noctiluca* biovolumes also increased in May except at Penn Cove Entrance and Port Susan. *Noctiluca* was not observed via FlowCam at the Port Susan site all year, however, stereo microscope observations indicated low abundance from May to June (data not shown). A basin-wide bloom of *Pseudo-nitzschia* was observed in June, much like the bloom at the northernmost stations in Central Basin a week prior. *Rhizosolenia* (*Sundstroemia*) briefly bloomed at Port Susan in July. Within Penn Cove in August, dinoflagellate biovolume contributions temporarily surpassed diatoms when *Noctiluca* bloomed. Diatom biovolume dominance resumed in September in Penn Cove with observations of *Ditylum, Asterionellopsis,* and a large bloom of *Chaetoceros*; this diatom bloom was also observed at Saratoga Passage. From October to November, a bloom of *Thalassiosira,* specifically *T. punctigera,* was observed at most stations. This is a common species in this basin but previously hasn't been a major biovolume contributor. Heavy rainfall in December resulted in increased river discharge that impacted samples from Saratoga Passage and Port Susan in the form of elevated particle concentrations consisting primarily of detritus, or non-biological particles like sediment and degraded organic matter (data not shown).

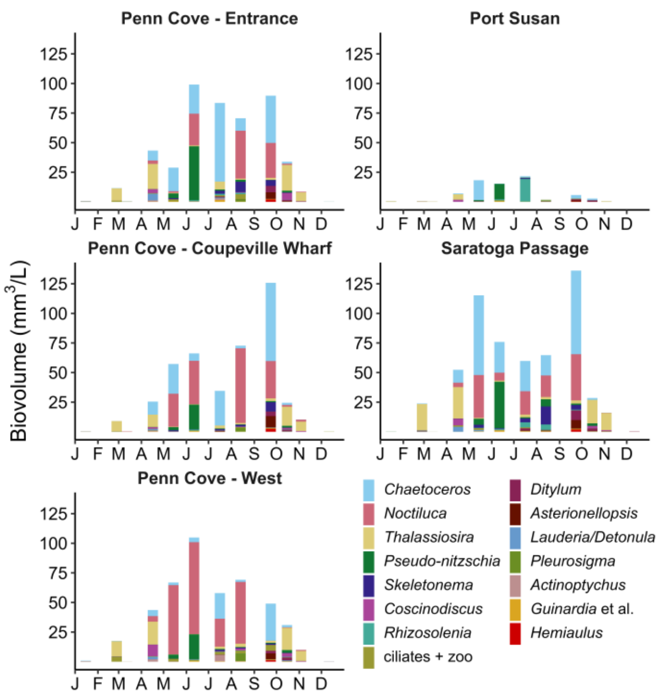

Figure 1: Biovolumes (mm^3/L) of the top 15 taxa identified using FlowCam® in 2025 at each station sampled in Whidbey Basin.

Puget Sound Zooplankton

Authors: Amanda Winans (awinans@uw.edu), Emily Seubert, Olga Kalata, Karen Chan (UW School of Oceanography)
Edited by: Wing-Ho Ko, Karen Chan and Emily Seubert
Website: https://karenchanlab.org/pszmp/
Additional website for data: https://obis.org/dataset/debc8f44-f70f-4d30-821e-d3a705f62cfb

Highlights

- In 2025, total mesozooplankton biomass in Puget Sound was generally below the past decade's monthly averages.
- At most stations, peak zooplankton biomass occurred later than the historical regional average, with isolated early, high peaks driven by blooms of specific taxa (e.g., larval invertebrates and *Noctiluca*).

Overview

Mesozooplankton were collected through vertical tows of a 200-µm mesh plankton net from 5 m off the bottom (or a max of 200 m) to the surface. Most stations (Fig. 1) were sampled bi-weekly from March through October. Samples were analyzed and identified at UW.

Narrative

Most total biomass values in 2025 were below the 2014–2024 monthly averages, with several falling outside one standard deviation of the mean (Fig. 2). Some stations (ELIV, TDBV, LSNT01V) exhibited earlier-than-average increases in biomass, while others peaked later than the historical regional average.

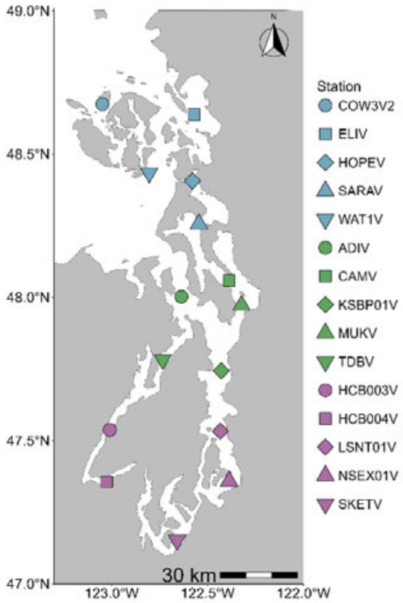

Figure 1 Map of the sampling stations. Symbols are color-coded by region (northern, central, & southern) & correspond to the symbols in Figure 2.

While most northern stations maintained below-average biomass through April, Eliza Island (ELIV) showed an unusual January peak driven by pandalid shrimp. After April, above-average biomass in the northern region was primarily associated with *Noctiluca* at Saratoga Passage (SARAV), along with larvaceans and small- to medium-sized copepods at ELIV.

Admiralty Inlet (ADIV) had the highest biomass among all stations, dominated by Cancridae crab larvae and smaller copepods. Biomass in May and June ranked as the 5th and 6th highest values on record for ADIV, respectively. Thorndyke Bay (TDBV) also showed elevated biomass in January relative to previous years, driven largely by euphausiids and medium-sized copepods.

At Point Williams (LSNT01V), unusually early and high biomass was likely associated with increased chaetognaths. In contrast, later seasonal peaks at Sisters Point (HCB004V) were driven by increases in polychaetes (June) and resident copepods (August).

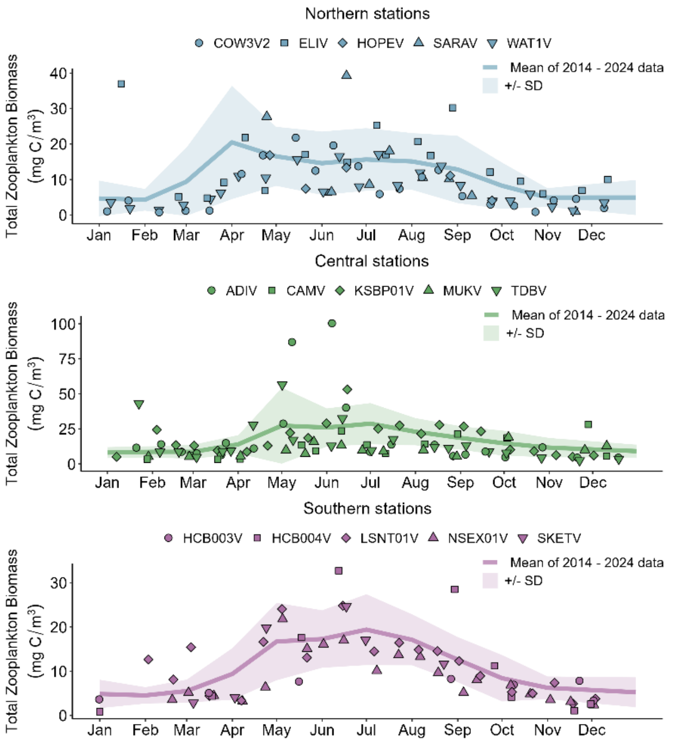

Figure 2 Time series of total mesozooplankton biomass (mg C/m^3) at northern, central, & southern stations in 2025, shown with monthly mean of 2014-2024 data ±1 SD.

Puget Sound Zooplankton Monitoring Program (PSZMP) sampling was conducted by King County, Nisqually Indian Tribe, Tulalip Tribes, Kwiáht, Lummi Nation (since 2015), Port Gamble S'Klallam Tribe, WA Dept. of Fish and Wildlife (WDFW), NOAA, Hood Canal Salmon Enhancement Group with WA Dept. of Ecology (since late 2016), Stillaguamish Tribe (late 2019-2024), and Shannon Point Marine Center (since mid-2025). Funding for 2025 sampling was provided by King County and the WDFW.

Zooplankton abundance and community composition in Padilla Bay

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Website: https://ecology.wa.gov/water-shorelines/shoreline-coastal-management/padilla-bay-reserve

Highlights

- Monthly zooplankton abundances were less than the average except in August when abundance was higher.
- Monthly zooplankton community compositions were similar to previous years though some months showed more similarity to each other than is typical.

Overview

Padilla Bay National Estuarine Research Reserve has monitored zooplankton communities since 2008 in conjunction with collection of long-term water quality, nutrient, and meteorological data. Data is collected at 3 sites, 2 within channels that drain eelgrass beds and 1 that is in the deep water off the subtidal edge of Padilla Bay (Gong Station). Vertical tows to 18 m depth were performed at least monthly using a 150 µm mesh net with a 1 ft diameter opening at Gong Station.

Narrative

Zooplankton abundances (2008-2025) were consistently lower during the winter and higher in both the spring and mid-summer to early fall (Figure 1A). Zooplankton community composition and abundance in Padilla Bay exhibited within-season variation but had distinct seasonal compositions that persisted annually despite environmental changes (2008-2025, Figure 1B).

Monthly total zooplankton abundances in 2025 were less than the long-term mean (2008-2024) but still within 1 standard deviation of the mean for most months. However, abundances in August, September, and December were greater than the mean with August total abundances greater than 1 standard deviation (Fig 1A). The increase in August was due to increases across the most common zooplankton groups in Padilla Bay (appendicularians, barnacles, copepods, hydrozoa, polychaetes).

Zooplankton community composition followed the normal cyclic pattern though several months were closer to the center of the ordination making them more similar to each other than in previous years (Feb, Mar, Apr, Nov). Notably, August community composition was similar to the August 2015 (a Blob year) composition and was due to an increase in the groups mentioned above (Fig 1B).

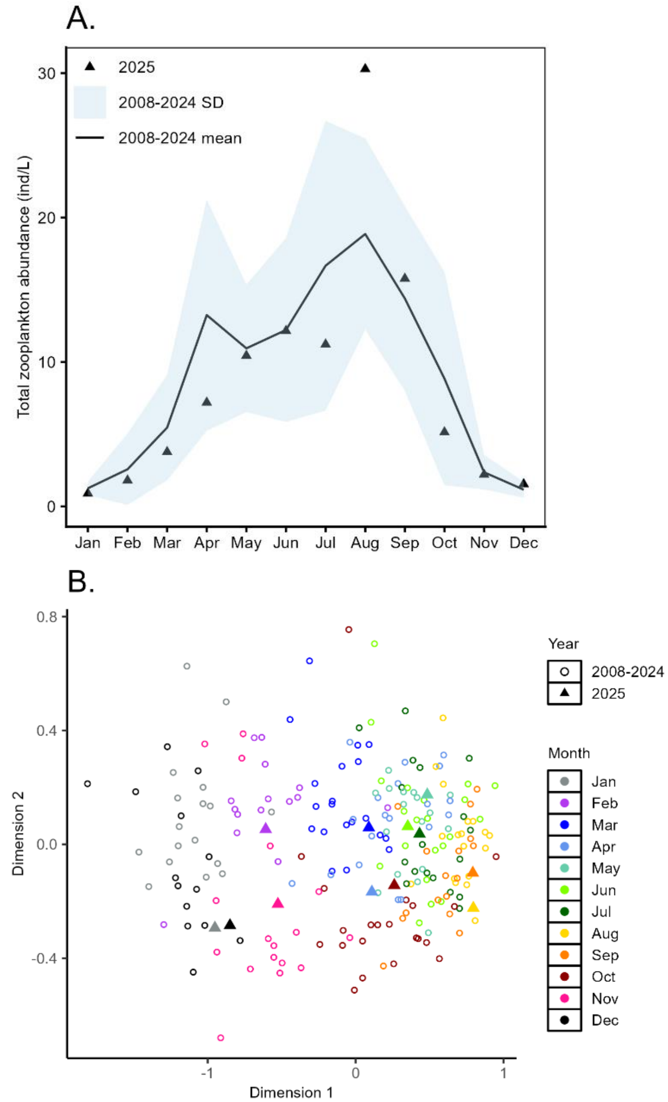

Figure 1 A) Mean monthly total zooplankton at Gong Station, 2008-2025. The triangles are monthly means of 2025 replicates. The black line is the monthly mean of total zooplankton from 2008–2024 and the gray band is +/- 1 SD. B) Non-parametric multidimensional scaling ordination (NMDS) of zooplankton community composition at Gong Station, 2008-2025. Each point (2008-2024 open circle, or 2025 triangle) is the mean of replicates for a sample month.

Spatial and temporal dynamics of larval Dungeness crab

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Edited by: Julie Barber (SITC)
Website: www.pnwcrab.com

Highlights

- Dungeness crab megalopae abundances were generally low relative to previous years, with the highest catches recorded at sites in Hood Canal.
- The network observed a shift in peak larval delivery timing, with Pacific coast sites peaking in May, central Salish Sea sites in June, and South Puget Sound sites in July.

Overview

The Pacific Northwest Crab Research Group (PCRG) comprises scientists, resource managers and community members working collaboratively to address critical research gaps and improve understanding of Dungeness crab (*Metacarcinus magister*) population dynamics. In 2019, PCRG initiated a long-term larval crab monitoring effort in Puget Sound, which has since expanded to the Pacific coast and British Columbia (BC) in partnership with Hakai Institute. The network uses standardized light traps deployed off docks and piers to quantify daily abundances of larval Dungeness crab from March to October each year, aiming to explore spatial and temporal patterns of recruitment and generate biologically relevant data to support fisheries management. To date, the PCRG and Hakai larval crab monitoring networks consist of 49 sites (20 WA; 29 BC) spanning the outer Pacific coast and Salish Sea, from South Puget Sound to the northern Strait of Georgia.

Narrative

In 2025, late-stage larval Dungeness crab (megalopae) were observed across the PCRG network from March 27 to September 12, with clear and consistent regional differences in phenology. The earliest observed megalopae were captured in March along the Pacific coast, followed by sites in the Strait of Juan de Fuca in April, then the waters to the north and south of the Strait. In the Strait of Juan de Fuca, early spring catches were low relative to previous years, likely indicating oceanographic conditions precluded larval transport from the outer coast into the Salish Sea. Megalopae abundances were also lower than previous years in August through the conclusion of the larval season, reflecting a more transitory period of larval delivery overall.

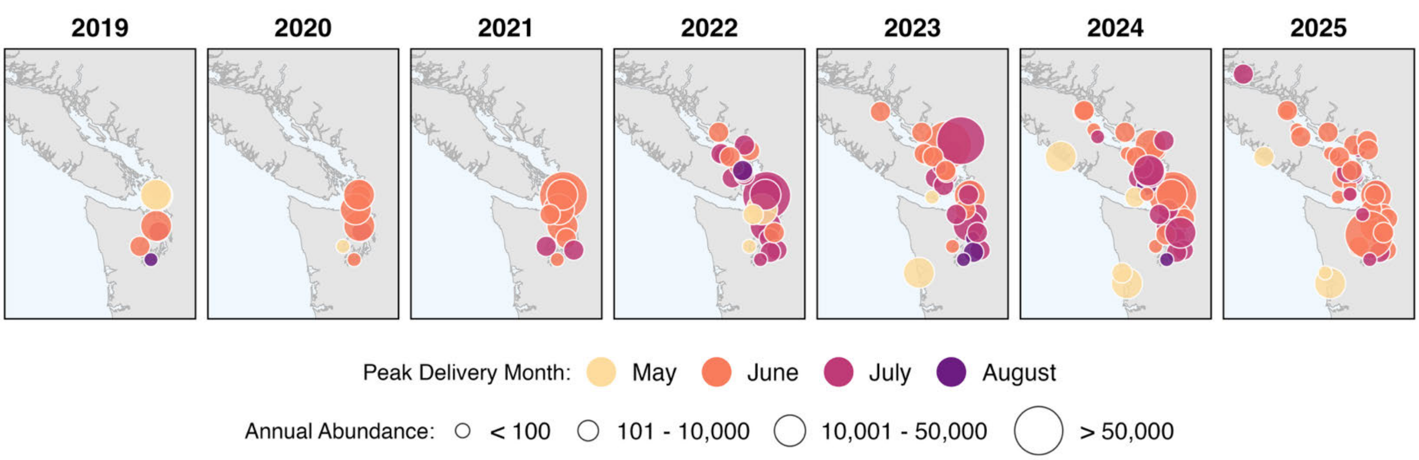

Figure 1. Total annual abundance of Dungeness crab megalopae captured at light trap network sites from March to October, 2019-2025. Circle size represents the magnitude of annual abundance; color denotes the month of peak larval delivery at each site. Note the increase in the number of sites monitored over time, with expansion to BC in 2022 and the outer Pacific coast beginning in 2023.

Marine Biotoxins

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Website: https://doh.wa.gov/community-and-environment/shellfish/recreational-shellfish/illnesses/biotoxins; https://doh.wa.gov/shellfishsafety

Highlights

- Marine biotoxins resulted in 28 recreational shellfish harvest closures and 7 commercial shellfish harvest closures
- PSP closures began later than usual, with isolated lethal levels (≥1,000 µg/100 g)
- There were no ASP/domoic acid closures

Overview

The Marine Biotoxin Program at the Washington Department of Health prevents the biotoxin related illness and death of shellfish consumers. Routine monitoring began in 1957, with the current program routinely testing shellfish from over 100 monitoring sites. Shellfish samples are tested for the toxins that cause Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP; domoic acid), and Diarrhetic Shellfish Poisoning (DSP) and shellfish harvest is closed based on regulatory thresholds.[1] Shellfish sampling increases from every other week if toxins are detected, and expands once thresholds are exceeded. Samples are submitted by a wide variety of partners and testing is informed by early-warning harmful algal bloom monitoring provided by SoundToxins and the Olympic Region Harmful Algal Blooms Partnership (ORHAB). Real-time biotoxin closure information is provided to the public on the Shellfish Safety Map at doh.wa.gov/shellfishsafety.

Closure thresholds for marine biotoxins in shellfish are:

- PSP ≥ 80 µg/100 g shellfish tissue
- DSP ≥ 16 µg/100 g shellfish tissue
- ASP; domoic acid ≥ 20 ppm

Narrative

The first shellfish closure for PSP was implemented more than a month later than usual, on July 3 in the east Strait of Juan de Fuca, Clallam County. By the end of July, PSP toxin levels resulted in all species shellfish closures in Island, Jefferson, King, Kitsap, and Whatcom counties in addition to Clallam. PSP exceeded the regulatory action level briefly in Pierce County and on the north Grays Harbor coast

(a) PSP Toxins in shellfish

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Sound	<38	0	39	51	41	53	88	224	247	291	99	33
Strait of Juan de Fuca	39	<38	<38	<38	42	63	193	1486	308	2654	675	118
Central Basin	<38	0	<38	<38	0	54	358	730	225	274	123	58
South Sound	0	0	0	0	0	0	21	0	0	26	23	47
Hood Canal	0	0	0	0	0	0	79	0	0	0	0	0
Coast	<38	63	53	<38	<38	0	34	140	129	26	19	0

0							80	1000

(b) DSP Toxins in shellfish

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Sound	3	3	2	1	2	11	9	4	9	4	9	9
Strait of Juan de Fuca	5	2	2	1	3	37	22	11	46	19	39	72
Central Basin	5	3	3	2	5	10	14	14	8	38	44	22
South Sound	77	29	36	12	17	6	3	1	2	4	5	36
Hood Canal	<1	3	3	2	2	3	2	<1	1	0	0	1
Coast	3	2	1	1	<1	1	1	4	33	10	12	17

0							16	70

Figure 1 (a) Maximum PSP levels in shellfish. Shellfish that retain PSP toxins, butter clams, varnish clams, razor clams, and scallops have been removed to indicate toxin activity. (b) maximum DSP levels in shellfish. Color scales range from no toxin detected (0) to lethal levels (≥1,000 µg/100 g), and above 70 µg/100 g tissue DSP.

in August. Though PSP toxins were widespread, lethal levels were restricted to Discovery Bay and Sequim Bay, with maximum levels detected in blue mussels in Discovery Bay at 1,486 µg/100 g on August 13, and in Sequim Bay at 2,654 µg/100 g on October 20. PSP caused 20 recreational harvest closures for all species and 5 commercial harvest closures. Of the commercial harvest PSP closures, three occurred in Discovery Bay, and one in Sequim Bay (Figure 1 (a), Figure 2).

The recurring winter South Basin DSP shellfish closure continued into 2025, resulting in the highest DSP toxin detection of the year in early January of 77 µg/100 g in blue mussels from Budd Inlet. In June, DSP toxins caused shellfish closures in Discovery Bay and Sequim Bay. DSP reached the maximum level ever recorded for the coast, at 33 µg/100 g in California mussels collected in September. In October, the Kitsap County recreational shellfish harvest closures were extended by DSP toxins. Sequim Bay harvest closures were similarly extended by DSP, with DSP peaking at 72 µg/100 g tissue in blue mussels collected on December 8. DSP toxins caused 8 recreational shellfish harvest closures for all species, and two commercial shellfish harvest closures, both in Sequim Bay (Figure 1 (b), Figure 3).

2025 marked the second year in a row with no shellfish closures for ASP, despite high *Pseudo-nitzschia* cell counts reported by SoundToxins (See SoundToxins). The highest ASP levels detected within the Salish Sea were 2 ppm in mussels from Discovery Bay and Port Susan, and 5 ppm statewide in razor clams from the Pacific County coast in August (data not shown).

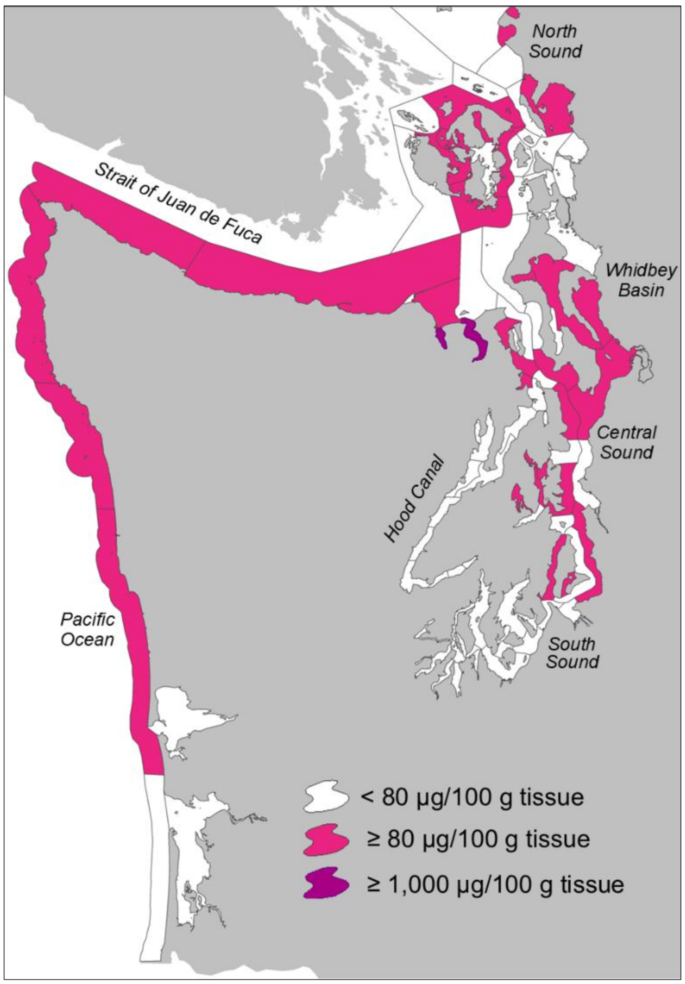

Figure 2 Distribution of shellfish samples where PSP exceeded the closure threshold in 2025. Shellfish may not be collected from every area, and areas may be closed based on nearby results.

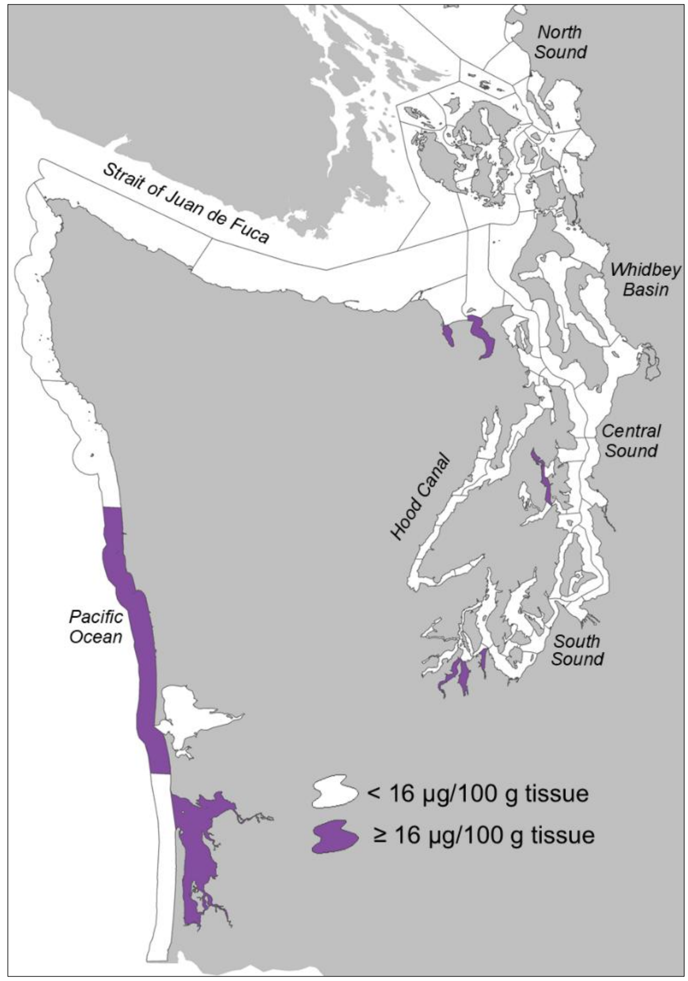

Figure 3 Distribution of shellfish samples where DSP exceeded the closure threshold in 2025. Shellfish may not be collected from every area, and areas may be closed based on nearby results.

References

1. U.S. Food and Drug Administration, & Interstate Shellfish Sanitation Conference. (2024). National Shellfish Sanitation Program guide for the control of molluscan shellfish: 2023 revision. https://www.fda.gov/food/federal-state-local-tribal-and-territorial-cooperative-human-food-programs/national-shellfish-sanitation-program-nssp

SoundToxins Phytoplankton Monitoring Program

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Edited by: Tracie Barry (Washington Department of Health)
Website: soundtoxins.org

Highlights

- The diatom to dinoflagellate ratio peaked in February, earlier than the 10-year median
- Frequently reported blooms and the presence of the target HAB genera were typical based on previous years of SoundToxins data.

Overview

SoundToxins, a diverse partnership of tribes, shellfish growers, environmental learning centers, health agencies, colleges, and community science volunteers, is a phytoplankton monitoring program designed to provide early warning of harmful algal blooms (HABs) to minimize human health risks and economic losses. Monitors sample weekly from March to October, and biweekly from November through February documenting phytoplankton diversity and relative abundance, with special attention to HABs that can cause human illnesses, environmental concerns, and animal mortality.

Narrative

In 2025, the SoundToxins network had a total of 1,164 sampling visits across 38 sites, including sites in Willapa Bay, a new region for the program.

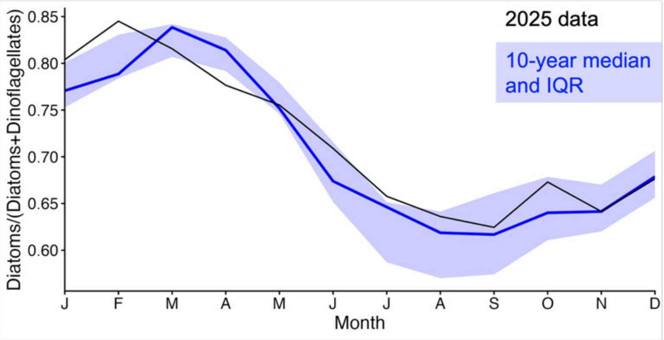

Figure 1. Diatom to dinoflagellate ratio calculated as the total number of diatom observations divided by the sum of all diatom and dinoflagellate observations by month.

The ratio of diatoms to dinoflagellates followed a similar curve as expected (Figure 1). Diatoms dominated early in the year, and dinoflagellates increased through summer, but the ratio peaked about a month earlier than the 10-year median in February rather than March.

Of 11,246 total phytoplankton observations recorded, 402 were classified as blooms. The most frequently recorded blooming genus overall was *Chaetoceros*, followed by *Rhizosolenia/Sundstroemia*, and *Pseudo-nitzschia* (Figure 2). *Thalassiosira*, *Skeletonema*, and *Chaetoceros* blooms were most frequently reported at the beginning of the year, but the number of reported blooms picked up in April and peaked in June. The diversity in blooming species increased in the second half of the year with more dinoflagellate blooms in late summer to early fall. The end of the year was dominated by *Chaetoceros*, *Ditylum*, and *Tripos* blooms. This distribution of blooms is typical based on previous years of SoundToxins data.

Three HAB genera that affect human health through toxin accumulation in shellfish, monitored by the Washington Department of Health (*Alexandrium*, *Dinophysis* and *Pseudo-nitzschia*) were present throughout the year. There were reported blooms of *Alexandrium* between July and September. There were no reported blooms of *Dinophysis*, but many observations of present and common abundances, peaking in September, a month later than usual. *Pseudo-nitzschia* had a typical year, with presence creating a bimodal pattern with peaks in spring and fall. Toxin levels associated with this genus did not result in shellfish closures (See Marine Biotoxins).

Two new target genera were added this year including *Azadinium*, which can cause azaspiracid shellfish poisoning and *Karenia*, which can cause neurotoxic shellfish poisoning and various environmental impacts. Neither of these genera were reported at high abundances this year.

Fish and shellfish-killing HABs include *Heterosigma*, *Akashiwo*, *Protoceratium*, and *Phaeocystis*. There were no reports of *Phaeoctystis* blooms in 2025. *Heterosigma*, *Akashiwo*, and *Protoceratium*, all had reports of blooms between June and September, following similar patterns to past years.

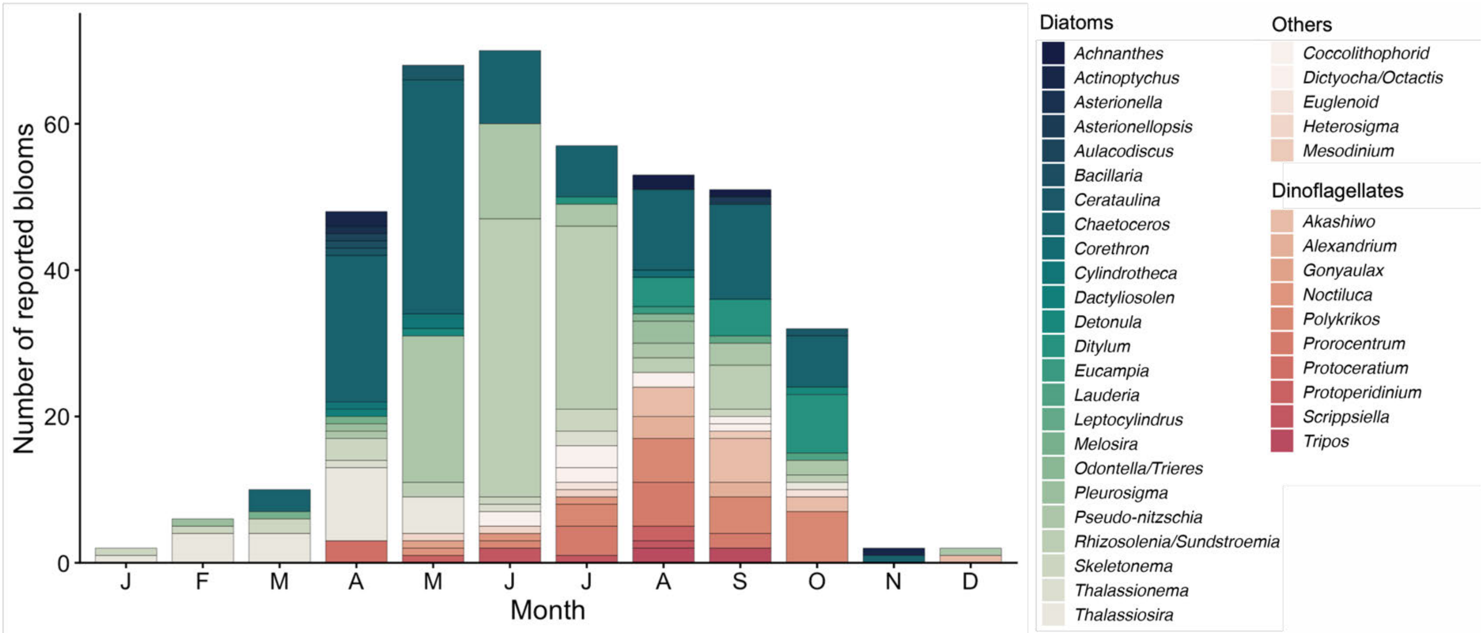

Figure 2. All phytoplankton blooms reported by SoundToxins monitors in 2025 by taxa and month observed.

CALLOUT 3 | Gray whales struggling to survive

By Christopher Dunagan Puget Sound Institute
Excerpted from *[Salish Sea Currents magazine]* *December 2025*

Warming waters off Alaska in recent years appear to be taking a major toll on gray whales along the West Coast, most of whom undertake one of the longest annual migrations of any mammal. Each fall, they travel some 6,000 miles from feeding grounds in Arctic and sub-Arctic waters south to breeding grounds in Baja California, before returning north in the spring.

After decades of ups and downs, the population of Eastern North Pacific gray whales has been in a steep decline for the past 10 years, dropping to about 13,000 animals this year — less than half the 27,000 estimated for 2016. This is the smallest number since 1972 — the year the Marine Mammal Protection Act was adopted by Congress.

For a variety of species, warming water favors the growth of less desirable prey over more nutritious choices. For gray whales, there is an additional effect that impairs their ability to get enough food. Warmer waters mean less sea ice, which supports the growth of algae that live on the underside of the ice, as described in a 2023 article in the *journal Science*. These algae die and sink to the bottom, where they feed the benthic (bottom-dwelling) organisms, particularly shrimplike amphipods. Gray whale anatomy is uniquely adapted for scooping out and filtering sediments on the bottom.

Less sea ice caused by longtime warming, not just marine heat waves, means less algae and fewer benthic critters, to the detriment of the whales. In addition, more open water leads to stronger currents, which can wash away the fine sediments required by some nutrient-rich amphipods.

Interestingly, two subgroups of these gray whales seem to be holding their own by adopting different migration patterns. One is a group that takes a detour into Puget Sound during the spring migration north when they are most vulnerable. Nicknamed "the sounders," they seek out a specific location near Whidbey and Camano islands.

While the sounders typically show up during the spring migration north, five showed up last December and into January, foregoing the rest of the trip to breeding and nursery grounds in Baja California, where mating takes place and calves are born. It turned out to be an unusually poor reproductive year — the lowest on record — with an estimated 84 births. That compares to a previous 10-year average around 730.

Perhaps lacking normal fat reserves, the whales that chose to stay in Puget Sound took advantage of the local ghost shrimp while avoiding the energy-depleting trip farther south.

Another notable faction within the gray whale population is the Pacific Coast feeding group, some 250 whales that travel from the southern breeding grounds to West Coast areas from California to British Columbia. These animals tend to be smaller in size, perhaps because they do not partake of the Arctic feast. Their numbers remain stable or in a slight decline, unlike the wild fluctuations of the larger population.

In several feeding areas along the coast, the whales consume swarms of mysid shrimp swimming near the surface and in kelp beds. Warmer water, particularly during marine heat waves, can affect the survival and reproduction of mysids directly as well as altering their habitat, including kelp. Given the uncertainties in ocean conditions, the future remains uncertain for this unique group of gray whales. §

A stranded dead gray whale at Leadbetter Point State Park, Washington in 2019. Photo: John Weldon, under NOAA Fisheries permit 18786-03

6

Bacteria and pathogens

Owen Beach. Photo: Rachel Wold

Central Basin Bacteria Monitoring

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Edited by: Kimberle Stark, Taylor Martin, Gregory Ikeda
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Additional website for data: https://data.kingcounty.gov/d/vwmt-pvjw

Highlights

- Fecal indicator bacteria concentrations at King County beach stations were generally low compared to the historical record except in December after heavy rains and flooding.
- Fecal indicator bacteria concentrations at offshore monitoring sites in the Central Basin were low like in previous years.

Overview

King County monitors fecal indicator bacteria (*Enterococcus* and fecal coliforms) monthly at 20 beach stations in Puget Sound's Central Basin. King County also monitors bacteria at 14 offshore locations, a mix of ambient and outfall stations, with samples collected from 1 m depth twice monthly most of the year (monthly in January and December). These data are used to determine if sites have chronic bacteria problems and to evaluate how concentrations are changing over time.

Narrative

Annual geometric mean beach bacteria concentrations were spatially variable in 2025, as is typical (Figure 1). However, both *Enterococcus* and fecal coliform annual geometric mean values were generally slightly below the historical (1981-2024) average at all beach monitoring stations except for Des Moines Creek (Figure 2A). Fecal coliform values at this station were slightly elevated above historical values, mostly due to several high values during the rainy season (January–April, November, and December). While bacteria concentrations were low for most of the year, the highest concentration at most stations occurred on December 17th (Figure 2B) after heavy rain and flooding.

As in previous years, 2025 bacteria concentrations offshore were much lower than those at beach stations due to their distance from various sources (e.g., creeks, stormwater and wastewater outfalls, and urban runoff). The offshore stations with the highest bacteria concentrations were those located within Elliott Bay (Figure 1), but geometric means of indicator bacteria at these locations were still low. Unlike beach stations, the highest bacteria concentrations were in January–April and October–November, not in December, as offshore sampling occurred before the heavy rains.

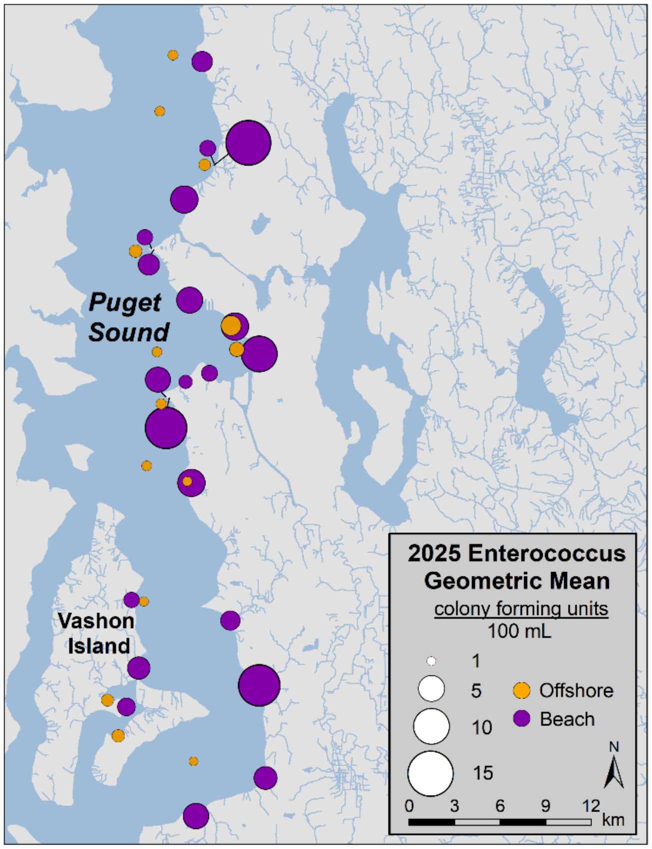
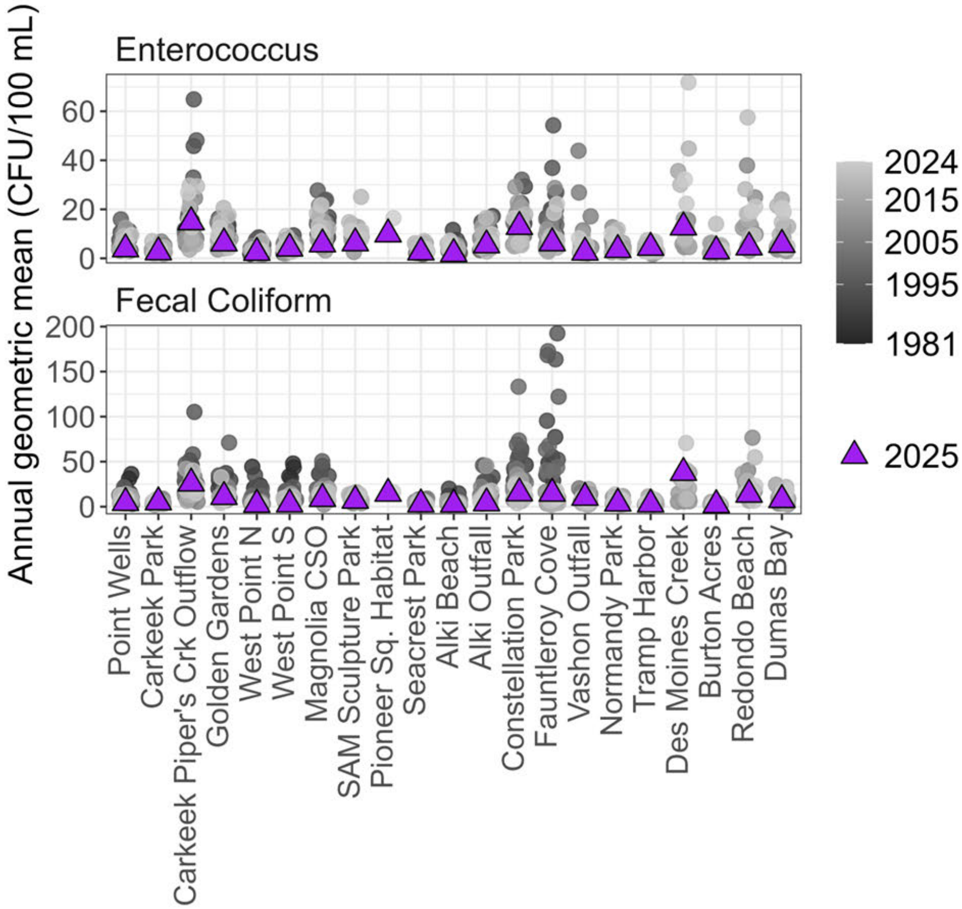


Figure 1. Annual geometric mean Enterococcus *concentrations.*

Title: Central Basin Bacteria Monitoring
Authors: Eash-Loucks, Martin, Ikeda

A.



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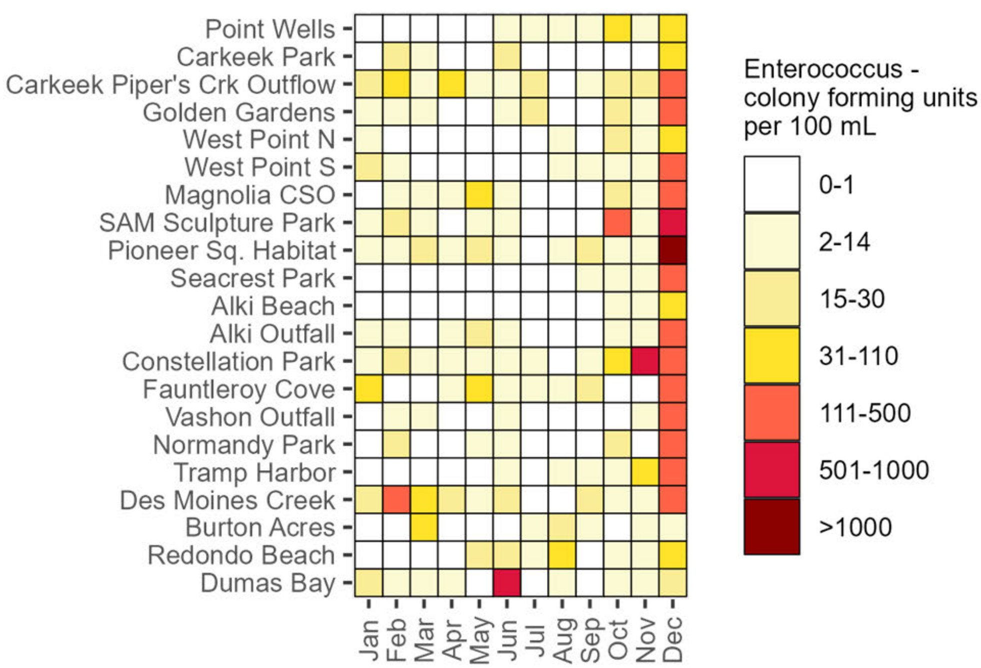

Figure 2. A) Annual geometric mean concentrations of indicator bacteria at beaches. 2025 values shown in purple and older data are shown in a grayscale gradient by year. Note the difference in scales. B) Enterococcus *concentrations at beach sites by month.*

Vibrio spp. Surveillance

Author: Elizabeth Lorence (Washington Department of Health, Elizabeth.Lorence@doh.wa.gov)
Edited by: Tracie Barry
Website: https://doh.wa.gov/community-and-environment/shellfish

Highlights

- In 2025 there were a total of 67 laboratory confirmed *Vp* illnesses from commercially harvested oysters.
- 12 illness were reported in September of 2025.

Overview

Vibrio are a genus of bacteria that occur naturally in marine and estuarine environments and are generally present in higher concentrations as water temperatures increase. In the United States, *Vibrio* species are responsible for most seafood related gastrointestinal illnesses. *Vibrio* populations grow faster at higher temperatures; therefore, most infections occur between May and October. In Washington, *Vibrio parahaemolyticus* (*Vp*) and *Vibrio vulnificus* (*Vv*) levels were monitored in oyster tissue during those warmer months. As waters begin to heat up, we would see increasing levels of both *Vp* and *Vv*, although no enteric *Vv* illnesses have been reported yet in Washington. Though our *Vibrio* monitoring program is no longer active, we still track, record, and report confirmed *Vibrio* illnesses from shellfish. The Washington State Department of Health employs three regulatory strategies to control *Vibrio*-related illnesses: require the commercial industry to cool oysters to 50°F after harvest; set temperature thresholds to limit harvest on the hottest days; and close growing areas to oyster harvest when illnesses occur.

Narrative

The *Vibrio* control season (May 1-Sept 30) 2025 was an active one, 67 total confirmed *Vp* illnesses were from commercially harvested oysters and 3 were from recreational harvest (Figure 1). In the 2025 control season, there were 31 laboratory-confirmed commercial, single-source illnesses from consumption of oysters contaminated with *Vp*, this is one more single source case than the 2021 heat dome year, and the most since 2018. 36 commercial multi-source illnesses were logged: 24 were traced back to multiple Washington growing areas and 12 were traced back to multiple Washington growing areas, other states and/or countries. There was one partial closure of Totten Inlet growing area, due to 5 confirmed *Vp* cases within 30 days (harvest dates 7/21-8/15/2025).

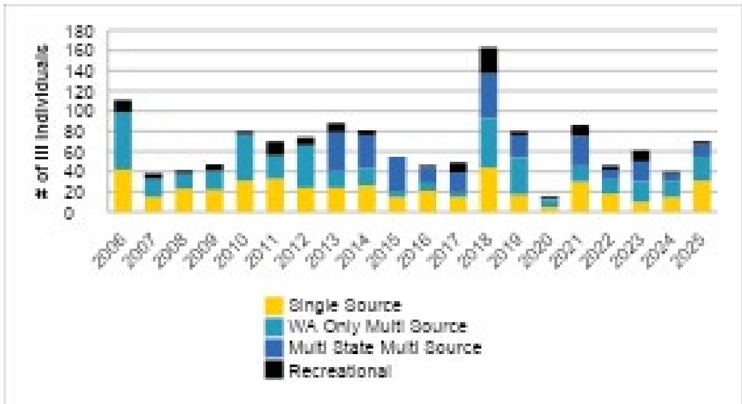

Figure 1. Confirmed (Vp) illnesses from oyster consumption, for both commercially and non-commercially harvested oysters.

From May to September 2025, illnesses were above the 5-year average every week except from June 16-30 and July 1-15, where they remained at or below average and peaking July 16-31. Additionally, in September 2025, Washington State experienced usually dry and warm conditions, which moved water temperatures to 1°- 4°F above average across the western part of the state. WADOH saw an increase in illnesses through the month of September. Double the confirmed illnesses were recorded in September 2025 as compared to the previous 5 years. (Figure 2).

Single-source Illness – *can be traced back to a single growing area*. Multi-source Illnesses –*cannot be traced back to a single growing area; case consumed or could have consumed oysters from 2 or more growing areas.* Confirmed illness – *Vp positive stool culture and epi-linked illnesses with no documented post-harvest abuse.*

Title: *Vibrio spp*. Surveillance
Author: Elizabeth Lorence

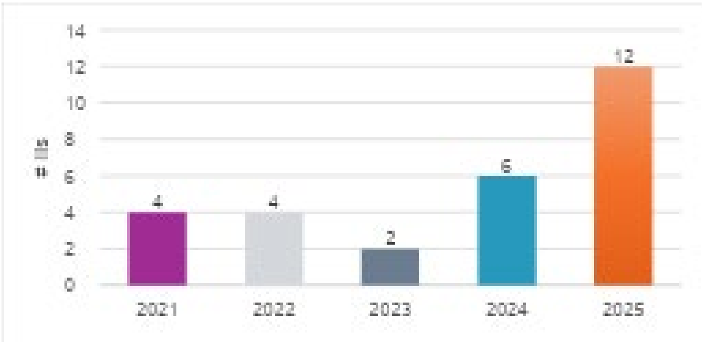

Figure 2. Confirmed Vp illnesses in September from WA shellstock by year 2021-2025

Oysters on beach

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3. KUOW News Stories & Environment. Ryan, John. (2025, October 9). “Return of the Blob: Heat wave spans Pacific Ocean.”

7

Forage fish

Estimated Spawning Biomass of Puget Sound Herring

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Edited by: Jamey Selleck, Natural Resources Consultants
Website: https://wdfw.wa.gov/fishing/management/marine-beach-spawning#herring;
Additional website for data: https://vitalsigns.pugetsoundinfo.wa.gov/VitalSignIndicator/Detail/36

Highlights

- Estimated Spawning Biomass (ESB) declined again from 11,404 mt to 8,862 mt.
- Spawning observed at Cherry Point for first time in 3 years.
- Late season spawning documented in Oro Bay.

Overview

Forage fish are a vital component of the marine food web, as they are prey throughout their life cycle for many fish, birds, and mammals. Pacific herring (*Clupea pallasii*) are the most studied forage fish and are an indicator species of Puget Sound health. The Washington Department of Fish and Wildlife (WDFW) monitors about twenty-one herring spawning areas in Puget Sound using surveys of eggs deposited on submerged aquatic vegetation. Although studies of herring genetics in Puget Sound are ongoing, some stocks of herring, such as the Cherry Point stock, have been identified as genetically unique, and there is evidence of a genetic link to spawn timing (Petrou et al., 2021).

Narrative

The Estimated Spawning Biomass (ESB) of herring in Puget Sound declined from 11,404 metric tons (mt) in 2024 to 8,862 mt in 2025, the 6th lowest estimate on record (Figure 2). Most of the spawning biomass continued to be concentrated in only a few areas, with over 70% of the total ESB occurring at three sites; Port Orchard/Port Madison, Carr Inlet (Figure 1), and Semiahmoo Bay, with over 1,000 mt at each location.

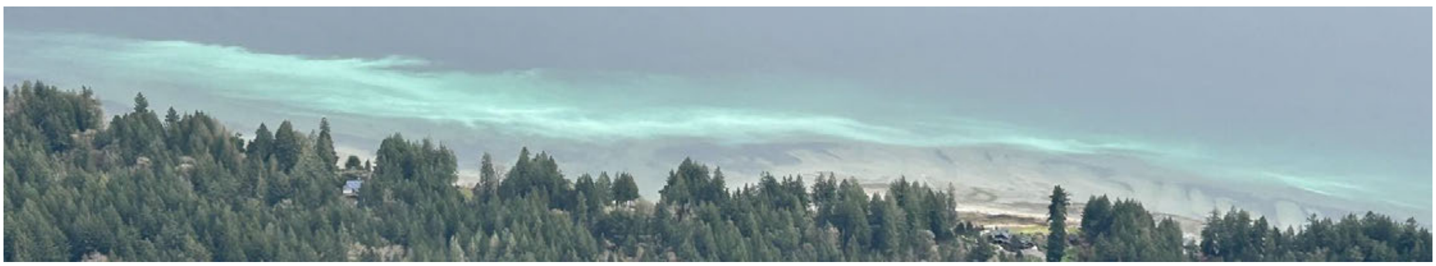

Figure 1: Aerial image of herring spawning event (white water) during 2025 season in Carr Inlet. Photo courtesy of WDFW Shellfish.

After two years of failing to detect spawning at Cherry Point, we were relieved to document spawning again in 2025. The Cherry Point spawning biomass was small but provides evidence that the Cherry Point herring have not entirely disappeared. We were also very excited to confirm herring spawning for the first time in Oro Bay, at Anderson Island in South Sound. The Oro Bay spawning biomass was also small, but notable because of its timing. The spawning observed in Oro Bay was the latest observed anywhere in Puget Sound during the 2025 season; even later than Cherry Point, which has historically been the latest spawning herring stock in Puget Sound.

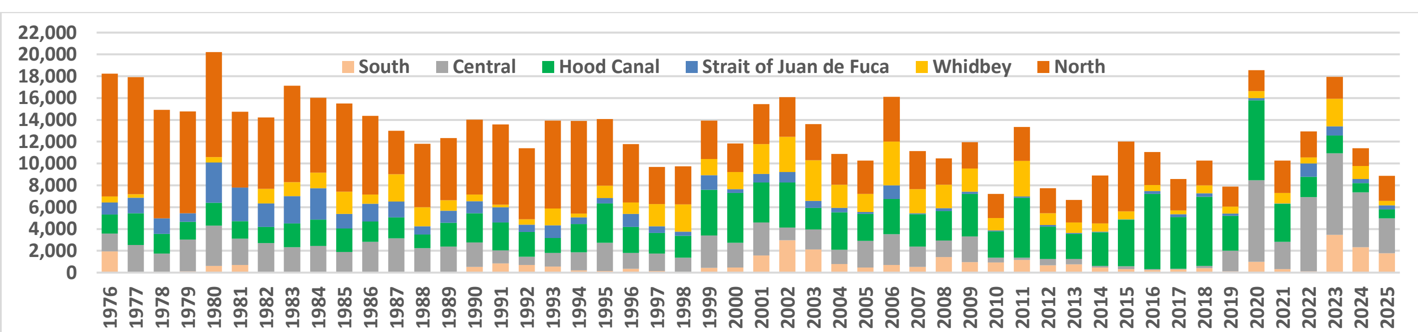

Figure 2: Annual estimated spawning biomass in metric tons, 1976 through 2025. The bar colors represent basins in Puget Sound.

Early Marine Survival and Marine Diet of Juvenile Chinook

Authors: Russel Barsh (Kwiaht, russel@kwiaht.org); Madrona Murphy (Kwiaht), Sophie Citro (Kwiaht)
Edited by: Jamey Selleck (Natural Resources Consultants)
Website: www.kwiaht.org

Highlights

- Early marine survival of Puget Sound-origin Chinook has remained low since 2014.
- These salmon have been eating fewer Pacific sand lance since but about the same amount of Pacific herring. This may indicate a decrease in sand lance populations.

Overview

Juvenile Chinook outmigrants are monitored by biweekly summer beach seines at two stations in the San Juan Islands: Watmough Bay (Lopez Island) and Cowlitz Bay (Waldron Island). Puget Sound-origin Chinook are best represented at the Watmough station, which is close to Admiralty Inlet, while Fraser-origin Chinook dominated samples from Cowlitz (Chamberlin et al., 2017), making it possible to compare the health of these two populations.

Narrative

Sampling is conducted each year from May to September using a 120-foot modified Puget Sound beach seine. Catch per seine set is used as a measure of abundance. A total of 10,797 juvenile Chinook outmigrants have been brought to hand since 2009 (Figure 1).

Unmarked Chinook brought to hand are subjected to nonlethal gut lavage, expressing the contents of their stomachs without harming the salmon. Gut contents of 4,774 Chinook have been identified thus far. On average, their diet in the San Juan Islands has been 77.4% larval and juvenile Pacific herring and Pacific sand lance, 1.3% other fishes, and the remainder marine and terrestrial invertebrates.

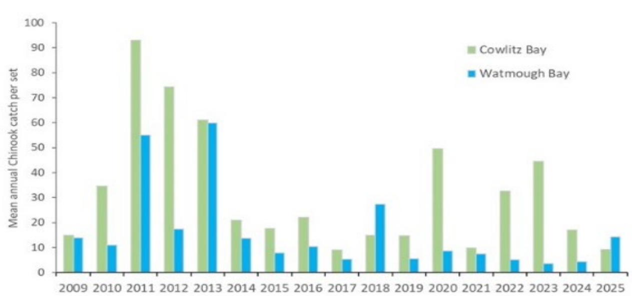

Figure 1. Mean annual catch per seine set of juvenile Chinook outmigrants at stations in the San Juan Islands 2009-2025.

Consumption of Pacific sand lance and total forage fish was generally greater at Watmough Bay than at Cowlitz Bay. Sand lance consumption at Watmough Bay declined relative to Pacific herring since the marine heat wave of 2014-2015 (Figure 2), resulting in an 18 percent decrease in total forage fish biomass by unmarked juvenile Chinook sampled at that location.

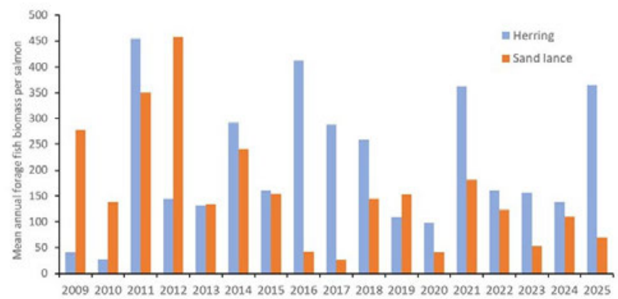

Figure 2. Mean annual consumption of forage fish biomass by juvenile Chinook outmigrants at Watmough Bay.

These data suggest that early marine foraging of Puget Sound-origin Chinook may be influenced by changes in Pacific sand lance availability. Sand lance feed on zooplankton, which have also experienced shifts in species composition in the past decade.

Gut contents of 578 Pacific sand lance collected by beach seine at Watmough Bay from 2018 to 2020 were dominated by larger calanoid copepods (*Eucalanus* spp. and *Neocalanus* spp.), larvaceans (*Oikopleura* spp.), and large diatoms (*Coscinodiscus centralis*), which comprised 77 percent of total prey biomass. These taxa also comprised roughly a third of prey biomass collected from Pacific herring at the same site, suggesting possible competition for high-value zooplankton prey.

References

Chamberlin, Gamble, Connelly, Gardner, Barsh, Keister, Beauchamp, Schmidt, Beckman, and Warheit. 2017. Assessing early marine growth in juvenile Chinook salmon: factors affecting variability in individual growth in Northern Puget Sound. Salish Sea Marine Survival Project. Available online: https://marinesurvivalproject.com/resources/

Beach on Whidbey Island. Photo: Rachel Wold

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