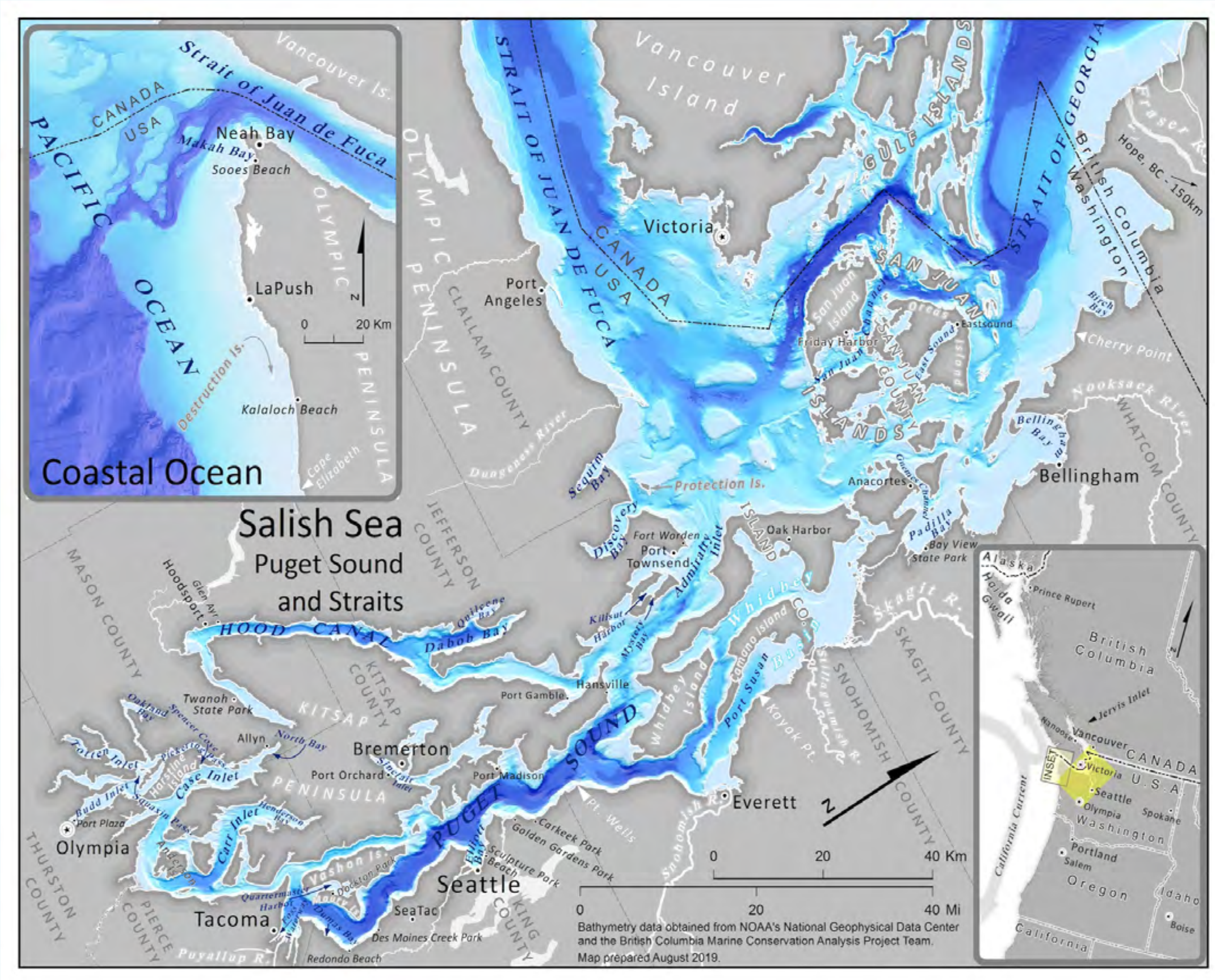
puget sound marine waters

2024 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: Ebey's Landing, Whidbey Island. Photo: Sylvia Kantor/PSI

Citation and contributors

Editors

Jude Apple, Rachel Wold, Kimberle Stark, and Jan Newton

Contributors

Alex Fisher
Alex Marquez
Ally Galiotto
Adrienne Sutton
Amanda Winans
Anna Boyar
Becca Guenther
Blair Winnacott
Cheryl Greengrove
Christopher Ikeda
Christopher Jendrey
Christopher Krembs
Claire Cook
Dan Sulak
Devynn Gately
Elizabeth Lorence
Emily Buckner
Emily Seubert
Emma LeValley
Erin Jaco
Greg Ikeda
Heath Bohlmann
Heather Earle
Holly Young
Jan Newton
Jennifer Blaine
Jerry Borchert
John Mickett
John Zalusky
Jude Apple
Julia Bos
Julie Masura
Karen Chan
Karin Bumbaco
Kat Barlow
Kimberle Stark
Lyndsey Swanson
Madrona Murphy
Margaret Homerding
Matilda Twigg
Melissa Petrich
Michelle Lepori-Bui
Mikayla Mayes
Natalie Coleman
Nicole Burnett
Nick Bond
Olga Kalata
Peyton Scheschy
Phill Dionne
Richard Feely
Russel Barsh
Sarah Grossman
Seth Travis
Simone Alin
Suzan Pool
Sylvia Yang
Tracie Barry
Wendy Eash-Loucks

Recommended citation

PSEMP Marine Waters Workgroup. 2025. Puget Sound marine waters: 2024 overview. J. Apple, R. Wold, K. Stark, and J. Newton (Eds).

Available: www.psp.wa.gov/PSmarinewatersoverview.php

Contact email: marinewatersoverview@gmail.com

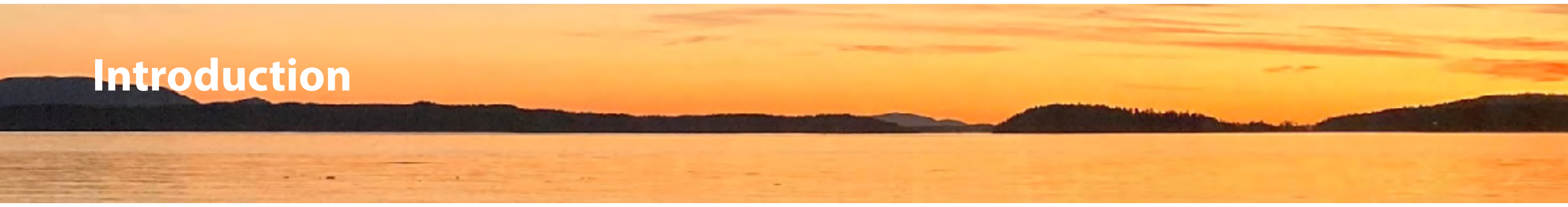
Contents

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 information about PSEMP and the Marine Waters Workgroup, please visit the PSEMP website.



Introduction

This Marine Waters Overview provides a perspective of 2024 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 fourteenth 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

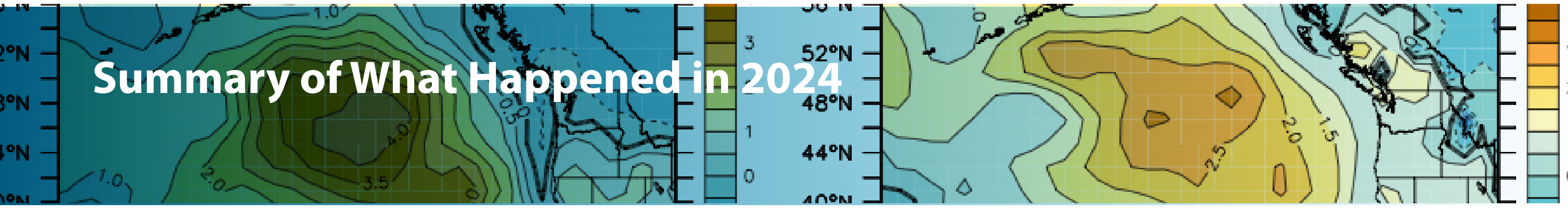
Our objective is to collate and distribute the valuable physical, chemical, and biological information obtained from various marine monitoring and observing programs in Puget Sound. Based on mandate, need, opportunity, and expertise, these efforts employ different approaches and tools that cover various 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 2024.

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 2024.

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 (http://www.nanoos.org).

The Canadian ecosystem report, The State of the Pacific Ocean Technical Reports (https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2024/pac-technical-report-rapport-technique-eng.html) provides a companion overview of monitoring and marine conditions in Canadian waters, covering approximately 102,000 km^2 from the edge of the continental shelf eastward to the British Columbia mainland, and includes large portions of the Salish Sea. This annual report provides information that is relevant to understanding marine conditions across the Salish Sea and is a recommended source of complementary information to the Marine Waters Overview report.



Summary of What Happened in 2024

This year, facing a lack of funding to produce the 2024 edition of the Marine Waters Overview, caused me to ponder the end of our annual workshop where we share scientific results and key take-home messages. A summary of 2024 that I penned that day goes like this:

Warm, salty, lowish DO
early phyto, then no mo' (August)
compared to average, zooplankton below, herring below,
San Juan marine mammals below.
Many challenges — Chinook holds a clue? upwelling too?
probably coupling and phenology could too?
A successful Overview depends on you!

Benefiting from the additional insights presented over the following pages, below are a few more words to elaborate that poetic story.

Large-scale climate patterns and local weather were unsensational on an annual basis but do not tell the full story. 2024 transitioned from strong El Niño to weak La Niña while the Pacific Decadal Oscillation favored cooler conditions for the fifth year in a row. However, summer was warmer than normal, with the 3rd warmest July on record as well as a warm December. Almost half of the 39 confirmed Vibrio parahaemolyticus illnesses from consuming commercially harvested oysters occurred in early to mid-July during the unusually warm air temperatures.

While annual precipitation was near normal, it was composed of five months of below normal precipitation balanced by four months of above normal precipitation. As a result of lower than normal precipitation in the spring, a drought emergency was issued in mid-April for most of the state. Upwelling winds on the coast, which started early and were steady, were associated with cooler coastal waters that were saltier and had lower dissolved oxygen levels at depth. An unusually strong weather system, a 'bomb cyclone' intensified off the WA coast in November that resulted in powerful winds off the coast and in Puget Sound.

A regional standout was the historically low river flow to Puget Sound. This reduced the estuarine exchange (by up to 40%) as well as the decreasing density stratification (layering) of the marine waters, described as weak and disjointed. Stratification affects phytoplankton bloom timing, mixing of the water column, and other processes.

The observed climate patterns would seem to select for cooler and saltier waters with lower dissolved oxygen. Yet observations throughout the Sound showed warmer than average temperatures, that were saltier and with lower dissolved oxygen. Puget Sound is retentive of its waters at the mixing sills, such as Admiralty Inlet. This may have led to heat being retained. This mechanism also may have retained an oxygen debt, since, oddly, the stronger mixing associated with less stratification would tend to mix away low oxygen zones. Early and large phytoplankton blooms may have also contributed to an oxygen debt, though the bloom season ended early, in August, in many areas this year.

Early blooms did not appear to result in more zooplankton biomass, as it was generally lower than the monthly averages observed from the last decade. Similarly for early spawning herring stocks in the southern Salish Sea, which declined in most areas and remained concentrated in just a few spawning areas. No spawning activity was observed at Cherry Point for the 2nd year in a row, and biomass in Port Gamble fell below a 100 metric ton threshold for the first time since monitoring began in 1976. While fall time seabird density in the San Juan Channel/Strait of Juan de Fuca was the highest in the >20 year record, marine mammal density was the lowest.

The data presented here by the participants hold many clues, but must be further analyzed in order to reveal the relationships and factors causing the observed variation. This data collection truly is an underutilized treasure, that if further synthesis analysis were funded, could unlock useful information for informed stewarding of the Salish Sea. While the Overview participants stepped up in 2024 to do what was needed to assemble this report without funded effort, the editors know there is so much more to be understood.

By Jan Newton, with input by the Editorial Team

Highlights from 2024 Monitoring

Large-scale climate variability and wind patterns

- The tropical Pacific featured a transition from strong El Niño to weak La Niña conditions in 2024.
- The Pacific Decadal Oscillation (PDO) was negative during 2024, for the fifth year in a row. The PDO minimum in October was the most negative value since 1955.
- A deep low-pressure system ("bomb cyclone") intensified off the Washington Coast on November 19 resulting in strong winds in coastal and inland waters.

Local climate and weather

- Annually, Puget Sound air temperatures were near-normal for 2024 (+0.4°C), similar to 2023. However, consistent with the previous two years, summer was warmer than normal with July ranking as the 3rd warmest July since records began in 1895. December was also warmer than normal, the 10th warmest on record.
- Annually, Puget Sound total precipitation was near-normal for 2024, with five months of below normal precipitation balanced by four months of above normal precipitation.
- February through early spring were drier than normal with March and April together ranked as the 25th driest March-April period since records began. As a result, a drought emergency was issued in mid-April for nearly all of Washington State. August was the 22nd wettest on record in contrast to below normal precipitation 2016-2023 and December was also wetter than normal.

Coastal ocean and Puget Sound boundary conditions

- Upwelling winds on the Washington Coast started early and were steady, in contrast to 2022 (weak and late) and 2023 (strong, early-spring downwelling).
- With the onset of steady upwelling winds, deep water rapidly cooled by a degree in May and remained ~1 °C below 2023 and ~0.5 °C below average until November.
- Summer surface temperature on the Washington Coast was cooler, and surface salinity was higher than average.
- Unlike 2023, deep dissolved oxygen (DO) on the Washington Coast in 2024 was low, often hypoxic (<2 mg/L) from early to mid-August until fall storms mixed this away.
- The November 19-20 "bomb cyclone" induced rapid downwelling on the Washington Coast and mixed the full water column, rapidly increasing deep temperature and DO and rapidly decreasing salinity.

River inputs

- Model estimates (Salish Sea and Columbia River Operational Forecast System) suggest that historically low river flows may have reduced the estuarine exchange flow by as much as 40% in Puget Sound.

Water quality

Temperature

- Throughout 2024, Puget Sound waters were warmer than normal with November 2023-April 2024 depth-averaged temperature anomalies exceeding 1oC at many locations. Warm water temperature anomalies persisted in Hood Canal and the Whidbey Basin for most of 2024 and in Puget Sound overall, January-October was the 3rd warmest since 1999.
- Water temperature in the Central Basin has remained anomalously warm since mid-2023, with some record high 2024 surface temperatures in July and near record-high in January and December. January and December temperature anomalies were observed at almost all depths.
- During fall 2024, warmer surface water temperatures were observed at both North and South stations in the San Juan Channel/Strait of Juan de Fuca.
- Padilla Bay daily mean water temperatures throughout 2024 were generally warmer than pre-2015 long-term daily means and spring temperatures were warmer than the 2017-2023 mean.
- Padilla Bay annual average water temperature in 2024 was much warmer compared to the pre-2015 long-term anomaly record, but similar to more recent years post-2016.
- In the Whidbey Basin, water temperature inversions (warmer, deeper waters than the surface) were observed in the winter months.

Salinity and water column structure

- In all basins, salinity was higher than normal and likely due to reduced river and rainfall input. This continues a several-year trend of higher salinity that results in higher density, reduced stratification, and increased mixing. Relatively weak and disjointed stratification was observed in the Central Basin as a result of higher-than-normal salinities.
- Northern stations in the Whidbey basin showed more mixing, induced by strong flow through Deception Pass, and less variability compared to those in the south, which showed greater Skagit River influence.
- Surface salinities in the northern Whidbey Basin at Little Hope showed a broad seasonal range with prolonged periods of freshening attributed to storm events.

- Saltier surface and deep waters at station North and South in the San Juan Channel/Strait of Juan de Fuca were observed in the fall.

Nutrients

- Several nutrient concentrations and ratios (e.g., nitrate, phosphate, N:P, SiOH:DIN) in Puget Sound exhibit interdecadal cycles, with SiOH:DIN declining due to falling silicate levels.
- Nitrite in Puget Sound is strongly correlated with both SiOH:DIN (negative) and the North Pacific Gyre Oscillation (positive), linking regional nutrient trends to large-scale oceanographic patterns.
- Surface nitrate+nitrite-N in the Central Basin was low during phytoplankton blooms but never below detectable levels at any location, including Quartermaster Harbor, an unprecedented occurrence.
- Central Basin average monthly nitrate+nitrite-N and silica in deep waters (>150 meters) were lower than the monthly baseline (1997-2013) for most of 2024. Average monthly silica in surface waters at East Passage has been mostly below the baseline since mid-2022.

Chlorophyll

- After a 20-year decline, chlorophyll *a* concentrations in Puget Sound began to increase in 2022.
- The spring phytoplankton bloom in the Central Basin occurred earlier in 2024 than the past several years, around April 1. The season ended after August 19 following significant rain events. Chlorophyll a peaks and troughs corresponded well with density stratification patterns and overall, Central Basin annual chlorophyll a was lower in 2024 than the prior two years.

Dissolved oxygen (DO)

- Modest dissolved oxygen (DO) anomalies were observed in most basins, alternating between periods of positive and negative anomalies. Widespread negative DO anomalies were observed in the winter and spring, while anomalies switched to weakly positive during the late fall.
- DO in the Central Basin was below normal for most of the year except June-August, with some record lows in Quartermaster Harbor.
- Hypoxia was observed at Twanoh (southern Hood Canal) in late summer at depths greater than 10m, before modulating but staying low to the end the year.
- DO values as low as 3.5 mg/L in the Whidbey Basin were seen at depth in late fall and winter.

Ocean and atmospheric CO2

- Monthly average atmospheric CO2 levels on the outer coast were 0–7 ppm higher than the globally averaged marine surface air in 2024 and monthly coastal surface seawater xCO2 averages were above average during October–December, when most 2024 coastal mooring observations occurred.
- Compared to the historical record, coastal mooring sites ranged from being a weaker sink than average to a stronger sink than average during September–December 2024.
- Atmospheric CO2 in Hood Canal averaged 12–13 ppm higher than the globally averaged marine surface air, with larger differences in fall–winter (14–20 ppm) than spring–summer (6–12 ppm) when regional primary production reduces the offset.
- Surface seawater xCO2 averages in Hood Canal were mostly within historical ranges at both sites, but were substantially higher at both sites in January and lower at Dabob in March than long-term means, resulting in a stronger than normal CO2 source to the atmosphere in January and stronger sink than normal in March of 2024.
- Puget Sound subbasins have exceptionally wide ranges of carbonate chemistry, with the most extreme values in Hood Canal and Whidbey Basin.
- Since 2014, the strongest biogeochemical anomalies in Puget Sound were observed in 2015–2017, with no major anomalies during 2019–2024.
- In 2024, Puget Sound acidification and oxygen conditions were somewhat more stressful than normal overall in stratified basins, and somewhat better than normal in surface waters of well-mixed basins during July.

Plankton

Phytoplankton

- In 2024, the most frequently reported blooms throughout Puget Sound were diatoms in the genera Chaetoceros, Rhizosolenia/Sundstroemia, and Ditylum.
- The largest observed microplankton bloom in the Central Basin occurred in June, consisting mainly of the chain-forming diatoms Chaetoceros, Ditylum, and Rhizosolenia.
- The dinoflagellate Heterocapsa bloomed in record high abundances throughout the Central Basin in April, with the highest abundances in the northern region.
- In Whidbey Basin, a large basin-wide Heterocapsa bloom was seen in April, concurrent with a similar bloom in Central Basin. Large blooms of Eucampia, Alexandrium, and Asterionellopsis were observed late summer and fall in Penn Cove.

Harmful algae and biotoxins

- Marine biotoxins that cause Paralytic (PSP), Diarrhetic (DSP) Shellfish Poisoning caused 20 commercial and 30 recreational shellfish harvest closures along the Pacific Coast and in Puget Sound. PSP reached lethal levels (≥ 1,000 µg/100g tissue) on the Coast, Strait of Juan de Fuca, North and Central Sounds, and Whidbey Basin. There were no ASP/domoic acid closures in 2024.
- An unprecedented PSP event (caused by Alexandrium) affected the Pacific Coast in May that sickened several people in OR and WA and caused the first commercial shellfish closure in Willapa Bay since 1997. In response to the PSP event, a special survey found Alexandrium cysts in surface sediments of Willapa Bay and Grays Harbor to provide early warning of potential future blooms for shellfish growers.
- Within Puget Sound, Alexandrium observations peaked about a month later than previous years.
- Several notable cockle mortalities occurred in July. Shellfish tissue from Point Julia in northern Hood Canal tested positive for the presence of yessotoxins which are produced by Protoceratium and a few other genera.
- Karenia was observed at higher than normal frequencies on the Pacific Coast during the summer.

Zooplankton

- In 2024, mesozooplankton total biomass in Puget Sound (including the San Juan Islands) was generally lower than the monthly averages observed from 2014 to 2023.The timing of peak mesozooplankton biomass was mostly within the expected window or occurred earlier.
- There was less zooplankton in Padilla Bay compared to previous years, except in the fall when total abundances were higher. Zooplankton community composition in Padilla Bay deviated from the normal composition in both April and October.
- Dungeness crab megalopae abundance was highest in the central Salish Sea region, with decreasing abundance to the north and south.
- Megalopal abundance was moderate in 2024 compared to previous years, with regional variations in timing and peak larval flux.

Bacteria and pathogens

- Fecal indicator bacteria concentrations at beaches in the Central Basin were generally low to average compared to the historical record with few exceptions. Fecal indicator bacteria concentrations in offshore waters were low as in previous years.
- In 2024 there were a total of 39 laboratory confirmed Vibrio parahaemolyticus (Vp) illnesses from commercially harvested oysters. A record-breaking heat wave occurred around the first week of July, and 48.7% of confirmed Vp illnesses were related to commercial oysters harvested between 7/2-7/16/2024.
- Twelve samples from three different sites had detectable levels of Vibrio vulnificus (Vv), although no illnesses were reported.

Fish

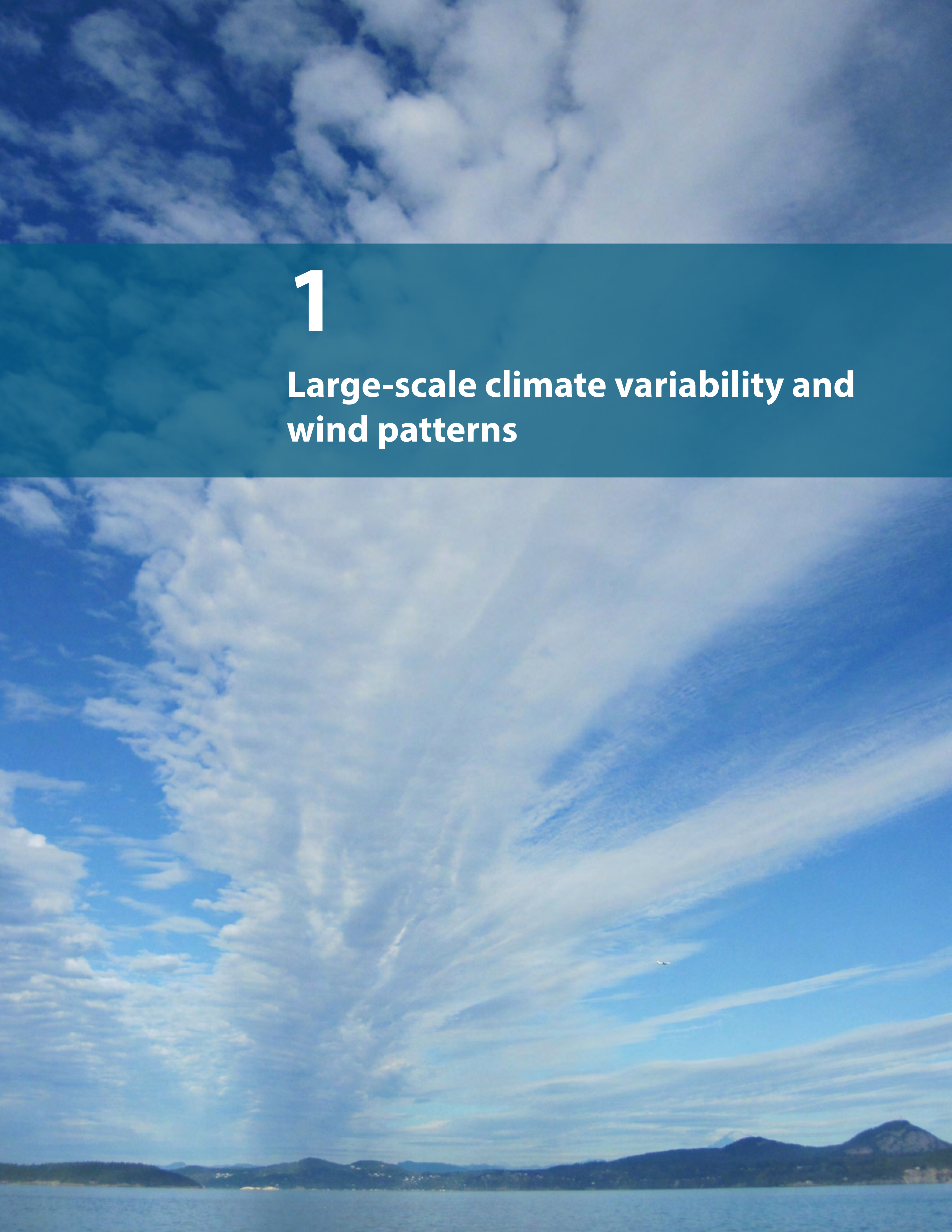
- Most bottomfish species groups in the Salish Sea were within range of 5-year means for biomass and abundance estimates, with the exception of codfish abundance which was below the 5-year mean.
- Estimated Spawning Biomass (ESB) of herring in the southern Salish Sea dropped to 11,404 metric tons (mt), but was still within 500 mt of the 10-year average. The ESB of herring in the southern Salish Sea declined in most areas and remained concentrated in just a few spawning areas.
- No herring spawning activity was observed at Cherry Point for the 2nd year in a row, and the ESB in Port Gamble fell below 100 mt for the 1st time since monitoring began in 1976.
- Early marine survival of juvenile Puget Sound-origin Chinook salmon in the San Juan Islands has remained low since 2014. These salmon are also eating fewer forage fish.
- Fraser River-origin Chinook salmon in the San Juan Islands did a little better in response to cooler 2019-2024 conditions than Puget Sound-origin Chinook. They are eating as much forage fish as they did 15 years ago.

Marine mammals and birds

- During fall, seabird densities in the San Juan Channel/Strait of Juan de Fuca were the highest on record, mainly due to the abundance of Common murres. In contrast, marine mammal abundance has been decreasing since 2013 with 2024 having the lowest density on record.

Technical Summaries

Zooplankton sampling. Photo: Christopher Krembs



1

Large-scale climate variability and wind patterns

North Pacific Climate in 2024

Authors: Nicholas Bond, Washington State Climate Office/Climate Impacts Group (CIG)/University of Washington (UW), nab3met@uw.edu
Edited by: Karin Bumbaco
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**
> - The tropical Pacific featured a transition from strong El Niño to weak La Niña conditions in 2024.
> - The PDO was negative during 2024, for the fifth year in a row.

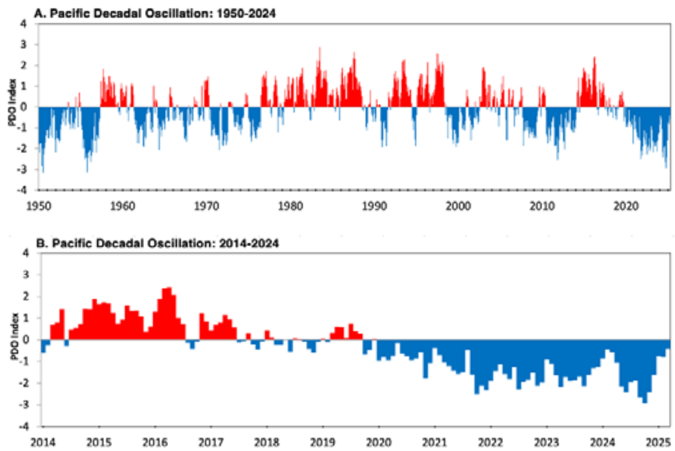
Narrative

A. El Niño-Southern Oscillation (ENSO)

The central and eastern tropical Pacific Ocean cooled over the course of 2024 following El Niño conditions that peaked near the end of 2023. The Oceanic Nino Index (ONI) reached a three-month minimum of -0.6 in January 2025, which barely reaches the threshold of a weak La Niña. That may help explain why the period of October through December of 2024 included a weather pattern uncharacteristic of La Niña that featured lower than normal sea level pressure (SLP) over the Northeast Pacific Ocean north of 35°N. There has been a preponderance of La Niña versus El Niño events during the last two decades; it is uncertain whether this is just a fluke due to random variability, or more reflective of a systematic shift in the tropical Pacific's coupled atmosphere-ocean system.

B. Pacific Decadal Oscillation (PDO)

The PDO was negative during 2024, decreasing from approximately -0.5 early in the year to a minimum in October of about -2.9. The latter represents the most negative value for the PDO since 1955 (*see figure at upper right*). The negative state of the PDO can be attributed in large part to an area of persistent sea surface temperature (SST) anomalies of +1-2°C between roughly 30°N and 50°N extending from the east coast of Asia across the dateline into the eastern North Pacific; a secondary contribution was made by cooler than normal SSTs in the Gulf of Alaska and southern Bering Sea.



Monthly values of the Pacific Decadal Oscillation (PDO) Index from a) 1950 through 2024 and b) 2014 into 2025

C. Pacific Northwest Offshore Waters

The near-surface waters along the west coast of North America were slightly warmer than normal during the first half of the year (relative to 1991-2020 norms), and near-normal temperatures generally prevailed during the latter portion of 2024. The low-level atmospheric circulation offshore of Washington state produced near-normal downwelling for the winter of 2023-24 as a whole. The mean weather pattern in summer 2024 resulted in slightly weaker than usual upwelling. A deep low pressure system intensified off the Washington coast on 19 November 2024 (see image below), resulting in strong winds in the state's coastal and inland waters.

NASA Earth Observatory Image by Lauren Dauphin

2

Local climate and weather

Decatur and Lopez Islands. 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**
> - Annually, Puget Sound air temperatures were near-normal for 2024 (+0.4°C), similar to 2023.
> - Annually, Puget Sound total precipitation was near-normal for 2024, with five months of below normal precipitation balanced by four months of above normal precipitation.

Overview

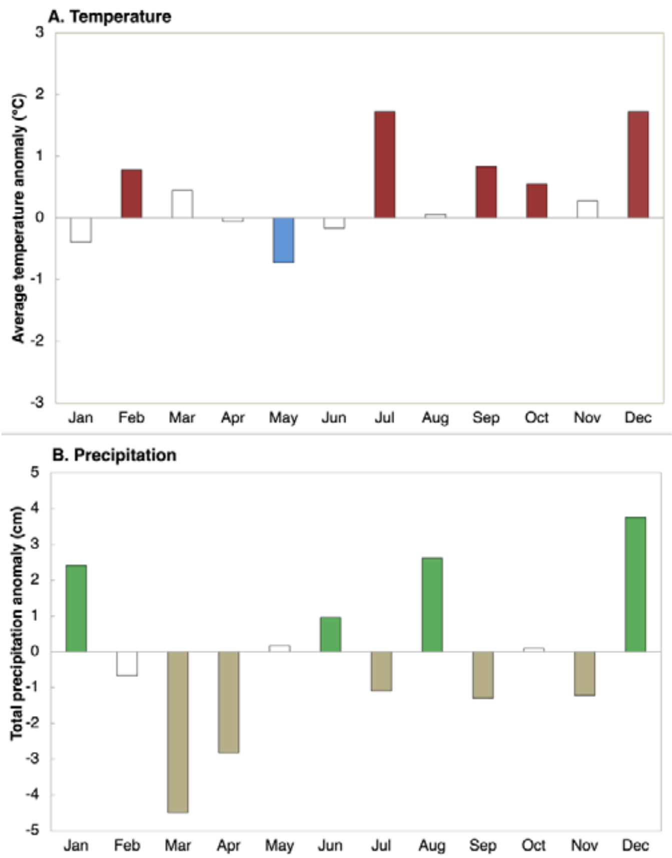
Washington is divided into 10 separate climate divisions based on similar average weather conditions. The following summary uses data from the Puget Sound Lowlands division that encompasses most of Puget Sound.

Narrative

The 2024 Puget Sound annual average air temperature (11.1°C; 52.0°F) was near the 1991-2020 normal (+0.4°C), similar to 2023, warmer than 2018-2022, and cooler than 2014-2016. Total annual precipitation was 112.3 cm (44.23”), which was 99% of normal and similar to 2018.

Monthly values are used to illustrate the variability in the weather during the year. There was less month-to-month temperature variability in 2024 compared to recent years. Figure 1 shows monthly temperature and precipitation anomalies for the Puget Sound region relative to the 1991-2020 normal.

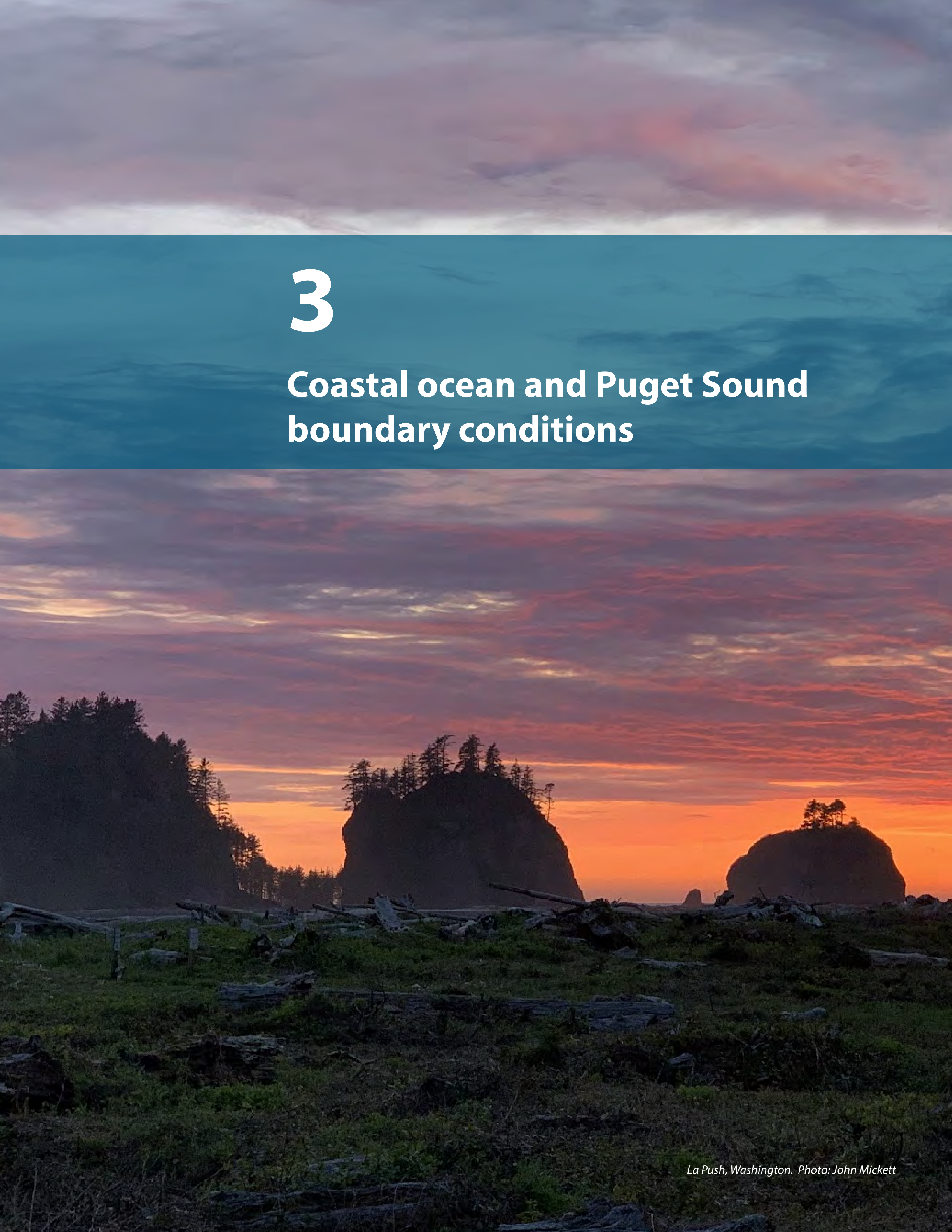
January was wetter than normal, but the remainder of the winter and early spring was drier than normal. March and April received only 63 and 70% of normal precipitation, respectively, and together ranked as the 25th driest March-April period since records began in 1895. As a result of this below normal spring precipitation and a significant atmospheric river heavy rain event at the end of January that melted accumulated mountain snow, spring snowpack was below normal. Averaged statewide, the April 1 snowpack was only 69% of the 1991-2020 median. In mid-April, a drought emergency was issued for nearly all of Washington State. Consistent with the previous two years, summer was warmer than normal. July was a particularly warm month, ranking as the 3rd warmest July since records began. August was wetter than usual, ranking as the 22nd wettest August. This was in contrast to the August months of 2016 through 2023, during which precipitation was below normal. The August precipitation reduced some of the anticipated drought impacts statewide. The start of fall (September-November) was relatively warm and dry. Finally, the last month of the year was quite warm relative to normal, ranking as the 10th warmest December since 1895, and was also wetter than normal (123% of normal).



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 2024 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.

3

Coastal ocean and Puget Sound boundary conditions



La Push, Washington. Photo: John Mickett

Northwest Washington Coast water properties

Authors: John Mickett (University of Washington – Applied Physics Laboratory (UW APL), jmickett@apl.uw.edu); Jan Newton (UW - APL), Seth Travis (UW - APL)
Edited by: Alex Fisher (WA-ECY) and Kimberly Stark (King County)
Website: https://www.nanoos.org; **Additional website for data**: https://nwem.apl.washington.edu

Highlights

- Upwelling winds started early and were steady, in contrast to 2022 (weak and late) and 2023 (strong, early-spring downwelling).
- With the onset of steady upwelling winds, deep water rapidly cooled by a degree in May and remained ~1 °C below 2023 and ~0.5 °C below average until November.
- Summer surface temperature was cooler, surface salinity was higher than average.
- Unlike 2023, deep dissolved oxygen (DO) was low, often hypoxic (<2 mg/L) from early to mid August until fall storms mixed this away.
- The November 19-20 ”bomb cyclone” induced rapid downwelling and mixed the full water column, rapidly increasing deep temperature and DO and rapidly decreasing salinity.

Overview

Since 2010, the Northwest Association of Networked Ocean Observing Systems (NANOOS) and the University of Washington (UW) have maintained a large surface mooring, C̀háʔba·, and a nearby subsurface profiling mooring, NEMO-subsurface, on the Northwest Washington shelf to collect oceanographic and meteorological data. These observations give insight into boundary condition changes for Puget Sound. In addition to providing invaluable offshore context for Salish Sea changes, in 2024 the C̀háʔba·winter mooring collected unique and valuable observations highlighting the outsized and rapid impact of a series of fall storms, including the 19-20 November “bomb cyclone” on shelf dynamics and water properties.

Narrative

In contrast to the largely warmer-than-average conditions throughout much of the water column during 2023, shelf observations from 2024 showed cooler-than-normal water throughout most of the year (Figure 1). This cool anomaly started with the onset of upwelling winds over the first several weeks of May, when deep water rapidly cooled by about 1 °C –erasing the warm anomaly that lingered through the previous winter. After this rapid cooling, deep temperatures remained about 0.5 °C below normal until November, when a series of strong storms, including the November 19-20 bomb cyclone, induced strong downwelling and vigorous vertical mixing, bringing fresher, warmer surface water to near-bottom depths (Figure 2a,b).

At the surface, over the May-September upwelling season, temperature was cooler than normal by about 0.5 °C and salinity saltier than normal by about 0.5 psu (Figure 3a,b)–anomalies that were likely related to the stronger and steadier upwelling winds in 2024 (not shown).

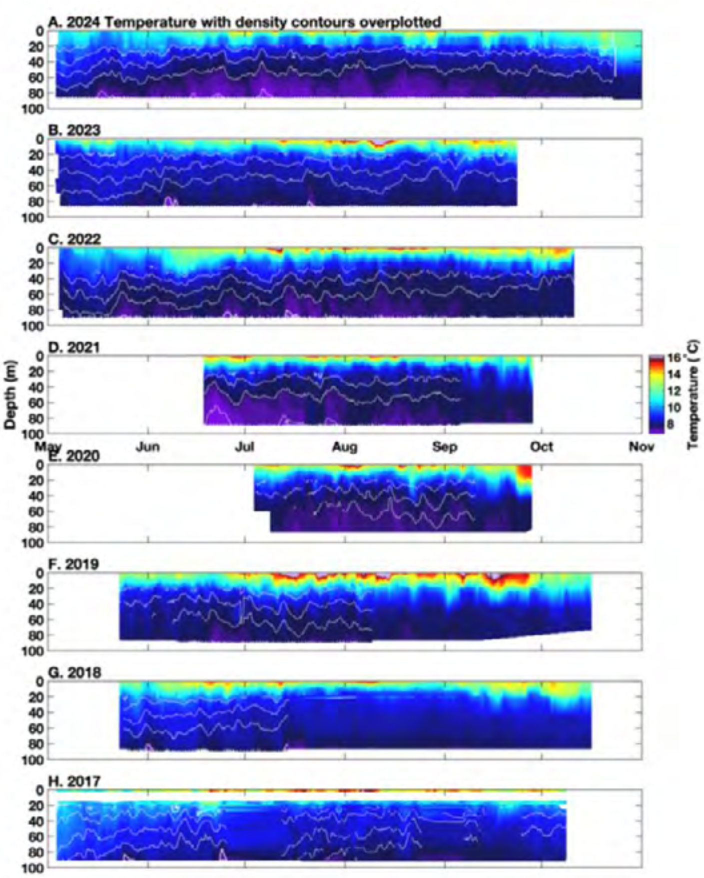


Figure 1. Water column temperature with density contours shown in gray for 2017-2024 (A-H).

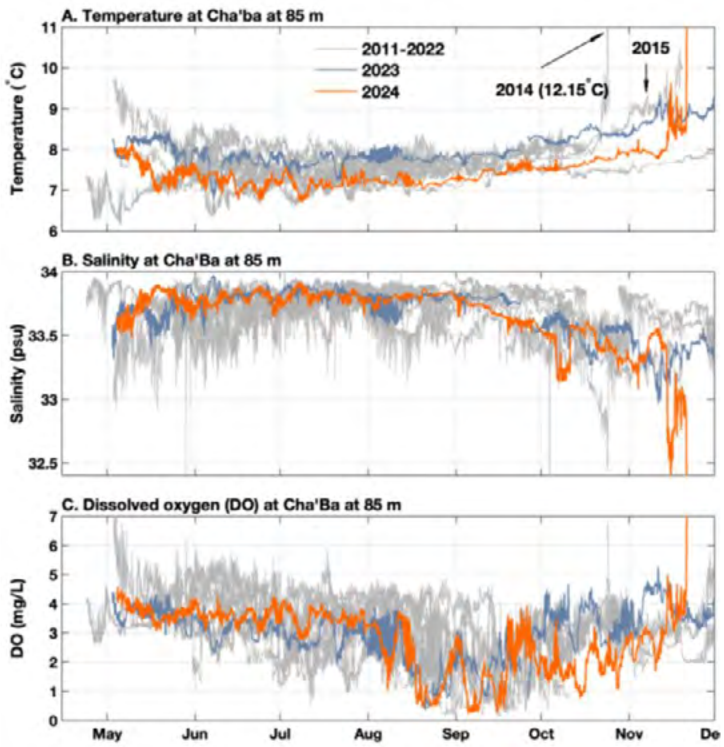


Figure 2. Interannual comparison of near-bottom properties (85 m). (A) temperature, (B) salinity, (C) dissolved oxygen.

Deep dissolved oxygen (DO) levels remained average or above average with no hypoxic (< 2 mg/l) events until August, after which episodic hypoxic events, lasting ~3-8 days each, occurred almost until November (Figure 2c). The occurrence of these hypoxic events in October was unusual, and are the lowest deep-DO observations at this site since the first fall records in 2011. Following this period, deep DO rapidly increased with the onset of November storms, similarly to temperature, and likely a consequence of the combination of strong downwelling and mixing.

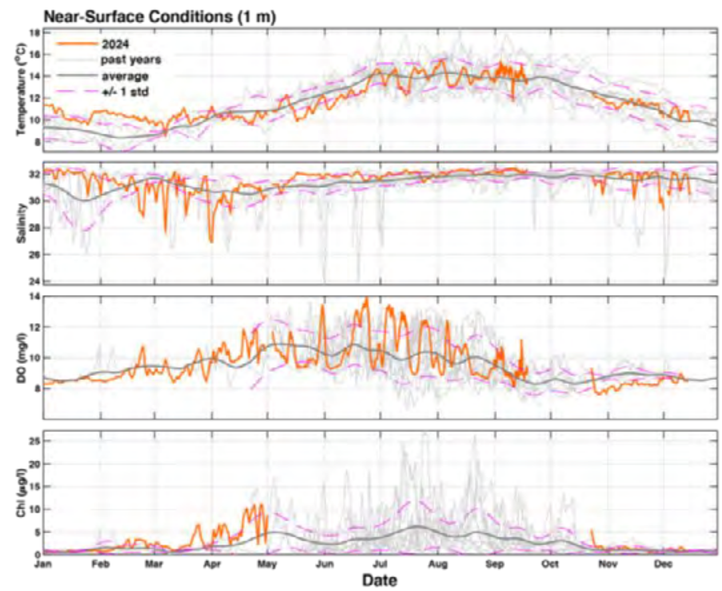
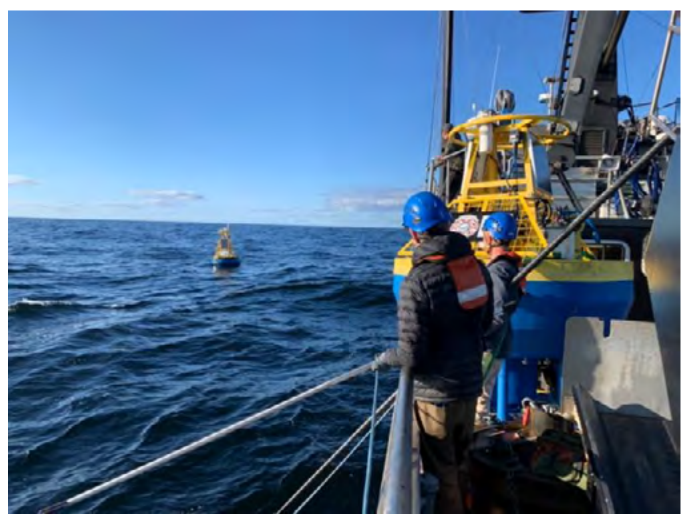


Figure 3. Interannual comparison of near-surface properties (1 m). (A) temperature, (B) salinity, (C) dissolved oxygen and (D) chlorophyll. Past years start in 2010, with most coverage in the summer months.



Ocean and atmospheric CO_2 from Washington coastal moorings

Authors: Simone R. Alin (NOAA Pacific Marine Environmental Laboratory (NOAA/PMEL)), simone.r.alin@noaa.gov); Adrienne Sutton (NOAA/PMEL), Jan Newton (University of Washington), John Mickett (University of Washington)
Edited by: Kimberle Stark
Website: https://pmel.noaa.gov/co2/story/Cape+Elizabeth; https://pmel.noaa.gov/co2/story/La%20Push; **Additional website for data**: https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/Moorings/Cape_Elizabeth.html; https:/www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/Moorings/LaPush.html

Highlights

- Monthly average atmospheric CO_2 levels on the outer coast were 0–7 ppm higher than the globally averaged marine surface air in 2024.
- Monthly coastal surface seawater xCO_2 averages were above average during October–December, when most 2024 coastal mooring observations occurred.
- Compared to the historical record, coastal mooring sites ranged from being a weaker sink than average to a stronger sink than average during September–December 2024.

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, air-sea flux, and ocean acidification rates. 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 (2006–2025) 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.

Narrative

Preliminary data returns during 2024 spanned October 23–December 15 at Ćháʔba· (14% of the year) and September 3–December 31 at Cape Elizabeth (32%, Figure 1, Table 1). The atmospheric xCO_2 range was 421–443 parts per million (ppm) at Ćháʔba· and 413–453 ppm at Cape Elizabeth in 2024. Monthly average atmospheric xCO_2 values for months with ≥50% of data return across both sites were 4–7 ppm higher than the monthly globally averaged marine surface air values (NOAA Global Monitoring Laboratory, NOAA/GML, 2025), except during September when coastal atmospheric xCO_2 was the same as the global monthly average at Cape Elizabeth. The lowest annual values are observed during August–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 ±3–4 ppm during all 2024 months sampled.

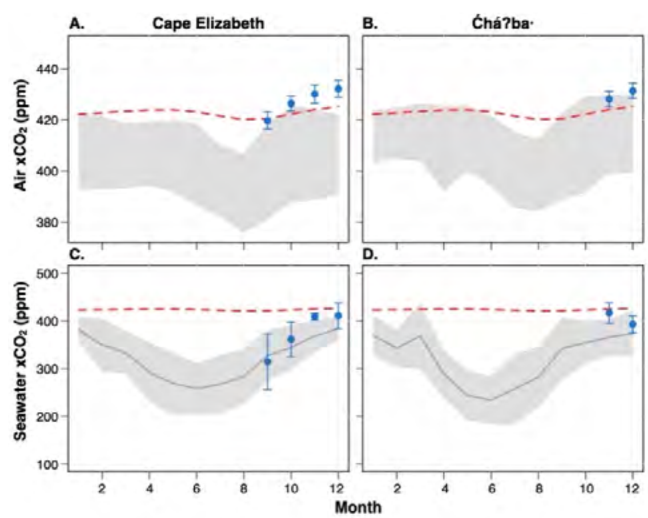


Figure 1. xCO_2 in air at 1.5 m above seawater (A, B) and in surface seawater at 0.5 m depth (C, D) on the Cape Elizabeth (A, C) and Ćháʔba· (B, D) moorings. Because atmospheric CO_2 increases year after year, comparisons provided for the current year (2024) are the minimum and maximum monthly means observed across 2006–2023 at Cape Elizabeth and 2010–2023 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 2024 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 2024 (NOAA/GML 2025).

Surface seawater xCO_2 measurements spanned 282–470 ppm at Ćháʔba· and 130–456 ppm at Cape Elizabeth during 2024. Monthly means and most 1SD bars at Cape Elizabeth mostly fell within the historical range (defined here as the time series mean ± 1SD through 2023) for September–October 2024. Mean seawater xCO_2 values were above the historical range at both sites in November, with higher-than-normal means at both sites in December but 1SD ranges that partially (Cape Elizabeth) or fully (Ćháʔba·) overlapped historical ranges.

	Ćháʔba·				Cape Elizabeth			
	Air		Seawater		Air		Seawater	
Month	2024	2010–2023	2024	2010–2023	2024	2006–2023	2024	2006–2023
Jan.	n.a.	403–424	n.a.	369 ± 41	n.a.	393–422	n.a.	381 ± 27
Feb.	n.a.	405–425	n.a.	342 ± 40	n.a.	393–421	n.a.	349 ± 55
Mar.	n.a.	404–426	n.a.	368 ± 69	n.a.	393–419	n.a.	333 ± 45
Apr.	n.a.	392–425	n.a.	288 ± 50	n.a.	394–419	n.a.	291 ± 63
May	n.a.	400–426	n.a.	244 ± 53	n.a.	392–420	n.a.	269 ± 65
Jun.	n.a.	394–422	n.a.	234 ± 50	n.a.	386–418	n.a.	258 ± 53
Jul.	n.a.	385–415	n.a.	257 ± 74	n.a.	382–410	n.a.	267 ± 61
Aug.	n.a.	384–412	n.a.	283 ± 63	n.a.	376–407	n.a.	283 ± 58
Sep.	n.a.	389–423	n.a.	342 ± 65	420 ± 3	381–418	314 ± 59	327 ± 53
Oct.	n.a.	392–429	n.a.	354 ± 44	426 ± 3	387–425	361 ± 36	344 ± 47
Nov.	428 ± 3	399–430	416 ± 22	365 ± 38	430 ± 4	389–424	408 ± 7	368 ± 33
Dec.	431 ± 3	399–430	393 ± 18	373 ± 47	432 ± 3	391–422	411 ± 27	384 ± 24

Table 1: Atmospheric and surface seawater xCO_2 at the coastal Ćháʔba· and Cape Elizabeth moorings (in ppm). Monthly means ± 1SD for 2024 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 2023. 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.

Across the historical record, air xCO_2 monthly averages were 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. The monthly average air-seawater xCO_2 difference at these sites has historically been larger during April–August (106–173 ppm) than fall and winter months (20–69 ppm). During September–December 2024, monthly coastal seawater xCO_2 means across both sites fell below the average monthly local air xCO_2 values by 12–106 ppm. Comparing 2024 and historical average air-seawater differences by month, the CO_2 sink at coastal Washington moorings was 14–54% weaker than average during August–September at Cape Elizabeth, 38–74% stronger than average during November at both sites, and within 10% of average during December at both sites.

First Beach, La Push, Washington.

References and contribution number

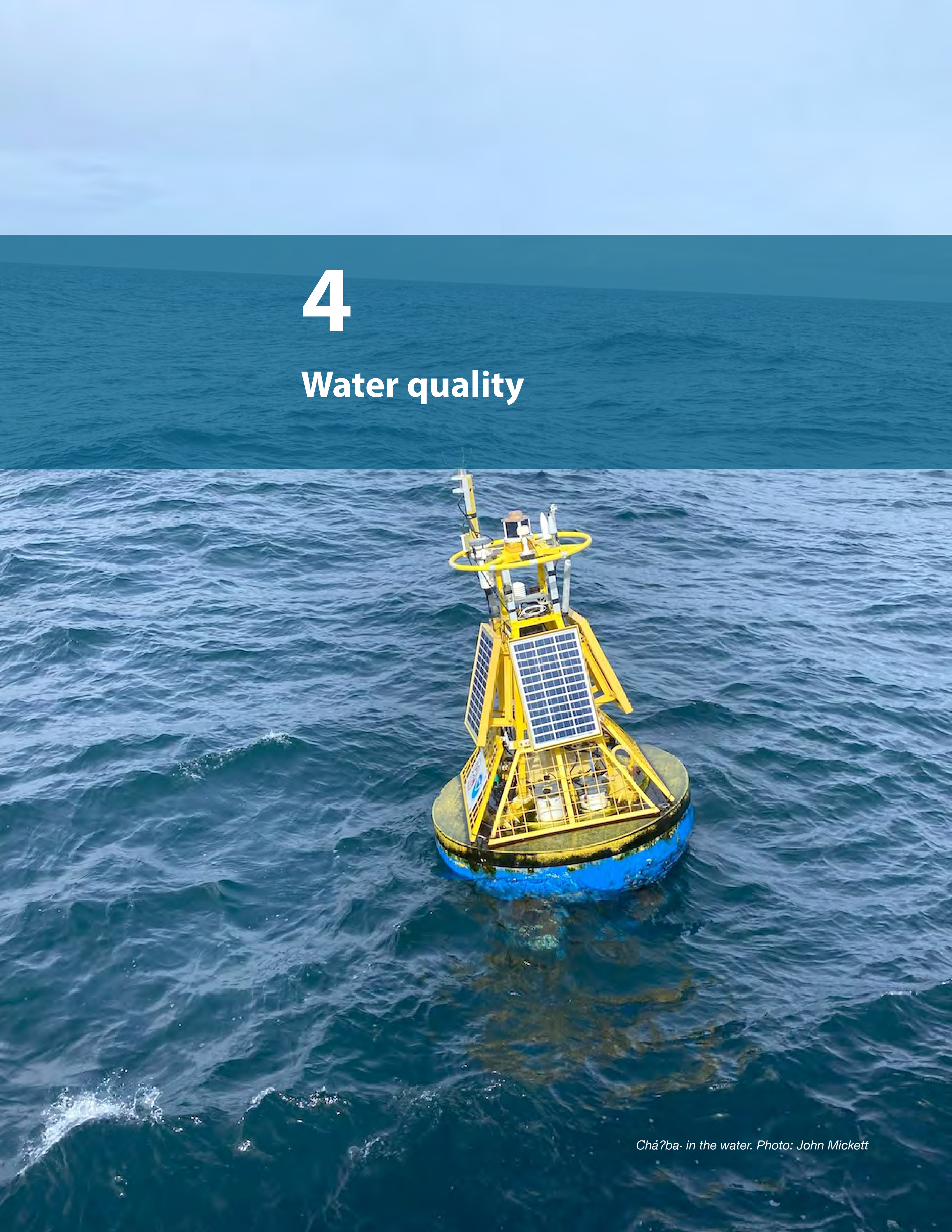
NOAA Global Monitoring Laboratory (2025): Global Monthly Mean CO_2 data, https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_mm_gl.txt; accessed on April 29, 2025.

Sutton, A.J., R.A. Feely, S. Maenner-Jones, S. Musielewicz, J. Osborne, C. Dietrich, N. Monacci, J. Cross, R. Bott, A. Kozyr, A.J. Andersson, N.R. Bates, W.-J. Cai, M.F. Cronin, E.H. De Carlo, B. Hales, S.D. Howden, C.M. Lee, D.P. Manzello, M.J. McPhaden, M. Meléndez, J.B. Mickett, J.A. Newton, S.E. Noakes, J.H. Noh, S.R. Olafsdottir, J.E. Salisbury, U. Send, T.W. Trull, D.C. Vandemark, and R.A. Weller (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 5782.

4

Water quality



Cháʔba· in the water. Photo: John Mickett

Temperature, Salinity, and Dissolved Oxygen Anomalies

Authors: Alex Fisher (afis461@ecy.wa.gov); Natalie Coleman, Chris Jendrey, Christopher Krembs, Emma LeValley, Suzan Pool, and Holly Young. (Washington State Department of Ecology)
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 2024, Puget Sound was warmer and saltier than usual with widespread negative DO anomalies in the winter and spring.
- January-October 2024 was the 3rd warmest, 4th saltiest, and had the lowest average DO concentration of any such period since 1999.
- Model estimates suggest that historically low river flows may have reduced the estuarine exchange flow by as much as 40%.

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 2024 temperature, salinity, and dissolved oxygen anomalies relative to a 1999-2023 baseline and explore the connection between reduced river discharge and the estuarine exchange flow using simulation results from the Salish Sea and Columbia River Operational Forecast System (SSCOFS).

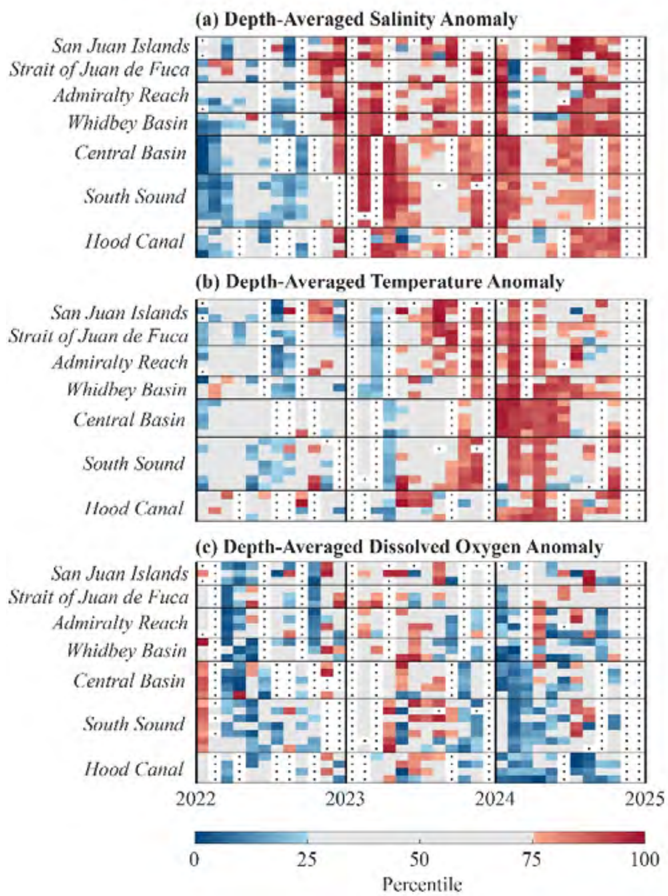


Figure 1: Depth-averaged anomalies of (a) salinity, (b) temperature, and (c) dissolved oxygen concentration across WA Ecology's long-term sampling network. Colorscale indicates rank order within historical dataset. Anomalies are calculated relative to 1999-2023 baseline.

Narrative

Throughout 2024, Puget Sound waters were warmer and saltier than historical averages. Depth-averaged positive salinity anomalies greater than 0.5 PSU were observed throughout greater Puget Sound, briefly relaxing to near normal in the spring, before rebounding to 0.4 PSU in the fall. Strong negative anomalies (-0.5 PSU) were briefly observed at northern stations following large discharge events in February in the Fraser, Skagit, and Nooksack watersheds. These observations mark the continuation of high salinities that began in late 2022 driven primarily by extended periods of low river flows in the region, which have persisted over the last 2 years (Figure 1).

Coinciding with the strong El Niño that peaked during the 2023-2024 winter, November 2023 through April 2024 was among the warmest such period recorded since 1999 with depth-averaged temperature anomalies exceeding 1 °C at many stations. While warm anomalies reemerged in South Sound and Central Basin in October, warm water temperatures persisted within Hood Canal (0.4-0.8 °C) and Whidbey Basin (0.3-0.65 °C) for the majority of 2024.

Widespread negative DO anomalies, which in some locations were less than -1.5 mg/L, developed in late 2023 and persisted in Puget Sound during the first half of 2024. Much larger deficits were observed at individual station-depths, including -5 to -2 mg/L anomalies observed in the upper 50m in Hood Canal in July. Concentrations appeared to return to near normal levels in October, but vessel issues prevented sampling during November and December.

These observations indicate that January-October 2024 was the third warmest (0.63 ± 0.08 °C), fourth saltiest (0.26 ± 0.03 PSU), and had the lowest volume-averaged DO anomalies (-0.28 ± 0.06 mg/L) since 1999. Increased water temperatures and salinity likely contributed to low oxygen levels by decreasing the solubility of oxygen. Additionally, historically low freshwater discharge 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.

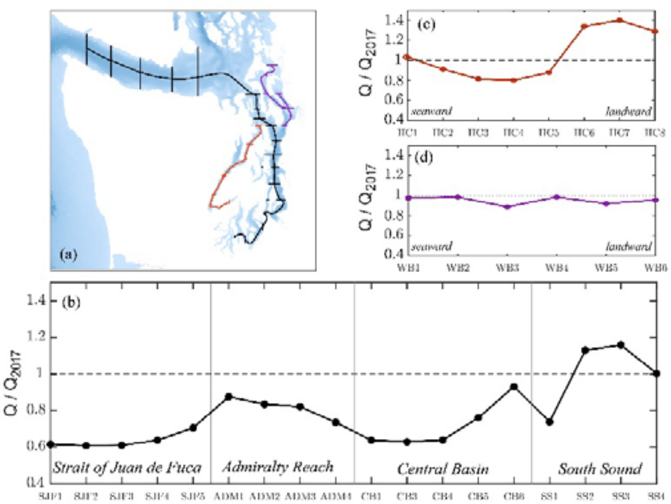


Figure 2: Simulated total exchange flow (Q) comparison between 2024 and 2017 (July-December). (a) Map showing locations of transects used in TEF calculations. (b-d) Ratio of exchange flow strength between 2024 and 2017 simulations for (b) the Strait of Juan de Fuca to South Sound, (c) Hood Canal, and (d) Whidbey Basin. Simulation results for 2017 courtesy of Tarang Khangaonkar (Salish Sea Modeling Center).

To evaluate the impact of river flow on Puget Sound circulation, SSCOFS nowcast products were used to calculate the total exchange flow (TEF) at 32 transects spanning the Strait of Juan de Fuca through South Sound, Whidbey Basin, and Hood Canal. When compared to the 2017 simulation (Premathilake & Khangaonkar 2022), which was a hydrologically near-normal year, results indicate that the strength of the exchange flow may have been reduced by as much as 40% below normal between July-December (Figure 2). The Strait of Juan de Fuca and Central Basin exhibited the largest reductions with sill locations exhibiting the least sensitivity. A notable exception is in Hood Canal, where simulation results suggest that above average Skokomish discharge drove an increase in the strength of the exchange flow landward of the Great Bend. Whidbey Basin exhibited modest reductions of approximately 10%.

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.

Spatiotemporal averaging was performed using an inverse-variance weighting of the mean and standard deviation to account for uncertainty in baseline medians and reduce the influence of station-depths with a high degree of variability on global mean and standard deviation estimates. Annual averaging was limited to 20 stations that were sampled at least 200 months during the baseline period.

The strength of the exchange flow at each model transect location was calculated using the TEF method as described in MacCready (2011) and dividing salinity method (MacCready et al 2018, Lorenz et al 2019). Prior to estimating the total exchange flow, simulated velocity and salinity fields were linearly interpolated from the unstructured triangular grid used in SSCOFS to regular grided transects with consistent vertical sigma layers.

References

Lorenz, M., Klingbeil, K., MacCready, P., & Burchard, H. (2019). Numerical issues of the Total Exchange Flow (TEF) analysis framework for quantifying estuarine circulation. Ocean Science, 15(3), 601-614.

MacCready, P. (2011). Calculating estuarine exchange flow using isohaline coordinates. *Journal of Physical Oceanography*, *41*(6), 1116-1124.

MacCready, P., Geyer, W. R., & Burchard, H. (2018). Estuarine exchange flow is related to mixing through the salinity variance budget. *Journal of Physical Oceanography*, *48*(6), 1375-1384.

Premathilake, L., & Khangaonkar, T. (2022). Explicit quantification of residence and flushing times in the Salish Sea using a sub-basin scale shoreline resolving model. *Estuarine, Coastal and Shelf Science*, *276*, 108022.

Nutrients and Chlorophyll

Authors: Christopher Krembs (Ecology), christopher.krembs@ecy.wa.gov); Alex Fisher, Holly Young, Natalie Coleman, Suzan Pool, Christopher Jendrey, and Emma LeValley (Ecology)
Edited by:
Website: https://ecology.wa.gov/researchdata/monitoring-assessment/puget-sound-andmarine-monitoring
Additional website for data: https://ecology.wa.gov/

Highlights

- Several nutrient concentrations and ratios (e.g., nitrate, phosphate, N:P, SiOH:DIN) in Puget Sound exhibit interdecadal cycles, with SiOH:DIN declining due to falling silicate levels.
- Nitrite is strongly correlated with both SiOH:DIN (negative) and the North Pacific Gyre Oscillation (positive), linking regional nutrient trends to large-scale oceanographic patterns.
- After a 20-year decline, chlorophyll *a* concentrations began to increase in 2022.

Overview

Ecology's marine water monitoring program spans a large geographic area, allowing for the analysis of monthly data with a focus on long-term, large-scale patterns and trends across the southern Salish Sea. A critical step in this analysis involves removing variability related to depth, regional differences, and seasonal fluctuations, enabling the calculation of annual averages of anomalies across the entire network of monitoring stations. The data are processed as follows: 1) Monthly samples from 27 stations (at target depths of 0 m, 10 m, and 30 m) are reduced to median values. 2) Regional and seasonal variability are removed by subtracting site-specific monthly baselines (from 1999 to 2024), calculated using depth-integrated medians. 3) The resulting anomalies, which are normally distributed are then averaged annually across the entire station network. This method is intentionally designed to minimize regional and high-frequency noise in the dataset (Krembs, 2012).

Narrative

Many surface water nutrient concentrations and nutrient ratios in Puget Sound exhibit interdecadal variability, which should be considered in long-term water quality monitoring. Nitrate (15 years), nitrite (26 years), phosphate (18 years), the N:P ratio (15 years), and the SiOH:DIN ratio (18 years) all show cyclical behavior on interdecadal timescales (Fig. 1 A–E). In addition, nitrite and SiOH:DIN exhibit significant long-term trends (Fig. 1 B, E), with SiOH:DIN declining significantly over time (Spearman's $\rho = -0.69$, $p < 0.001$, $n = 26$), driven by a decadal-scale decrease in silicate concentrations (Krembs et al. 2024).

Nitrite and SiOH:DIN are strongly negatively correlated (Spearman's $\rho = -0.81$, $p < 0.001$, $n = 26$), while nitrite , for unknown reasons, is positively correlated with the North Pacific Gyre Oscillation (NPGO) (Spearman's $\rho = 0.67$, $p < 0.001$, $n = 26$). The NPGO, the second leading mode of sea surface height variability in the northeast Pacific (Di Lorenzo et al. 2008), is generally closely linked to salinity and nutrient fluctuations and influences broader ecosystem dynamics along the North West coast of north America.

As of 2024, nitrate levels have begun to decline following a peak anomaly in 2021. Phosphate concentrations reached a cyclical high in 2024, while the N:P ratio reached a low. These observations have prompted ongoing discussion within the PSP Marine Work Group regarding their implications for nutrient cycling, ecosystem balance, and status and trend monitoring in Puget Sound.

Anomalies of chlorophyll *a* concentration showed a significant long-term decline from 2001 to 2021 (Spearman's $\rho = -0.82$, $p < 0.001$, $n = 26$; Fig. 1 G). However, this trend ended in 2022, with a current rate of concentration increase approximately five times steeper than the previous decline.

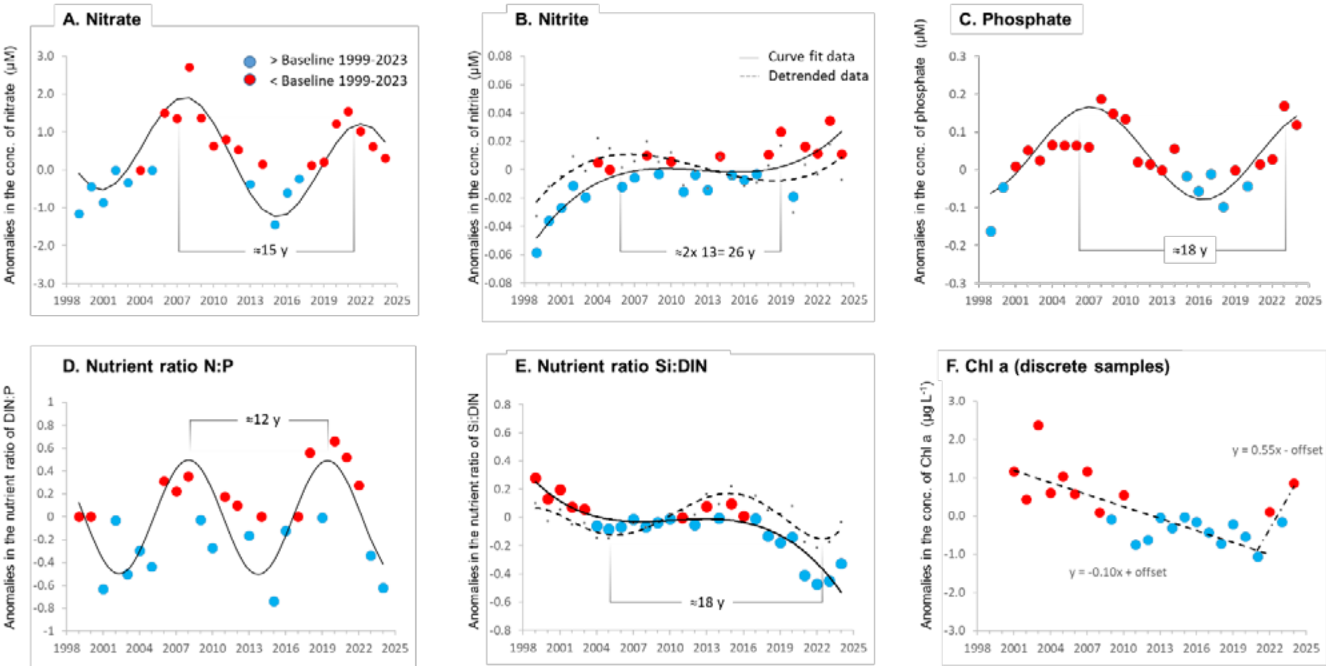


Figure 1. Interdecadal variability and trends in nutrient concentrations and ratios in surface waters of Puget Sound. (A) Nitrate, (B) Nitrite, (C) Phosphate, (D) N:P ratio, and (E) Silicate to dissolved inorganic nitrogen ratio (SiOH:DIN) show cyclical behavior on 15–26-year timescales. Nitrite and SiOH:DIN also exhibit long-term trends, with a significant decline in SiOH:DIN driven by decreasing silicate concentrations (Krembs et al. 2024). (F) Annual discrete Chlorophyll a values declined from 2001 to 2021 and began a reversal in 2022.

References

Di Lorenzo, E., Schneider, N., Cobb, K. M., Franks, P. J. S., Chhak, K., Miller, A. J., ... & Bograd, S. J. (2008). North Pacific Gyre Oscillation links ocean climate and ecosystem change. Geophysical Research Letters, 35(8), L08607. https://doi.org/10.1029/2007GL032838

Krembs, C. (2012). *Marine Water Condition Index*. Washington State Department of Ecology. Publication No. 12-03-013. https://apps.ecology.wa.gov/publications/documents/1203013.pdf

2024. Puget Sound marine waters: 2023 overview. J. Apple, R. Wold, K. Stark, J. Bos, S. Yang, J. Selleck, N. Burnett, A. Marquez, L. Loehr, J. Rice, S. Kantor, C. Krembs. and J. Newton (Eds).

Puget Sound profiling buoys and environmental metrics

Authors: Seth Travis (University of Washington – Applied Physics Laboratory (UW APL), setht1@uw.edu); John Mickett (UW APL), Jan Newton (UW APL), Anna Boyar (UW APL)
Edited by: Alex Fisher (Washington State Department of Ecology)
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 heat fluxes for the first half of the year.
- In all basins salinity was higher than normal and likely due to reduced river and rainfall input. This continues a several-year trend of higher salinity that results in higher density, reduced stratification and increased mixing.
- Modest dissolved oxygen anomalies were observed in most basins, alternating between periods of positive and negative anomalies.
- Hypoxia was observed at Twanoh in late summer, 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). Climatologies are based upon the data record available at all buoy sites, with 15 years of data available, being the years of 2010-2024.

Narrative

i) Temperature

ORCA mooring observations indicate warmer-than-normal temperatures across all basins in 2024, 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, suggesting a shallow mixed layer and surface-confined forcing on short time scales. At Hoodsport, the annual late-summer/fall deep-water intrusion presented as a warm anomaly which intensified in mid-to-late August and shoaled through the fall, after which the anomaly modulated in strength, returning to values seen before the start of the intrusion (Figure 1B). This pattern of a short-lived, strong anomaly is likely indicative that the intrusion arrived earlier than usual, with the start of the intrusion occurring in mid-August, rather than a typical timing of mid-September.

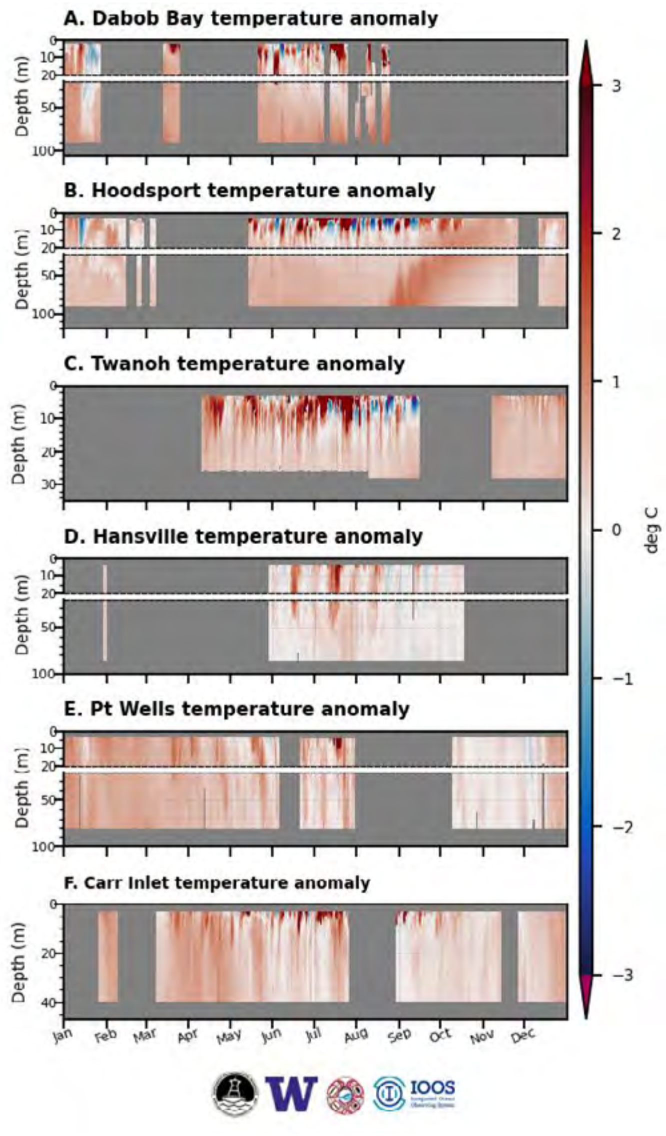


Figure 1: Depth-time color maps of water temperature anomalies in 2024 relative to the climatological averages (years included in the climatologies: 2010–2024) at six ORCA mooring sites: Dabob Bay in north Hood Canal (A), Hoodsport in mid–Hood Canal (B) and Twanoh in South Hood Canal (C), Hansville in Main Basin (D) Point Wells in Main Basin (E), Carr Inlet in South Sound (F).

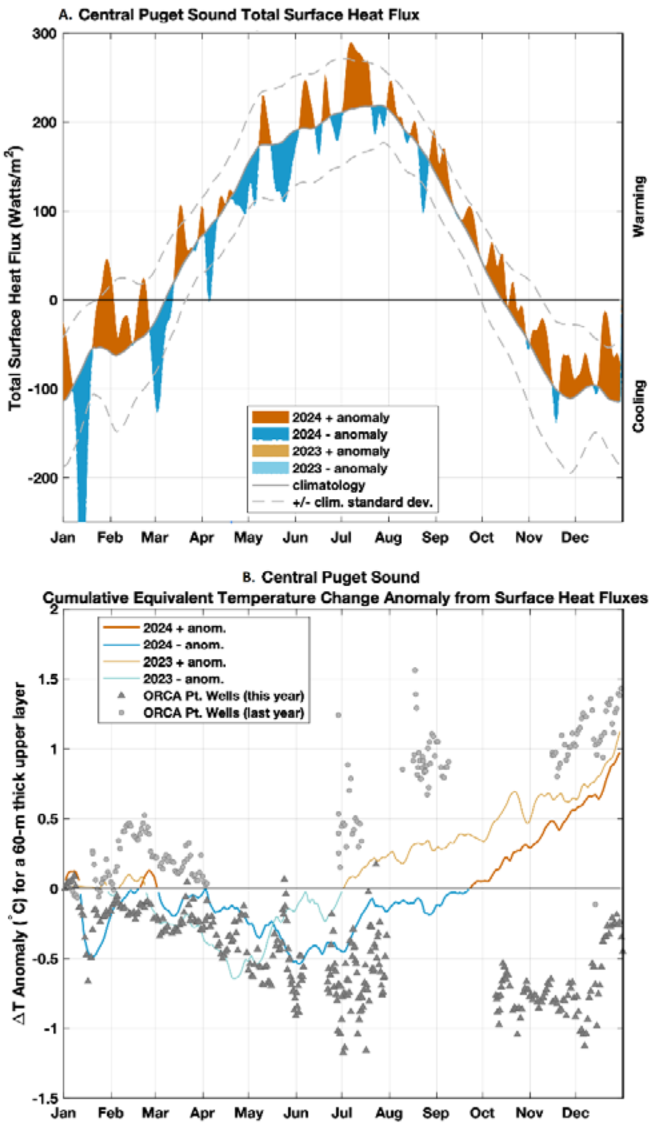


Figure 2. Impact of surface heat flux on temperature anomalies. (A) Total heat fluxes in 2024 relative to climatological averages with positive anomalies shown in orange and negative anomalies in blue. (B) Central Sound equivalent change in temperature from accumulated heat gain or loss over a fixed 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 June to November—interrupted by a brief warm event in late July—then warmed again by year's end (~1°C anomalies). In the first half of the year, reduced surface heat flux would cause ~0.5°C cooling in the upper 60 m, consistent with Point Wells observations (Figure 2). In contrast, elevated surface heat flux in the second half of the year would suggest ~1°C net warming compared to the start of the year. However, this elevated temperature is not seen (Figure 2B), where observations show that net temperature change for the year remains negative through the fall before returning to near zero to end the year (i.e. no net change in temperature since the start of the year). One possible process that could cause this discrepancy would be 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 2024 (Figure 3), except for brief periods of fresher surface waters (<10 m) in Hood Canal. Salinity anomalies exceeded +0.5 psu early in the year, weakened during spring—especially at Point Wells, with observations nearing normal—then intensified through summer and fall (+0.5–1.0 psu). In Hood Canal (Figure 3 A-C), surface salinity anomalies were more intense, regularly exceeding +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 2024 positive salinity anomalies primarily to reduced freshwater input (Figure 4), and is a continuation of the signal observed in 2022 and 2023. River flow remained below average throughout 2024, except for a few large events (Figure 4A). The model closely mirrored depth-averaged ORCA buoy observations, particularly at Carr Inlet, with both showing elevated salinities for the whole year except during early spring (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.

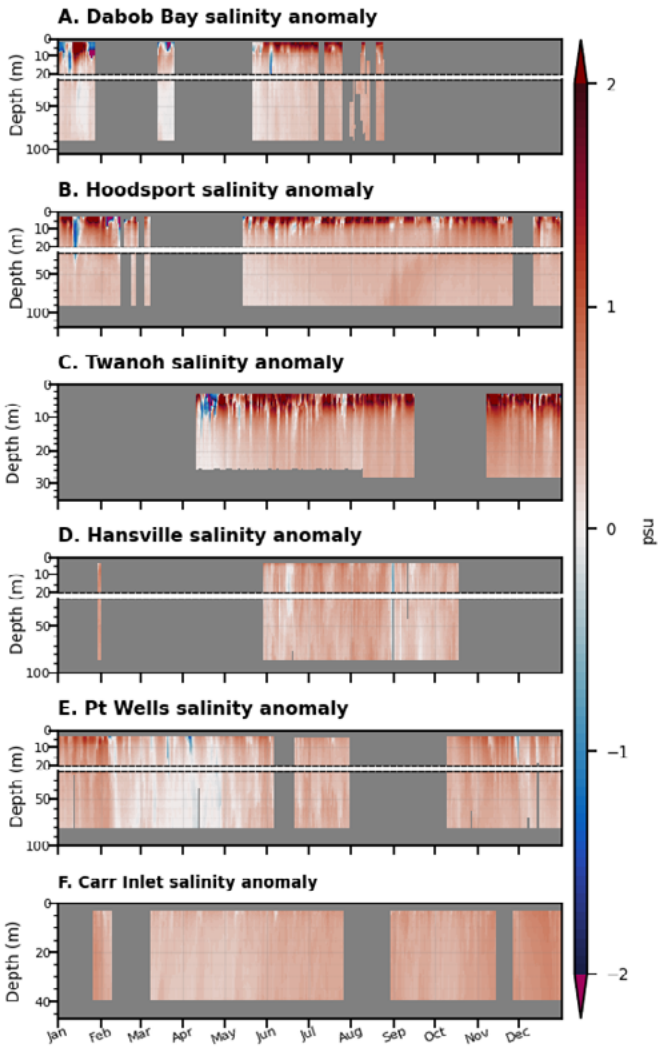


Figure 3: Depth-time color maps of salinity anomalies in 2024 relative to the climatological averages (years included in the climatologies: 2010–2024) at six ORCA mooring sites: Dabob Bay in north Hood Canal (A), Hoodsport in mid–Hood Canal (B) and Twanoh in South Hood Canal (C), Hansville in Main Basin (D) Point Wells in Main Basin (E), Carr Inlet in South Sound (F).

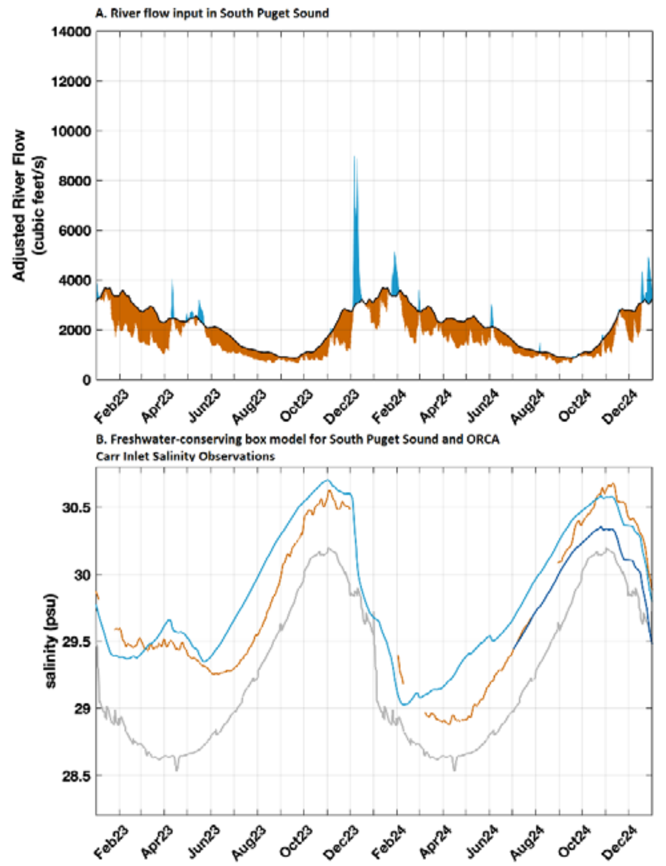


Figure 4. Top panel: Adjusted river flow anomalies for the Main Basin for the two-year period from January 2023 through December 2024. Bottom panel: depth-averaged salinity climatology (gray), ORCA Carr Inlet measurements (orange) and freshwater box-model estimates (blue). Near-surface values are excluded 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 2024, with relatively modest anomalies of less than ±1 mg/L for most of the year, but intermittent, localized events exceeding these thresholds (Figure 5). The Main Basin and South Sound began the year with weakly-negative to neutral anomalies to start the year before transitioning to modestly-positive anomalies through the spring and summer. Brief events occurred during this time where DO levels exceeded 2 mg/L above normal concentrations. During the late fall, anomalies reverted to weakly-positive anomalies.

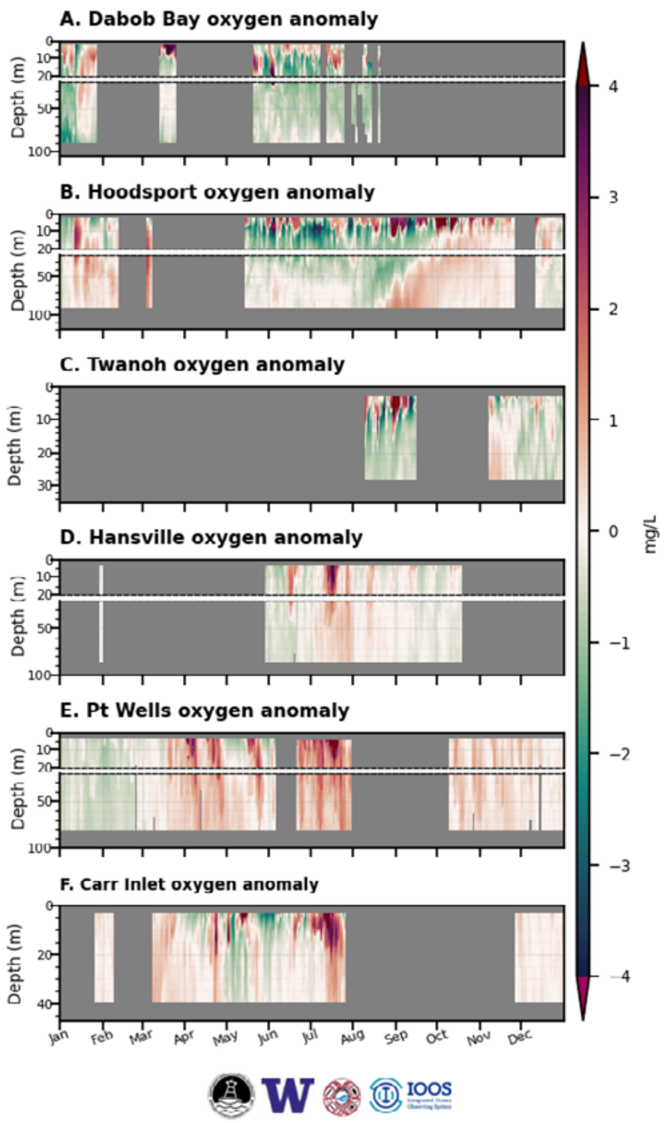


Figure 5: Depth-time color maps of dissolved oxygen anomalies in 2024 relative to the climatological averages (years included in the climatologies: 2010–2024) at six ORCA mooring sites: Dabob Bay in north Hood Canal (A), Hoodsport in mid–Hood Canal (B) and Twanoh in South Hood Canal (C), Hansville in Main Basin (D) Point Wells in Main Basin (E), Carr Inlet in South Sound (F).

In Hood Canal, negative oxygen anomalies are observed in the late spring and throughout the summer (Figure 5). At Hoodsport, the annual deep-water intrusion displaced the modestly-low DO waters, leading to positive anomalies caused by the early arrival of the intrusion before returning to near-normal levels at the end of the year. At Twanoh, hypoxic waters with DO concentrations of 1-2 mg/L were observed in late summer at depths greater than 10 m, modulating to approximately 2 mg/L in November, and remaining low to end the year. Hypoxic water, indicated in purple in Figure 6, persisted to the end of the year. This only occurred in three of the last 10 years, including 2024, so is somewhat unusual. While data are lacking, stronger hypoxia was observed in late summer (August-September), was not apparent at all in early November, but then mild hypoxia was observed again in mid-November through the end of the year.

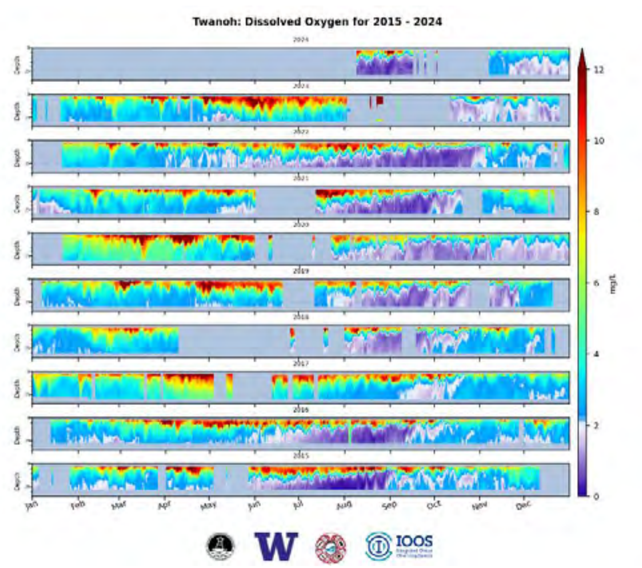


Figure 6. Time series of water column dissolved oxygen concentrations at the Twanoh mooring between 2015 and 2024 (not the full record, selected years to fit). Pressure (or depth) is shown on the y-axis and time in monthly increments on the x-axis between January and December.

The second half decade of Washington Ocean Acidification Center cruises

Authors: Simone R. Alin (NOAA Pacific Marine Environmental Laboratory (NOAA/PMEL)), simone.r.alin@noaa.gov), Jan Newton (University of Washington), Richard Feely (NOAA/PMEL), Anna Boyar (University of Washington), Christopher Ikeda (University of Washington)

Edited by: Kimberle Stark

Website: https://nvs.nanoos.org/CruiseSalish;

Additional website for data: https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/SalishCruises_DataProduct.html

Highlights

- Puget Sound subbasins have exceptionally wide ranges of carbonate chemistry, with the most extreme values in Hood Canal and Whidbey Basin.
- Since 2014, the strongest biogeochemical anomalies were observed in 2015–2017, with no major anomalies during 2019–2024.
- In 2024, acidification and oxygen conditions were somewhat more stressful than normal overall in stratified basins, and somewhat better than normal in surface waters of well-mixed basins during July.

Overview

The Washington Ocean Acidification Center (WOAC) has conducted seasonal cruises (April, July, September) throughout Puget Sound since 2014. The first five years of cruises illuminated the seasonality and impacts of extreme events (e.g., the NE Pacific 2013–2016 marine heatwave, anomalous river inputs) on biogeochemistry, along with the relative frequencies of hypoxia, aragonite and calcite undersaturation, and fCO_2 values exceeding a hypercapnia threshold in Puget Sound, described in Alin et al. (2024a,b). Here, we introduce the second five years of seasonal WOAC cruise biogeochemistry results (2019–2024). The WOAC cruise time-series and its analysis have been supported by WOAC and NOAA/PMEL during 2014–2025 (PMEL contribution number 5782).

Narrative

Puget Sound subbasins have exceptionally wide ranges of carbonate chemistry, with WOAC cruise data revealing carbon dioxide fugacity (fCO_2, effective partial pressure of CO_2 in water) ranges of 69–3465 microatmospheres (µatm), aragonite and calcite saturation states (Ω_{arag}, Ω_{calc}) of 0.23–3.89 and 0.37–6.28, and pH (total scale, pH_T) values of 7.14–8.59. Dissolved oxygen (DO) spanned 18–612 µmol kg^{-1} (0.6–19.9 mg L^{-1}), with temperatures of 7.6–23.0 °C across the time series. The widest ranges and most extreme biogeochemical conditions are typically observed in stratified Hood Canal or Whidbey basins, with the strongest anomalies during the WOAC cruise time-series observed during 2015–2017, driven by extreme marine heatwave, precipitation, and river runoff events. Unlike during the first half-decade, no major fCO_2 or Ω_{arag} anomalies were observed during 2019–2024 WOAC cruises (Figure 1).

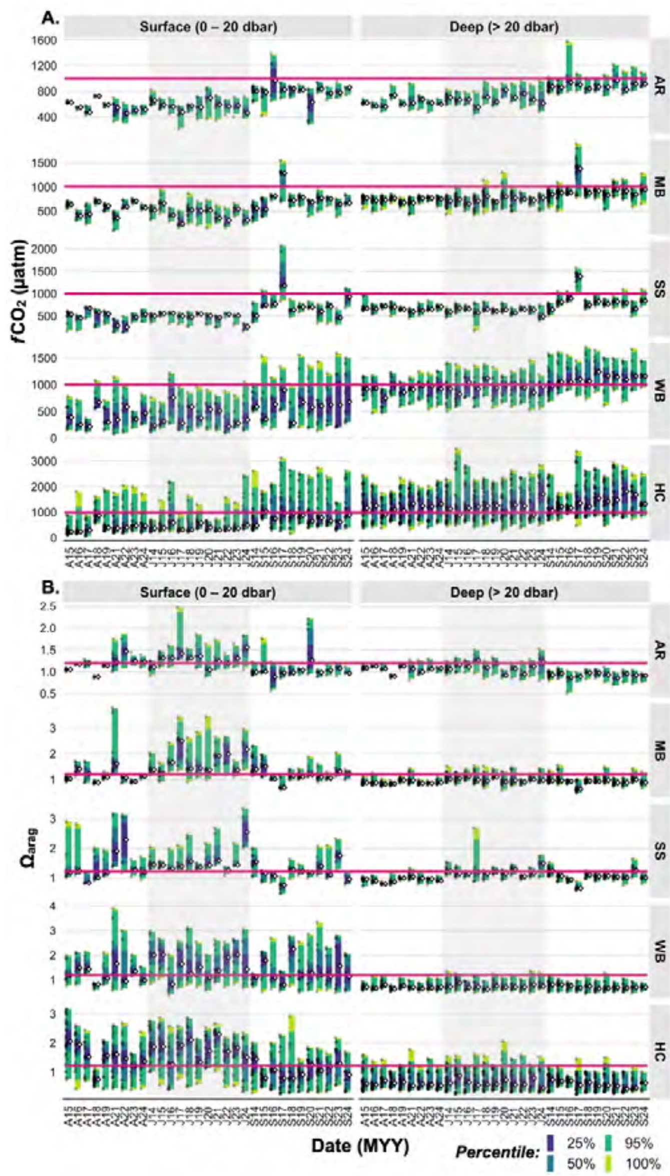


Figure 1. Distribution of fCO_2 and Ω_{arag} values across Puget Sound basins for 2014–2024 cruises. Magenta lines show a hypercapnia threshold of 1000 µatm fCO_2 and an acute Ω_{arag} exposure threshold for regional bivalves and pteropods (1.2). Basins: AR=Admiralty Reach, MB=Main Basin, SS=South Sound, WB=Whidbey Basin, and HC=Hood Canal. Cruise dates are in MYY format (Julys shaded). Note independent scales of y-axes.

Across basins, depth, and the past WOAC record (2014–2023), seasonal fCO_2 medians and interannual variability (represented by 1SD) tend to be highest in fall; this pattern held in September 2024 (Figure 1, Table 1). However, compared to past years, 2024 surface median fCO_2 was 22–48% lower in July in AR, MB, and SS and 11–32% higher across seasons in HC and during April and July in SS and WB. Subsurface fCO_2 medians were within 10% of the long-term median except during July in SS (–23%) and April–July in HC (+15–51%). Seasonally, Ω_{arag} values tend to peak across depth and basins during summer (Figure 1, Table 1). In 2024, Ω_{arag} medians were mostly within 10% of historical seasonal medians, with July values 22–80% higher in AR, MB, and SS surface waters and 11–26% higher at depth in subsurface AR and SS. Ω_{arag} medians were 10–30% lower across seasons and depth in HC (except September at depth) and in surface waters in SS in September and April–July in WB in 2024.

Basin–month	fCO_2 (µatm) Surface (0–20 dbar) 2024	fCO_2 (µatm) Surface (0–20 dbar) 2014–2023	fCO_2 (µatm) Deep (>20 dbar) 2024	fCO_2 (µatm) Deep (>20 dbar) 2014–2023	Ω_{arag} Surface (0–20 dbar) 2024	Ω_{arag} Surface (0–20 dbar) 2014–2023	Ω_{arag} Deep (>20 dbar) 2024	Ω_{arag} Deep (>20 dbar) 2014–2023
AR–Apr.	514 ± 82	594 ± 104	597 ± 52	619 ± 91	1.22 ± 0.13	1.12 ± 0.20	1.08 ± 0.07	1.07 ± 0.11
AR–Jul.	458 ± 172	589 ± 112	613 ± 193	683 ± 104	1.55 ± 0.38	1.27 ± 0.24	1.22 ± 0.27	1.10 ± 0.14
AR–Sep.	858 ± 66	802 ± 161	913 ± 92	881 ± 126	0.96 ± 0.08	1.01 ± 0.27	0.91 ± 0.08	0.93 ± 0.10
MB–Apr.	568 ± 49	588 ± 155	746 ± 76	734 ± 78	1.12 ± 0.08	1.08 ± 0.49	0.88 ± 0.09	0.86 ± 0.11
MB–Jul.	307 ± 109	506 ± 154	773 ± 126	732 ± 124	2.16 ± 0.52	1.43 ± 0.51	0.96 ± 0.19	1.01 ± 0.17
MB–Sep.	666 ± 103	703 ± 228	946 ± 138	881 ± 192	1.22 ± 0.15	1.15 ± 0.34	0.88 ± 0.14	0.93 ± 0.16
SS–Apr.	536 ± 135	467 ± 168	714 ± 48	668 ± 84	1.18 ± 0.32	1.22 ± 0.68	0.90 ± 0.07	0.93 ± 0.12
SS–Jul.	265 ± 86	510 ± 90	487 ± 130	631 ± 85	2.55 ± 0.66	1.42 ± 0.33	1.47 ± 0.28	1.17 ± 0.19
SS–Sep.	927 ± 211	700 ± 305	842 ± 104	800 ± 210	0.94 ± 0.21	1.19 ± 0.37	1.00 ± 0.10	1.05 ± 0.19
WB–Apr.	465 ± 227	372 ± 259	923 ± 223	911 ± 178	0.98 ± 0.30	1.25 ± 0.67	0.72 ± 0.17	0.71 ± 0.14
WB–Jul.	346 ± 334	371 ± 264	964 ± 188	932 ± 219	1.44 ± 0.96	1.64 ± 0.69	0.75 ± 0.20	0.74 ± 0.21
WB–Sep.	682 ± 510	584 ± 374	1164 ± 161	1097 ± 245	1.12 ± 0.67	1.20 ± 0.72	0.71 ± 0.10	0.73 ± 0.17
HC–Apr.	458 ± 379	379 ± 424	1318 ± 579	1149 ± 521	1.37 ± 0.50	1.52 ± 0.69	0.54 ± 0.27	0.61 ± 0.29
HC–Jul.	494 ± 690	384 ± 318	1710 ± 787	1135 ± 621	1.51 ± 0.69	1.80 ± 0.58	0.45 ± 0.40	0.65 ± 0.34
HC–Sep.	896 ± 781	804 ± 616	1317 ± 467	1287 ± 593	0.91 ± 0.46	1.01 ± 0.49	0.63 ± 0.18	0.63 ± 0.25

Table 1: Monthly medians and standard deviations of surface and deep water by basin 2024 vs. long-term observations.

Harmful acidification levels, indicated by high fCO_2 and low Ω and pH, often co-occur in Puget Sound with low dissolved oxygen (DO) and high temperature levels harmful to important regional species. We observed, however, that harmful acidification levels were more frequent and widespread alone than in combination with the other stressors. On WOAC cruises, temperature and DO levels exceeding Dungeness crab tolerances (>15°C, <62 µmol kg^{-1} (=2.0 mg L^{-1})) have been observed in HC, while pH_T and Ω_{calc} sensitivity thresholds (<7.65 and <1.0) have been exceeded across all subbasins (Figure 2 and Tables 3–4 Alin et al. 2024b). During 2024, median temperatures were within 10% of long-term medians across subbasins and depth, but maximum surface water temperatures exceeded 15°C in July in SS and in July and September in WB and HC. DO levels in 2024 showed the inverse pattern to fCO_2, with July medians 16–51% higher in surface waters of AR, MB, SS, and WB, and 12–26% lower across seasons and depth in HC. In subsurface waters, long-term median pH_T values were <7.65 during all seasons in HC and September in WB; 2024 medians were lower still by 0.01–0.17 there. Otherwise, acidity maxima were mostly lower and minima mostly higher in 2024 across basins and depth. Seasonal Ω_{calc} anomalies were the same as for Ω_{arag}, indicating better conditions for calcification in July in AR, MB, and SS surface waters, and worse conditions in HC across depth and seasons.

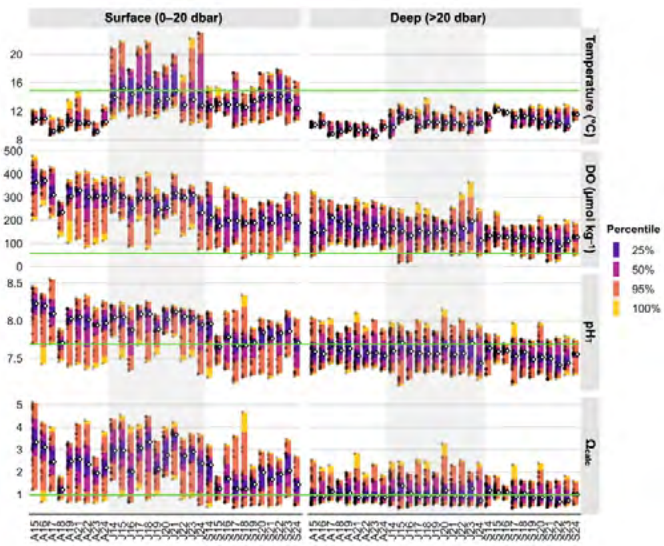


Figure 2. Hood Canal oceanographic conditions through 2014–2024, with Dungeness crab sensitivity thresholds in green. Cruise dates are in MYY format (Julys shaded).

WOAC cruises from 2014 to 2024 have revealed the biogeochemical seasonality in Puget Sound, as well as the occurrence and relative severity of multi-stressor conditions relevant to key marine species and linkages to regional and large-scale heat and river runoff anomalies.

References

Alin, S.R., J.A. Newton, R.A. Feely, B. Curry, D. Greeley, J. Herndon, and M. Warner (2024a). A decade-long cruise time-series (2008–2018) of physical and biogeochemical conditions in the southern Salish Sea, North America. *Earth System Science Data*.

Alin, S.R., J.A. Newton, R.A. Feely, S. Siedlecki, and D. Greeley (2024b). Seasonality and response of ocean acidification and hypoxia to major environmental anomalies in the southern Salish Sea, North America (2014–2018). *Biogeosciences*.

Central Basin Temperature, Salinity, and Dissolved Oxygen

Author: Greg Ikeda (King County DNRP, gikeda@kingcounty.gov)
Edited by: Kimberle Stark, Wendy Eash-Loucks, Diane Yeh, Beth LeDoux, Lincoln Loehr
Website: kingcounty.gov/marine-water-quality/offshore

Highlights

- Water temperature across Central Basin has remained anomalously warm since mid-2023, with some record high surface temperatures.
- Salinity was high throughout the year. Lower than normal freshwater input resulted in relatively weak and disjointed stratification.
- Dissolved oxygen was below normal for most of the year, with some record lows in Quartermaster Harbor.

Overview

King County conducts routine full water column sampling at 14 sites in Puget Sound's Central Basin, ranging from Point Jefferson in the North and East Passage in the South. 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. Two moorings are in Quartermaster Harbor, a shallow embayment with some of the lowest dissolved oxygen in Central Basin.

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

Narrative

2023’s pattern of warm and salty conditions persisted in Central Basin in 2024. Since July of 2023, CTD profiles show that the entire water column has remained anomalously warm throughout 2024 and into 2025. Salinity in deep water increased earlier in the year than normal, and lower freshwater inputs from late spring onwards led to a uniformly salty and dense water column. Dissolved oxygen was slightly lower than baseline conditions for most of the year, with an increase in July and August that corresponded with a phytoplankton bloom.

Water Temperature – All Central Basin stations exhibited warmer than baseline conditions. At Point Jefferson, Temperature anomalies in 2024 averaged around 0.68 °C above baseline, which is cooler than typical conditions seen during the 2014 – 2016 marine heat wave, though high anomalies in 2024 Winter months rival heat wave conditions (Figure 1, A). Most moorings recorded near record-high surface temperatures in January and December. These warm anomalies extended throughout Central Basin and at virtually all depths.

Salinity - 2024 had abnormally high salinity throughout most of the year and throughout most of the water column. At the surface, freshwater input was largely concentrated in brief periods in February and April then was relatively low for the rest of the year. This led to anomalously high surface salinity by late spring, especially in northern Central Basin. At depth, deep water salinity began increasing in May, approximately 1 – 3 months earlier than typical conditions. The combination of low freshwater input and high salinity deep water culminated in high salinity anomalies throughout the water column by May onwards, and a uniformly salty water column by July (Figure 1, B). Southern Central Basin had more consistent surface freshwater from February – June than northern Central Basin, but otherwise exhibited similarly high salinity.

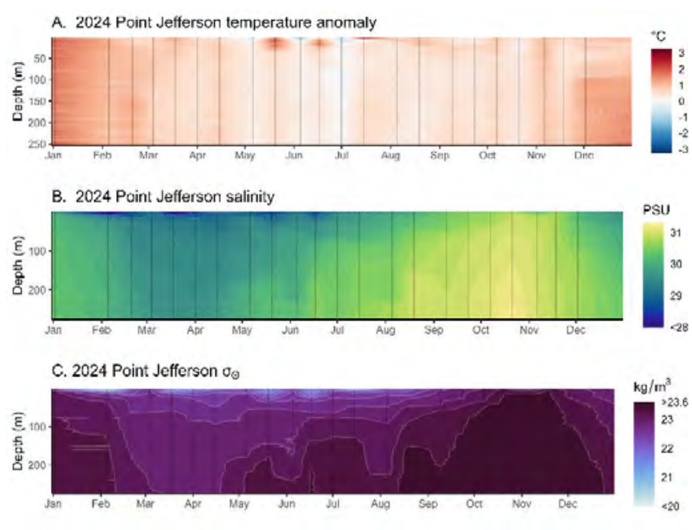


Figure 1 – Contour plots of temperature anomaly (A), salinity (B), and sigma-theta density (C) at Point Jefferson.

Density – Stratification was generally weaker and more disjointed than previous years. Reduced freshwater inputs and high salinity deep water led to an earlier shift to a uniformly dense water column.

In northern Central Basin, concentrated freshwater inputs led to brief periods of stratification that were interspersed with non-stratified conditions (Figure 1, C). East Passage, which had more consistent surface freshwater from March onwards, had a longer and more consistent period of stratification, though the overall strength was low. By July, all stations had transitioned to uniformly dense conditions lasting until December.

Dissolved Oxygen (DO) – DO concentration was below normal for most of 2024, except for a period from June – August that corresponded with a period of phytoplankton productivity (Figure 2, A, B). Outside of that period, DO percent saturation was also below normal, indicating that higher temperature and salinity (which reduces the amount of oxygen that can dissolve into water) didn't account for the full reduction in observed dissolved oxygen concentration. In Quartermaster Harbor, a shallow embayment with some of the lowest dissolved oxygen in Central Basin, moorings measured typical seasonal patterns and the expected strong high daily variation, with a large drop in DO in late October following the end of a fall phytoplankton bloom.

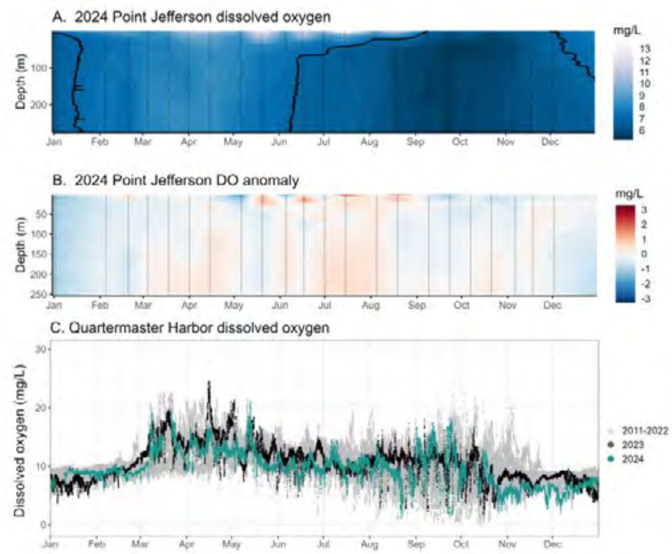


Figure 2 – contour plots of dissolved oxygen (DO) concentration (A) and DO anomaly (B) at Point Jefferson, as well as DO concentration in inner Quartermaster Harbor (C). The black line in panel A denotes DO of 7 mg/L.

2024 continued patterns that began in 2023 with similar timing and magnitude. Mid-2023 marked the beginning of a strong El Nino period that lasted until mid-2024, likely causing much of the warming in the water column that has persisted into 2025. Furthermore, earlier than normal upwelling on the Washington Coast coupled with reduced freshwater input likely facilitated an earlier shift to column-wide high salinity by July. On average, these warm and salty conditions accounted for roughly 25% of the reduction in dissolved oxygen experienced in 2024 due to reduced oxygen saturation.

King County Environmental Laboratory Scientists collecting samples aboard the R/V SoundGuardian.

Central Basin chlorophyll and nutrients

Authors: Kimberle Stark (King County DNRP, kimberle.stark@kingcounty.gov)
Edited by: Beth LeDoux (King County DNRP)
Website:https://green2.kingcounty.gov/marine; **Additional website for data**:
https://data.kingcounty.gov/Environment-Waste-Management/Water-Quality/vwmt-pvjw

Highlights

- The spring phytoplankton bloom occurred earlier in 2024 than the past several years, around April 1, the season ended after August 19 following significant rain events
- Surface nitrate+nitrite-N was low during phytoplankton blooms but never below detectable levels at any location, including Quartermaster Harbor, an unprecedented occurrence
- Average monthly nitrate+nitrite-N and silica in deep waters (>150 meters) were lower than the monthly baseline (1997-2013) for most of 2024

Overview

King County collects data twice monthly at 12 mainstem sites in the Central Basin and 2 in Quartermaster Harbor. Nutrients are analyzed in water from up to seven discrete depths and chlorophyll *a* is analyzed at five depths (two depths in Quartermaster Harbor). Entire water column profiles for chlorophyll fluorescence and nitrate are also collected at the 12 mainstem sites. Moorings at four locations collect chlorophyll fluorescence data at 15-minute intervals.

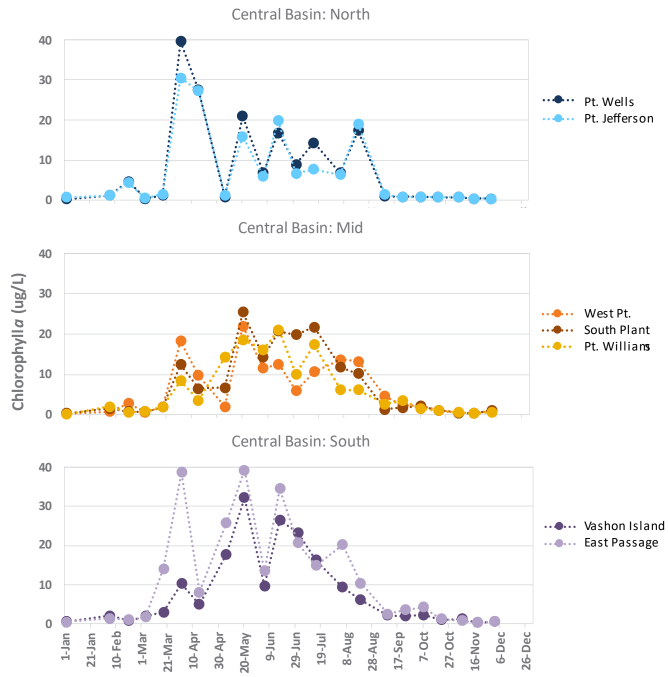


Figure 1. 2024 chlorophyll a in surface waters (< 2m) for seven Central Basin sites ordered north to south.

Narrative

Central Basin chlorophyll *a* data sampled twice monthly at 12 sites throughout the mainstem indicated the 2024 spring phytoplankton bloom occurred earlier than the past several years, around April 1st. Prior to 2024, a basin-wide bloom in early April had not been observed since 2017. Chlorophyll *a* declined sharply throughout the basin between the May 20-June 5 sampling events and the season ended after August 19th following significant rain events (Figure 1).

Chlorophyll *a* peaks and troughs corresponded well with upper water column density stratification patterns and overall, total annual chlorophyll *a* was lower in 2024 compared to the previous two years. High temporal resolution data (15-minute intervals) in inner Quartermaster Harbor (between Vashon/Maury islands) showed the trend of lower chlorophyll levels, particularly in late summer through fall, continued in 2024.

Dissolved nutrients (nitrate+nitrite-N, silica, and orthophosphate-P) in surface waters correlated with chlorophyll a levels, with the lowest values of the year observed in July corresponding with phytoplankton uptake and lack of freshwater input. However, nitrate+nitrite-N was never drawn down below detectable levels at any location, including Quartermaster Harbor, an unprecedented occurrence. Average monthly nitrate+nitrite-N and silica in deep waters (>150 meters) were lower than the monthly baseline (1997-2013) for most of 2024 (Figure 2). Although more variable at other locations, average monthly silica in surface waters at East Passage has been primarily below the monthly baseline since mid-2022.

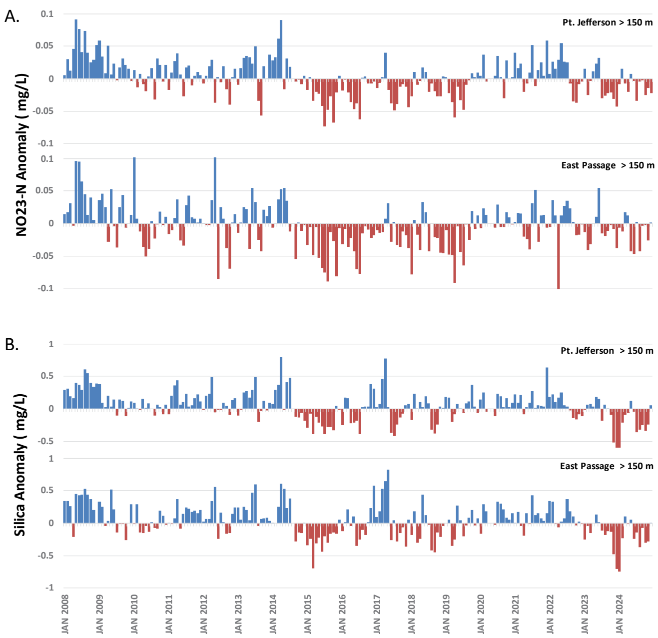


Figure 2. Nitrate+nitrite-N (A) and silica (B) monthly anomalies (compared to 1997-2013 baseline) for water > 150m at Pt. Jefferson and East Passage from 2008—2024.

King County Environmental Laboratory scientists (Christopher Barnes and Mattie Michalek) collecting samples on board the SoundGuardian

Harbor porpoises off Discovery Park

Brandt's cormorant with snake prickleback

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

Author: Jude Apple (Padilla Bay NERR/Dept of Ecology, japple@padillabay.gov), Sylvia Yang, Nicole Burnett, and Heath Bohlmann (Padilla Bay NERR/Dept of Ecology)
Edited by:
Primary Website: www.padillabay.gov
Additional website for data: https://cdmo.baruch.sc.edu/dges

Highlights

- Daily mean temperatures in Padilla Bay were generally warmer than pre-2015 long term daily means.
- Annual average temperature in 2024 for Padilla Bay waters was much warmer compared to the pre-2015 long-term anomaly record, but similar to more recent years post-2016.

Overview

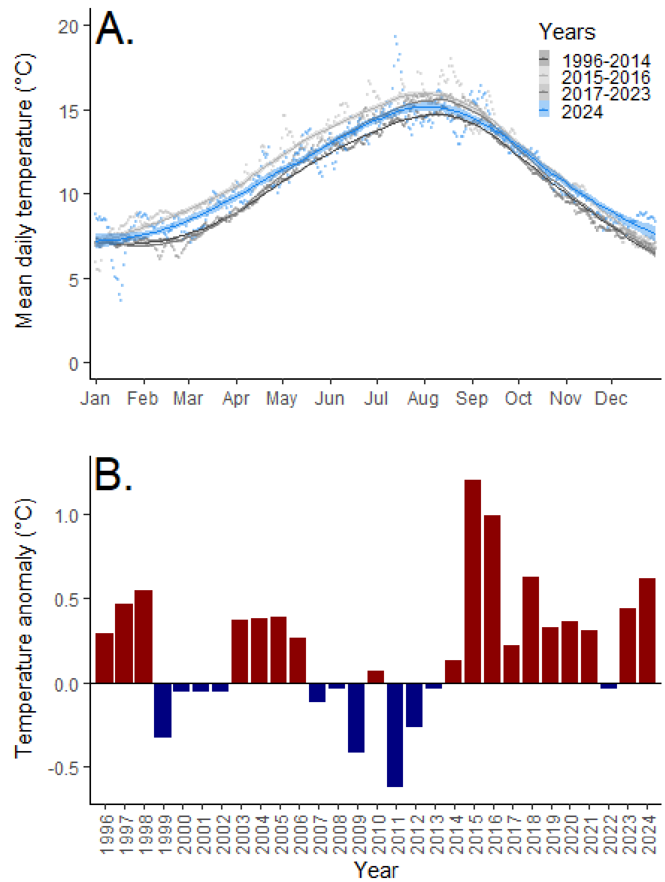
Padilla Bay is a tidally influenced shallow (<5 m) embayment north of Puget Sound and part of the National Estuarine Research Reserve System (NERRS). The Reserve maintains a long-term monitoring program (>20 years) at four stations throughout the bay that represent a range of conditions and nearshore habitats, including eelgrass meadows and deeper marine-dominated open water channels. High frequency (15-minute interval) monitoring data reveal trends in water column structure, plankton community dynamics, and 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 nearshore surface-waters in Padilla Bay reveals temperatures ranging from 0.5 to 22.4°C throughout 2024. By comparison, the minimum recorded water temperature in 2022 was -1.7°C. Mean annual water temperature (±SE) in 2024 (11.2 ± 0.2°C) was slightly lower than 2015 (11.7 ± 0.2°C) and 2016 (11.5 ± 0.2°C).

Throughout 2024, water temperatures all year were generally warmer than pre-2015 long-term daily means (1996-2014), and spring was warmer than the mean of the most recent 6 years (2017-2023), based on comparisons of non-overlapping confidence intervals (± 1 standard error). Compared to the 'blob' years (2015-2016), spring through summer temperatures were cooler, yet autumn was similar or warmer (Fig. A).

The annual mean temperature anomaly of +0.62°C for 2024 was lower than that of the 'blob' years (+1.1°C), but continued the pattern of positive anomalies occurring in recent years 2016-2023, with the exception of 2022 (Fig. B).



(A) Long-term patterns in temperature in Padilla Bay, including comparison of daily mean temperatures in 2015-2016, 2024 and long-term (1996-2014 & 2017-2023) daily means. LOESS fit (line) ± std. error (shaded) is shown. (B) long-term annual temperature anomalies (1996-2014 mean as baseline).

Temperature, salinity, and dissolved oxygen in northern Whidbey basin.

Authors: Daniel Sulak (Swinomish Indian Tribal Community, dsulak@swinomish.nsn.us)
Edited by: Sam Kastner (Western Washington University, College of the Environment)
Website: www.swinomish-nsn.gov/fisheries

Highlights

- 2024 represents the first full year of data collected for this monitoring program.
- Northern stations show more mixing and less variability compared to those in the south, which show greater Skagit River influence.

Overview

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

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 surface 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. 2024 represents the first full calendar year of measurements for this data set.

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 6.0 to 15.1°C with larger diurnal spreads in summer months (Fig. 1 C). Salinity ranged from 6.2 – 30.0 PSU with prolonged periods of freshening attributable to storm events (Fig. 1 G). Dissolved oxygen (DO) (Fig 1 K) measurements were not recorded during much of the spring and summer, but recorded values and those measured in depth profiles generally varied with chlorophyll *a* abundance (data not shown).

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 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 strong 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 daily, in individual profiles, and over the course of the year.

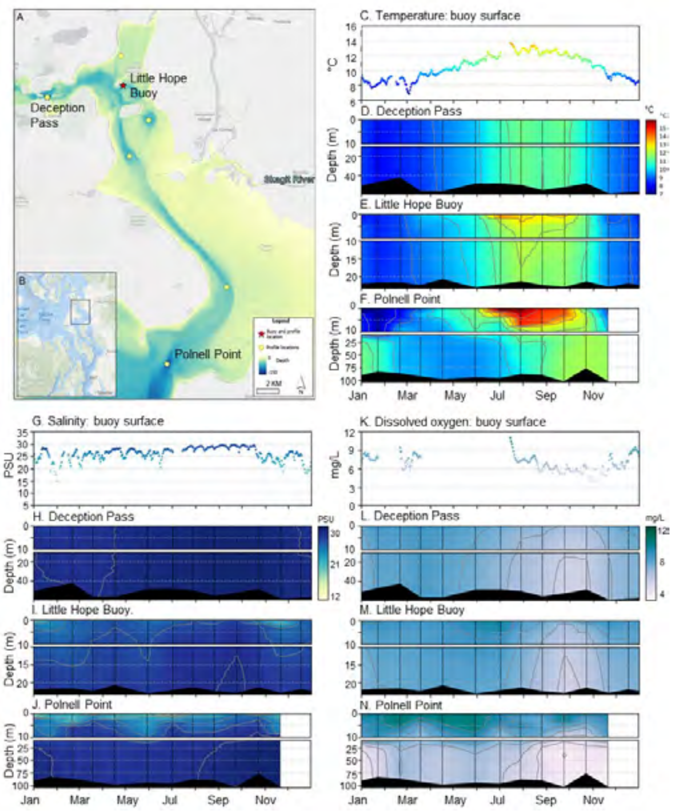


Figure 1: A: Observation locations in North Whidbey Basin. B: Study area extent. C, G, and K: daily means of continuous (15-minute interval) mooring data collected at the surface (0.7m) at Little Hope Buoy. D-F, H-J, and L-N: water column profiles for multiple parameters collected at Deception Pass, 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

Authors: Simone R. Alin (NOAA Pacific Marine Environmental Laboratory (NOAA/PMEL)), simone.r.alin@noaa.gov); Adrienne Sutton (NOAA/PMEL), Jan Newton (University of Washington), Seth Travis (University of Washington)
Edited by: Kimberle Stark
Website: https://pmel.noaa.gov/co2/story/Dabob; https://pmel.noaa.gov/co2/story/Twanoh;
Additional website for data: https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/Moorings/Dabob.html; https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/Moorings/Twanoh.html

Highlights

- Atmospheric CO_2 in Hood Canal averaged 12–13 ppm higher than the globally averaged marine surface air, with larger differences in fall–winter (14–20 ppm) than spring–summer (6–12 ppm) when regional primary production reduces the offset.
- Surface seawater xCO_2 averages were mostly within historical ranges at both sites, but were substantially higher at both sites in January and lower at Dabob in March than long-term means, resulting in a stronger than normal CO_2 source to the atmosphere in January and stronger sink than normal in March of 2024.

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, air-sea flux, and ocean acidification rates. Estuarine CO_2 seasonal and interannual variability is dynamic and reflects diverse river inputs, influence of upwelled marine waters, extreme events, and a strong imprint of primary production and respiration, resulting in exceptionally wide ranges of conditions and the longest "time of emergence" for the anthropogenic acidification signal across this global network (2044–2056; Sutton et al. 2019). Funding to support these observations and their analysis (2009–2025) has come from NOAA Global Carbon Cycle Program, NANOOS-IOOS, NOAA/PMEL, and the Washington Ocean Acidification Center.

Narrative

Preliminary 2024 data spanned most or all of the year at both sites, with observational gaps at Dabob during February 5–March 12 and November 17–December 31 and for atmospheric measurements only at Twanoh from November 7–December 31. Dabob had ~77% xCO_2 data return in 2024, and Twanoh had 95% and 81% for seawater and air data coverage, respectively. The 2024 atmospheric xCO_2 range at Dabob was 402–517 ppm and 395–547 ppm at Twanoh. Monthly average atmospheric xCO_2 at both Hood Canal moorings were higher than the globally averaged marine surface air as a result of regional emissions, by 6–12 ppm in March–August and 14–20 ppm during January–February and September–December (Figure 1). The smaller spring–summer offset between regional and global average atmospheric xCO_2 values likely reflects seasonal production of regional forests. Atmospheric xCO_2 variability, represented by 1SD bars, tends to be larger during summer–fall than winter–spring months, with the widest ranges in 2024 during July–September at both sites (Table 1).

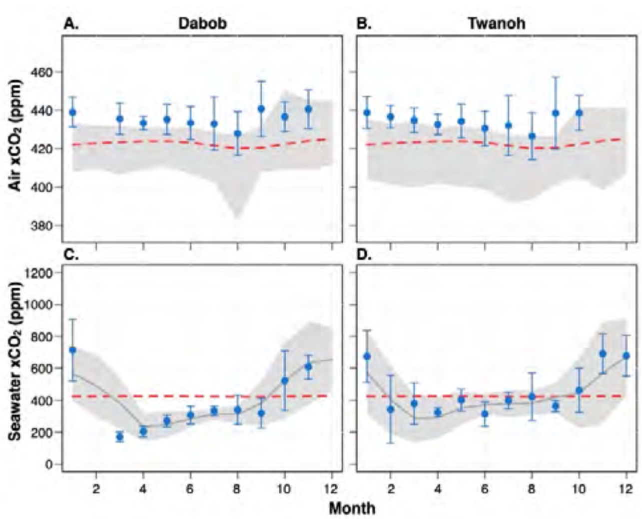


Figure 1. xCO_2 in air at 1.5 m above seawater (A, B) and in surface seawater at 0.5 m depth (C, D) on the Dabob Bay (A, C), and Twanoh (B, D) moorings. Because atmospheric CO_2 increases year after year, comparisons provided for the current year (2024) are the minimum and maximum monthly means observed across 2011–2023 at Dabob and 2009–2023 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 2024 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 2024 (NOAA/GML 2025).

During 2024, surface seawater xCO_2 measurements spanned 110–1471 ppm at Dabob Bay and 40–1870 ppm at Twanoh. At Dabob, mean ± 1SD seawater xCO_2 values for most months in 2024 were within the historical range (defined here as the time series mean ± 1SD through 2023), although the January mean was at the high end, and the March range was fully below the range, with means 146 ppm higher and 212 ppm lower than the long-term monthly averages, respectively. All 2024 monthly xCO_2 means at Twanoh were within the historical range, although both January and November had mean values 104 and 121 ppm higher than long-term averages, respectively. Variability was 63–90% higher at both sites in August and <50% of historical values in some spring and fall months at each site.

	Dabob				Twanoh			
	Air		Seawater		Air		Seawater	
Month	2024	2011–2023	2024	2011–2023	2024	2009–2023	2024	2009–2023
Jan.	436 ± 5	408–433	715 ± 193	569 ± 169	439 ± 8	404–436	675 ± 163	571 ± 262
Feb.	n.a.	410–432	n.a.	489 ± 196	437 ± 6	402–433	344 ± 213	403 ± 214
Mar.	433 ± 4	406–432	170 ± 31	382 ± 160	435 ± 6	400–434	379 ± 131	285 ± 153
Apr.	433 ± 4	410–431	204 ± 33	232 ± 89	432 ± 4	402–431	324 ± 29	291 ± 129
May	435 ± 8	410–431	269 ± 37	247 ± 82	434 ± 9	400–432	401 ± 67	351 ± 105
Jun.	433 ± 8	407–431	307 ± 56	282 ± 49	431 ± 9	399–430	313 ± 76	372 ± 67
Jul.	433 ± 14	402–429	333 ± 30	313 ± 37	432 ± 16	392–427	398 ± 50	378 ± 84
Aug.	428 ± 11	382–427	340 ± 92	311 ± 56	426 ± 12	394–427	422 ± 149	382 ± 78
Sep.	441 ± 14	407–432	319 ± 94	381 ± 142	439 ± 19	401–427	364 ± 34	416 ± 95
Oct.	437 ± 8	409–450	523 ± 186	521 ± 236	439 ± 9	405–441	461 ± 137	444 ± 223
Nov.	441 ± 10	409–445	608 ± 75	633 ± 260	n.a.	398–441	691 ± 125	570 ± 317
Dec.	n.a.	411–445	n.a.	655 ± 198	n.a.	407–441	679 ± 128	671 ± 242

Table 1: Atmospheric and surface seawater xCO_2 (in ppm) at the Dabob Bay and Twanoh moorings. Monthly means ± 1SD for 2024 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 across the time series through 2023. 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.

During spring–summer at the Hood Canal moorings, surface xCO_2 typically falls below local atmospheric xCO_2 values, reflecting surface primary productivity. Long-term air xCO_2 averages are higher than seawater by 37–190 ppm during March–September at Dabob and by 18–134 ppm during February–August at Twanoh. During 2024, high productivity conditions spanned March–September at Dabob and February–September at Twanoh, with air xCO_2 88–266 ppm and 4–118 ppm higher than seawater, respectively. In fall and winter months, seawater has higher xCO_2 than air by 68–231 ppm at Dabob and 20–246 ppm at Twanoh. In January and October–November of 2024, mean seawater xCO_2 was 23–279 ppm higher than air xCO_2 across both sites. These seasonal differences make surface waters a source of CO_2 to the atmosphere in fall–winter and a CO_2 sink during spring–summer. In 2024, air-sea CO_2 gradients indicated a much stronger source than average in January at both sites, a much stronger sink than average during March at Dabob, and a somewhat stronger sink in September at both sites.

Shellfish beds and harvesters on the Dosewallips River delta in Hood Canal.

References and contribution number

NOAA Global Monitoring Laboratory (2025): Global Monthly Mean CO_2 data, https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_mm_gl.txt; accessed on April 29, 2025.

Sutton, A.J., R.A. Feely, S. Maenner-Jones, S. Musielewicz, J. Osborne, C. Dietrich, N. Monacci, J. Cross, R. Bott, A. Kozyr, A.J. Andersson, N.R. Bates, W.-J. Cai, M.F. Cronin, E.H. De Carlo, B. Hales, S.D. Howden, C.M. Lee, D.P. Manzello, and 12 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 5782.

San Juan Channel/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: Kim Stark (King County)
Website for data: https://www.nanoos.org/products/san_juan_pef/home.php

Highlights

- Warmer surface water temperatures at station North and South
- Saltier surface and deep waters at station North and South
- Highest seabird density and lowest marine mammal density in the 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, marine bird and mammal observations are conducted on a transect line 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 2004-2024) for both stations at the surface (0-5 m) and deep waters (10 m above seabed; North - 120 m, South - 90 m).

During fall 2024, 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 and reversed to cooler than average during the last two cruises. Deep temperature anomalies (not shown) were warmer than average (five of six cruises) at North station and cooler than average at South station during the middle four cruises.

Salinity was consistently higher than average at both surface and deep waters at North and South station during Fall 2024 (Figure 2). Salty surface anomalies at North station were observed on each of the six fall cruises and five of six for South station. Deep anomalies were consistently (five of six cruises) salty in the North with a mixed signal in the South, reflecting a shift from upwelling (saltier than average) to downwelling (average).

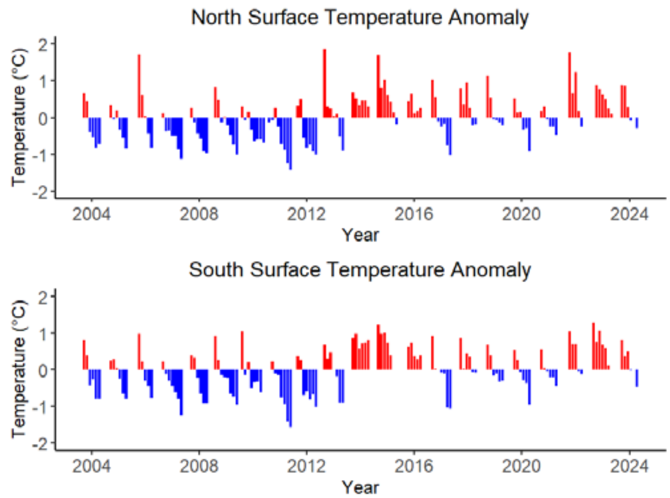


Figure 1: Temperature anomalies at North and South station during the fall from 2004-2024. Red indicates warmer (positive) temperature anomalies and blue indicates cooler (negative) temperature anomalies. The mean and standard deviation for fall surface temperature were 10.14 ± 0.65 °C at North and 10.08 ± 0.63 °C at South.

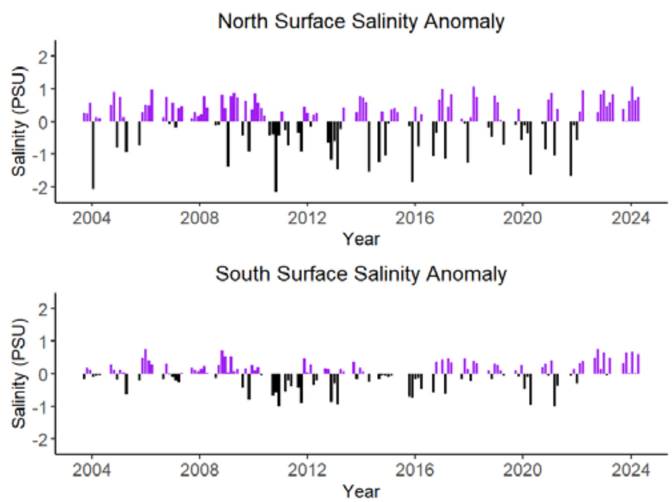


Figure 2: Salinity anomalies at North and South station during the fall from 2004-2024. Purple indicates saltier (positive) salinity anomalies and black indicates fresher (negative) salinity anomalies. The mean and standard deviation for fall surface temperature were 30.11 ± 0.79 PSU at North and 30.83 ± 0.39 PSU at South.

Observations of seabirds and marine mammals (harbor porpoises, harbor seals, Steller sea lions; Figure 3) from six transects during the fall reveal contrasting interannual patterns. Seabird densities were the highest on record. Notably, Common murres were very abundant (103 indiv./km^2) and contributed 54% of the total density, the highest in the record (previous high, 34% in 2012). In contrast, marine mammals show relatively low and decreasing densities starting with the marine heatwave of 2014. The last three years have shown especially low combined marine mammal densities with 2024 marking the lowest density in the record.

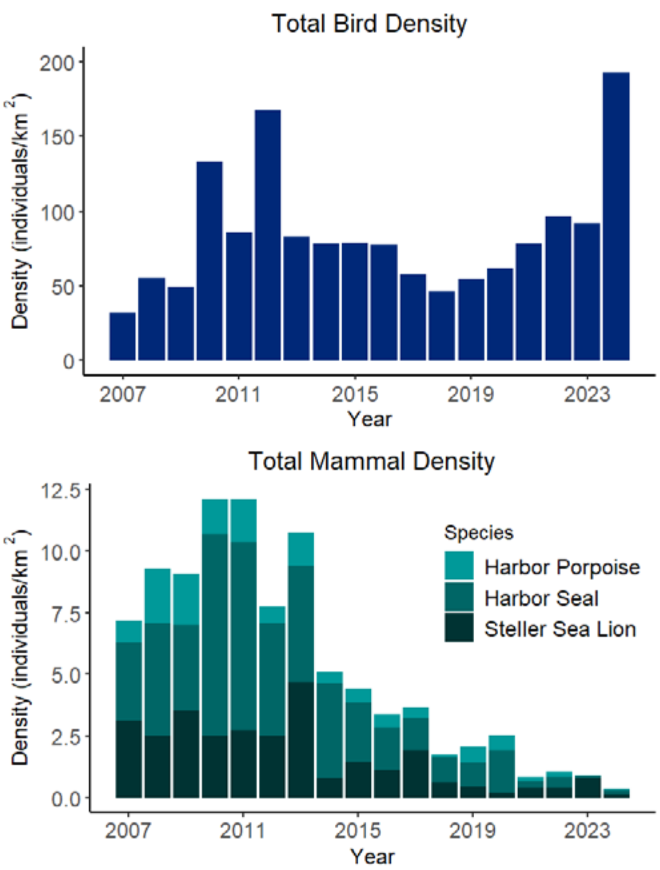


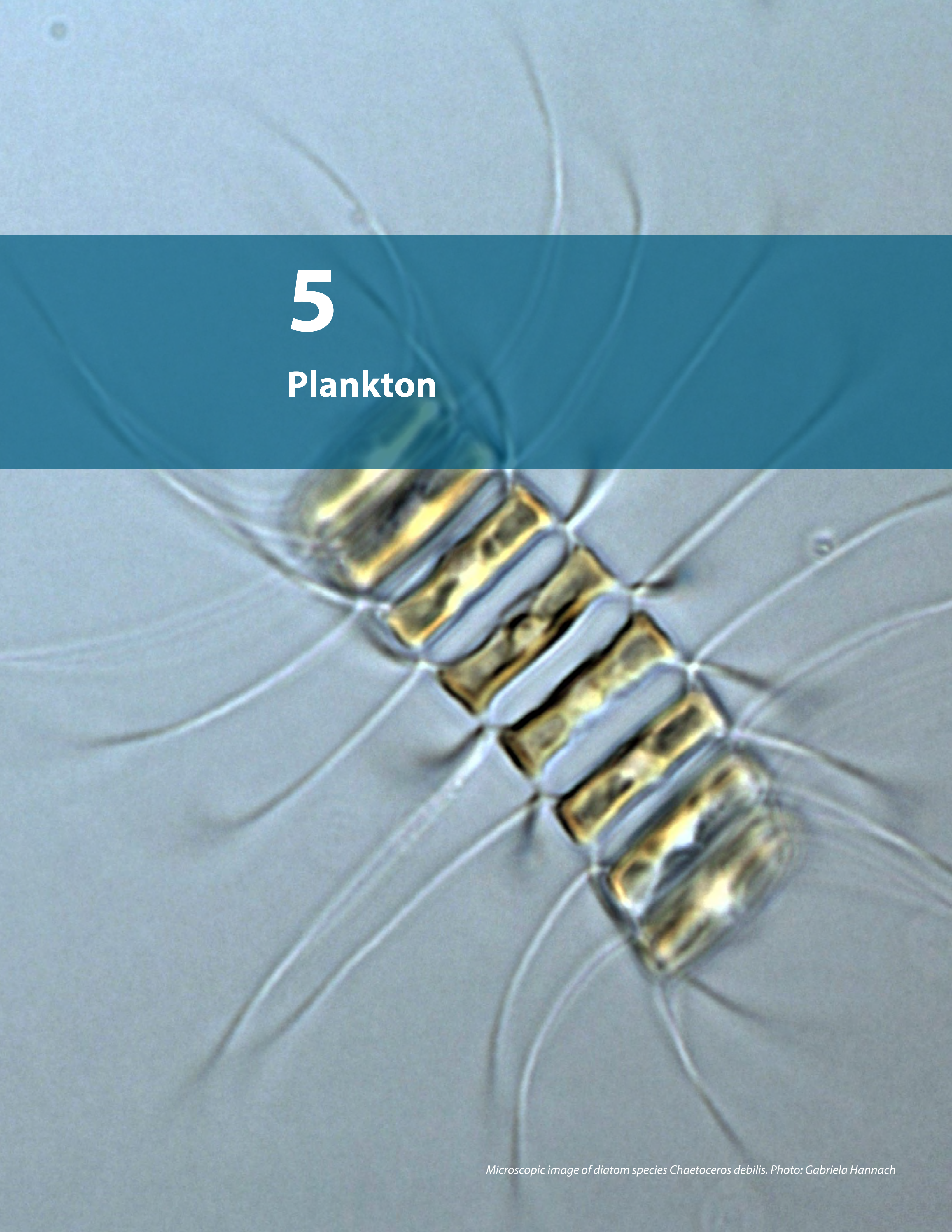
Figure 3: Bar plot displaying density (individuals/km^2) from fall surveys from 2007-2024 (note: different scales on the y-axis). Left panel shows total bird density; right panel shows mammal density, harbor porpoise (light teal), harbor seal (dark teal), Steller sea lion (dark green).

In summary, while temperature and salinity anomalies were within the typical range measured during the time-series, 2024 marked the third consecutive year that water temperatures were consistently warmer than average at the surface and the second consecutive year with more saline waters at the surface at both stations. Marine bird densities continued to increase following a low point in 2018 and reached a record high in 2024, largely due to the Common murre contribution. However, marine mammal densities continued a 12-year trend of decreasing densities since 2013. PEF continues to provide invaluable data and the only long-term record of these two oceanographic stations within the San Juan Archipelago.

R/V Kittiwake at Station North. Photo credit: Israel Marquez

5

Plankton



Microscopic image of diatom species Chaetoceros debilis. Photo: Gabriela Hannach

Marine Microplankton in Central Basin

Authors: Lyndsey Swanson (King County, Lyndsey.Swanson@kingcounty.gov); Kelsy Cain (King County), Julia Bos (King County), John Zalusky (King County)
Edited by: Elizabeth Frame 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; **Additional website for data**: https://data.kingcounty.gov/Environment-Waste-Management/Marine-Phytoplankton-Samples-by-Taxonomic-Group/uydm-m3ym/about_data

Highlights

- The largest observed microplankton bloom occurred in June, consisting mainly of the chain-forming diatoms *Chaetoceros*, *Ditylum*, and *Rhizosolenia*.
- The dinoflagellate *Heterocapsa* bloomed in record high abundances basin wide, with the highest abundances in North Central Basin.

Overview

King County analyzes microplankton 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 2024, including nine open water sites and one shallow embayment (Dockton in outer Quartermaster Harbor; not reported here).

Narrative

Total microplankton biovolume in 2024 was 19.8% higher than the previous 9-year average (2015-2023; data not shown). The top biovolume contributing taxa were predominantly chain-forming diatoms. The 2024 growing season began a month early in late March with a bloom dominated by *Thalassiosira* (Fig. 1). This diatom typically signals the beginning of the growing season in Central Basin, except in 2021 and 2022. By April, *Chaetoceros* had succeeded *Thalassiosira* and maintained dominance in the community through July. Small blooms of *Lauderia/Detonula* and *Skeletonema* were also observed in April. A bloom of the small-celled dinoflagellate *Heterocapsa* was observed at all stations in April, concurrent with a similar bloom in Whidbey Basin. Recorded abundances greatly exceeded previous observations of *Heterocapsa* in this basin, with the highest abundance observed at Point Wells of 783 particles/mL (data not shown). The largest microplankton bloom of the season was detected in June, primarily comprised of *Chaetoceros*, *Ditylum*, and *Rhizosolenia* (*Sundstroemia*). A *Chaetoceros* bloom observed at East Passage in June was the largest observed for this taxon (188.6 mm^3/L). *Rhizosolenia* bloomed from late May through late June and was succeeded by *Ditylum* which bloomed from late June through July. *Ditylum* persisted at lower biovolumes through the end of the growing season. From late June to early August a small, lingering bloom of *Eucampia* was recorded. The large-celled dinoflagellate, *Noctiluca,* was observed basin wide from April to September but never in high abundances. In early August, microplankton biovolume sharply decreased at all stations which coincided with a period of unusually high rainfall. The community rebounded slightly in late August with a small mixed diatom bloom; however, microplankton biovolumes never recovered to summer levels and steadily decreased into winter. The growing season ended nearly basin wide in early September except in Elliott Bay where *Ditylum*, *Thalassiosira* and *Chaetoceros* maintained low-level biovolumes into early October.

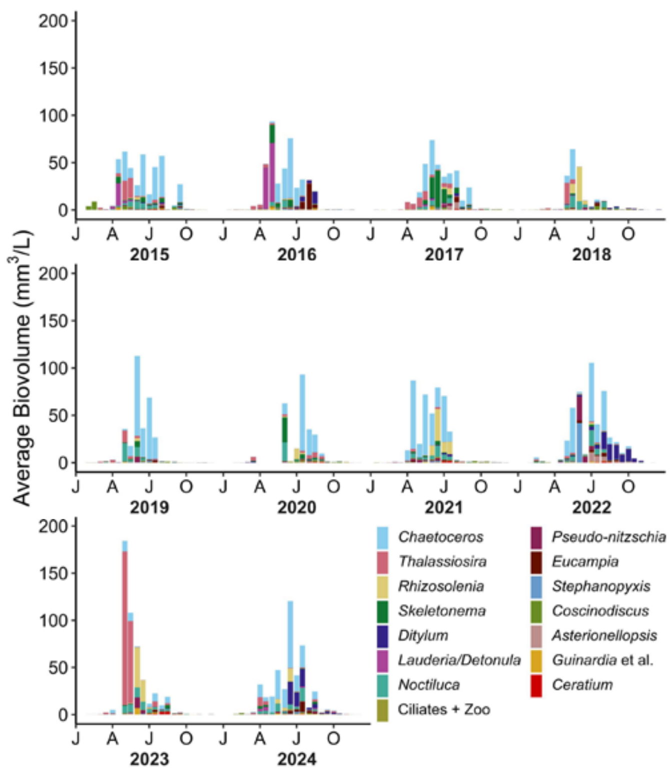


Figure 1. Biovolume (mm^3/L) of the top 15 taxa identified using FlowCam® from 2015 to 2024. Plotted values are the average of 9 Central Basin stations (Dockton not included). No data collected April-May 2020 and early April 2022.

Marine Microplankton in Whidbey Basin

Authors: Lyndsey Swanson (King County, Lyndsey.Swanson@kingcounty.gov); Kelsy Cain (King County), Julia Bos (King County), John Zalusky (King County)
Edited by: Elizabeth Frame 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; **Additional website for data**: https://data.kingcounty.gov/Environment-Waste-Management/Marine-Phytoplankton-Samples-by-Taxonomic-Group/uydm-m3ym/about_data

Highlights

- Large blooms of *Eucampia*, *Alexandrium*, and *Asterionellopsis* observed in Penn Cove.
- A large, basin-wide *Heterocapsa* bloom observed in April, concurrent with a similar bloom in Central Basin.

Overview

In 2022, King County began analyzing microplankton assemblages in Whidbey Basin twice monthly and 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 2024, including an open water site (Saratoga Passage), a submerged delta site (Port Susan), and three shallow embayment sites (Penn Cove).

Narrative

Microplankton biovolume increased from winter levels in April, which indicated that the 2024 growing season had begun. Biovolumes recorded at Port Susan were consistently lower than the other sites in this basin, likely related to the influence of the nearby Stillaguamish River. The first bloom observed consisted mainly of the chain diatoms *Lauderia*/*Detonula* and *Thalassiosira*. The small-celled dinoflagellate *Heterocapsa* was detected in high abundance in April, reaching a peak of 503 particles/mL at Saratoga Passage (data not shown), concurrent with a *Heterocapsa* bloom in Central Basin. Successively larger, discrete blooms of *Heterocapsa* have been observed in Whidbey Basin annually since 2022 and reached an abundance high in 2024. By May, the community was dominated by *Pseudo-nitzschia* and *Guinardia* et al., a mix of cylindrical chain diatoms which includes *Guinardia*, *Cerataulina*, *Leptocylindrus*, and *Dactilyosolen*. Blooms of the large-celled dinoflagellate *Noctiluca* contributed substantially to the spring bloom's total biovolume, then declined into summer and fall. Despite notable contributions to biovolume measurements, *Noctiluca* was not observed in high abundance at any station in 2024. A short-lived bloom of *Rhizosolenia (Sundstroemia*) peaked in June at every station except Penn Cove – West, followed by a steady decrease of the total microplankton biovolume, reaching a mid-season low in July. *Chaetoceros* largely dominated the community during July and remained a top biovolume contributor into late October. Two genera formed blooms in August larger than any observed in prior years: *Eucampia* at Penn Cove - Entrance (4.03 mm^3/L) and *Alexandrium*, a dinoflagellate that can produce saxitoxin, at Penn Cove – West (12.11 mm^3/L). The large-celled chain diatom *Ditylum* bloomed in August and maintained steady biovolume contributions throughout October. A mixed diatom bloom consisting mainly of *Chaetoceros*, *Asterionellopsis*, and *Ditylum* was detected in September and reached its peak in October. *Asterionellopsis* dominated the October community, reaching a peak biovolume of 110.4 mm^3/L at Penn Cove – Entrance. Biovolume levels dropped notably in November to low levels of *Thalassiosira* and *Ditylum*, signaling the end of the growing season in this basin.

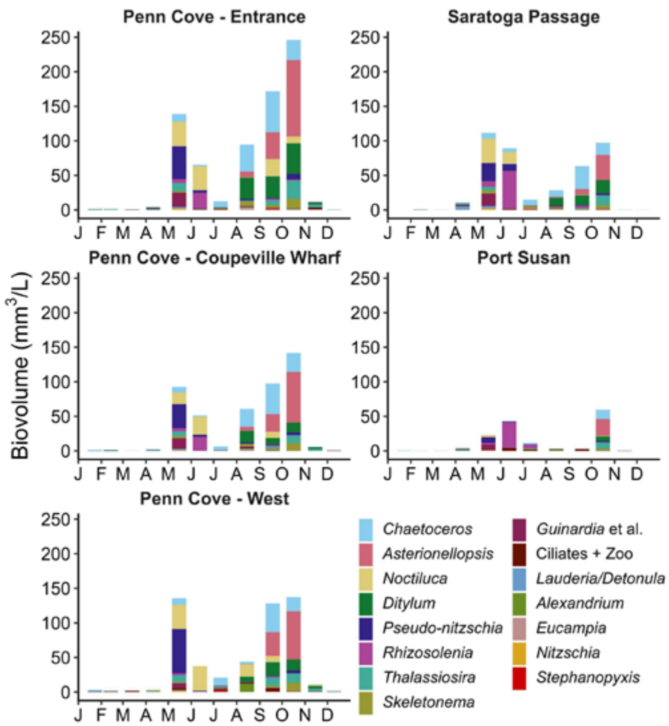


Figure 1: Biovolumes (mm^3/L) of the top 15 taxa identified using FlowCam® in 2024 at each station sampled in Whidbey Basin.

Puget Sound Zooplankton

Authors: Amanda Winans (University of Washington, School of Oceanography, awinans@uw.edu); Emily Seubert, Olga Kalata, Karen Chan (University of Washington, School of Oceanography)
Edited by: 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 2024, mesozooplankton total biomass in the southern Salish Sea was generally lower than the monthly averages observed from 2014 to 2023
- The timing of peak mesozooplankton biomass was mostly within the expected window or occurred earlier

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 locations (Fig. 1) were sampled bi-weekly from March through October. Samples were identified to species-level at UW.

Narrative

Most total biomass values in 2024 were below the 2014-2023 monthly averages, with several falling outside of one standard deviation from the mean (Fig. 2). Some central and southern stations experienced biomass build up earlier in the year, with slightly above average values in late winter or early spring.

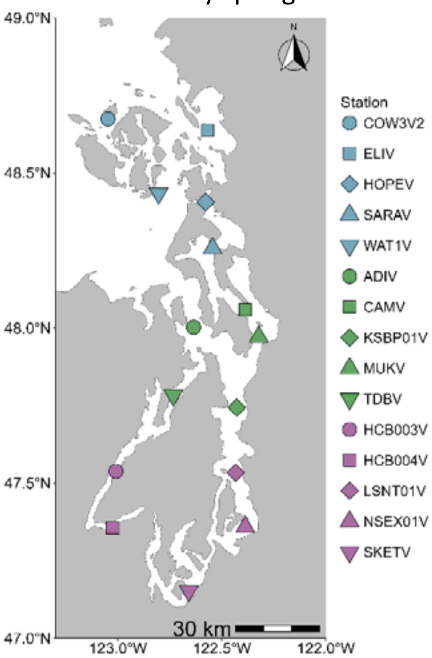


Figure 1 Map of the sampling locations. Symbols are color-coded by region (northern, central, southern) and correspond to stations in Figure 2.

Large subarctic oceanic copepods (*Eucalanus spp*. and *Neocalanus* spp.), which contributed to exceptionally high biomass at northern stations (COW3V2, WAT1V, ELIV) between 2019 and 2022, were still present in spring 2024, but at reduced levels. In Bellingham Bay (ELIV), biomass in May was above average, driven primarily by smaller copepods (*Pseudocalanus* spp.), *Neocalanus plumchrus,* and cancrid crab larvae. In Whidbey Basin, SARAV recorded biomass more than one standard deviation above average in September, dominated by amphipods, euphausiids, and the resident copepod *Calanus pacificus.* Admiralty Inlet (ADIV), historically one of the highest-biomass stations, recorded its sixth-highest value on record in its typical peak month of May, with chaetognaths, *Pseudocalanus* spp., crabs, and juvenile euphausiids comprising the dominant taxa.

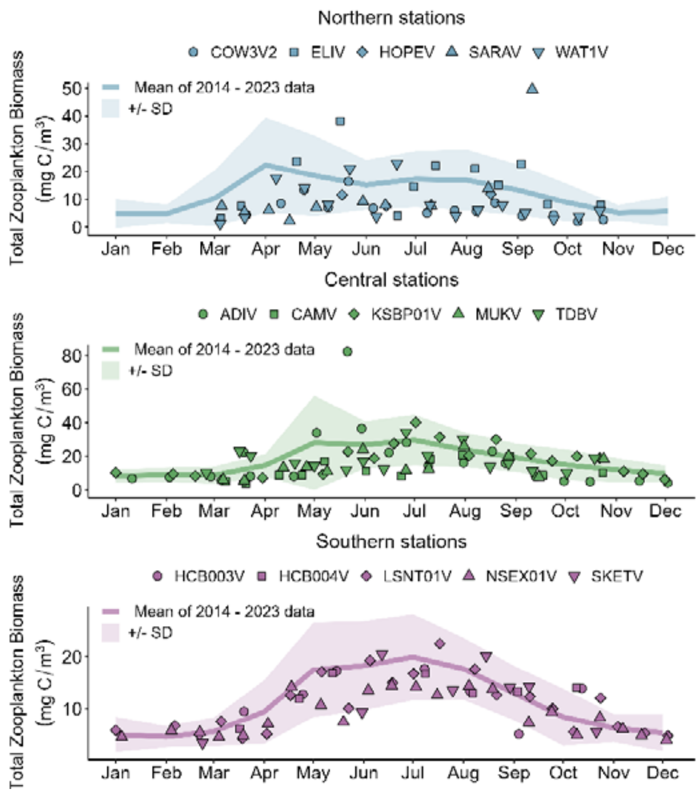


Figure 2 Time series of total mesozooplankton biomass (mg C/m³) at northern, central & southern stations in 2024, shown with monthly mean of 2014-2023 data ±1 SD.

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), and Stillaguamish Tribe (since late 2019). Funding for 2024 sampling was provided by King County and the WDFW.

Zooplankton abundance and community composition in Padilla Bay

Authors: Nicole Burnett, Padilla Bay National Estuarine Research Reserve/Dept of Ecology (PBNERR, nburnett@padillabay.gov); Sylvia Yang (PBNERR), Heath Bohlmann (PBNERR)
Edited by: Sylvia Yang
Website: https://ecology.wa.gov/water-shorelines/shoreline-coastal-management/padilla-bay-reserve;

Highlights

- There was less zooplankton in Padilla Bay compared to the previous years, except in the Fall when total abundances were higher.
- Zooplankton community composition deviated from the normal composition in both April and October.

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 153 µm mesh net with a 1 ft diameter opening at an open-water site located in a large, ~20 m deep channel adjacent to Padilla Bay (Gong Station).

Narrative

Zooplankton abundances (2008-2023) were consistently lower during the winter and higher in both the spring and mid-summer to early fall, though the timing and magnitude of these peaks vary annually (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 (2008-2023, Figure 1B).

The monthly total zooplankton abundances in 2024 were less than the long-term mean (2008-2023) but still within 1 standard deviation of the mean for most months. However, the total abundances in August were less than 1 standard deviation below the mean, and September and October total abundances were greater than 1 standard deviation above the mean (Fig 1A).

Additionally, the zooplankton community composition in April skewed towards June and October skewed towards August. The difference in April is due, in part, to fewer copepod nauplii and more polychaetae larvae than usual (data not shown). The difference in October is due to an increase in numerous plankton groups including copepods, barnacles, and polychaetes; however, appendicularians showed the most dramatic increase (Fig 1B).

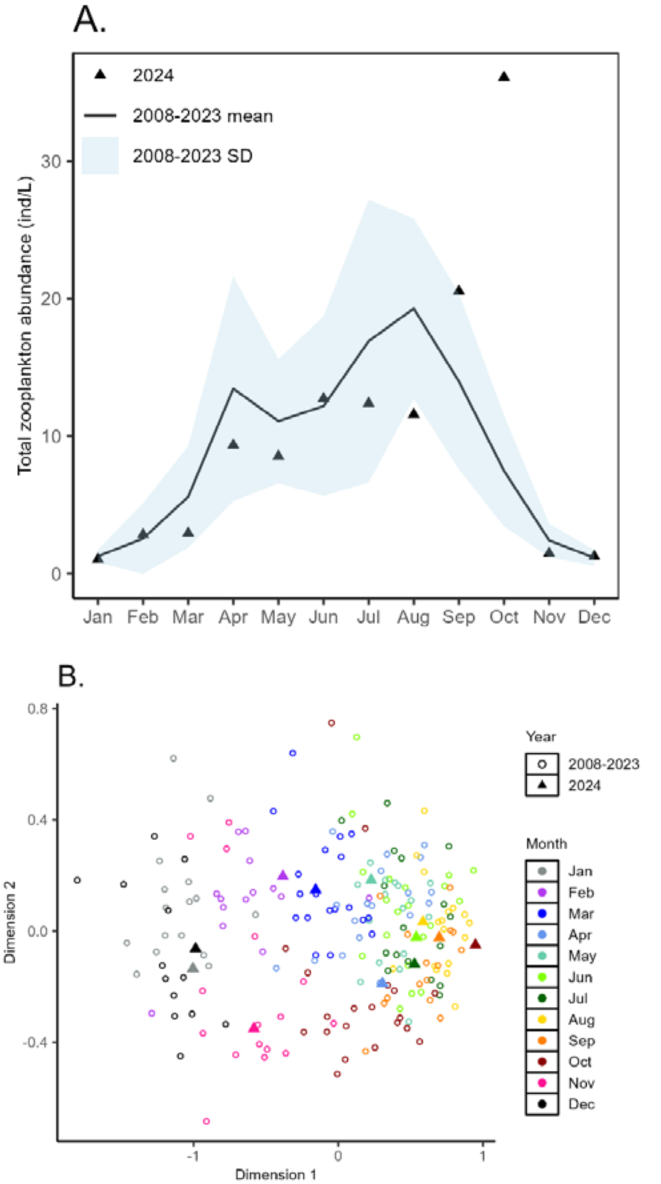


Figure 1 A) Mean monthly total zooplankton at Gong Station, 2008-2024. The triangles are the monthly mean of 2024 replicates. The black line is the monthly mean of total zooplankton from 2008–2023 and the gray band is +/- 1 SD. B) Non-parametric multidimensional scaling ordination (NMDS) of zooplankton community composition at Gong Station, 2008-2024. Each point (2008-2023 open circle, or 2024 triangle) in the NMDS is the mean of replicates for a sample month.

Spatial and temporal dynamics of larval Dungeness crab

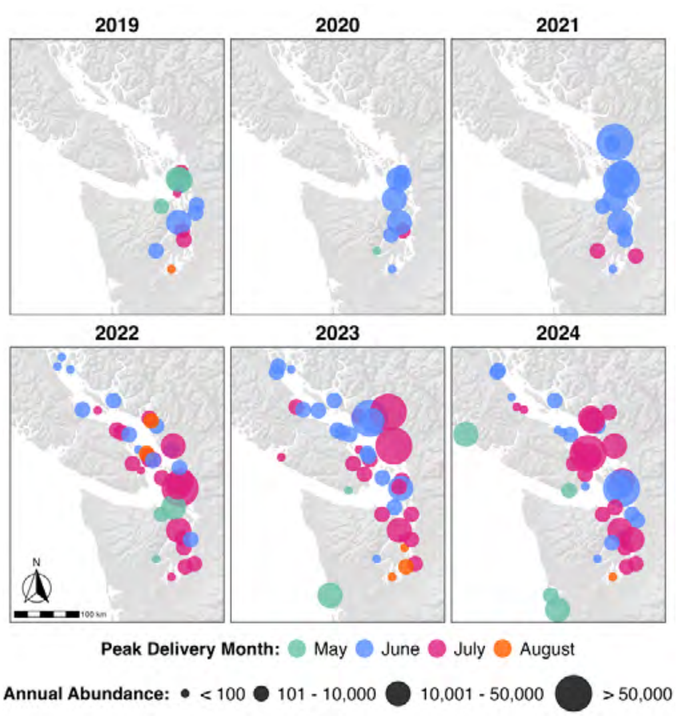
Authors: Ally Galiotto (Puget Sound Restoration Fund, pnwcrab@gmail.com), Emily Buckner (Puget Sound Restoration Fund), Claire Cook (University of Washington), Heather Earle (Hakai Institute), Devynn Gately (Jamestown S'Klallam Tribe), Sarah Grossman (Swinomish Indian Tribal Community), Margaret Homerding (Nisqually Indian Tribe), Blair Winnacott (Washington Department of Fish & Wildlife)
Website: www.pnwcrab.com

Highlights

- Dungeness crab megalopae abundance was highest in the central Salish Sea region, with decreasing abundance to the north and south.
- Megalopal abundance was moderate in 2024 compared to previous years, with regional variations in timing and peak larval flux.

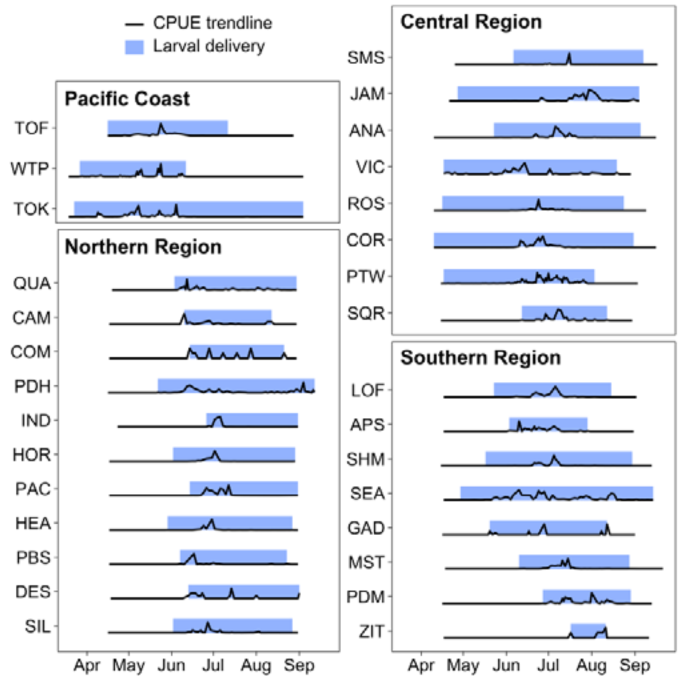
Narrative

In 2024, Pacific Northwest Crab Research Group (PCRG) and Hakai Institute partners deployed light traps at 50 sites spanning Washington and British Columbia (22 WA; 28 BC) to monitor daily late-stage larval (megalopal) Dungeness crab abundance trends from April to September. Dungeness crab megalopae were first reported on the outer coast in late March, followed by sites in the eastern Strait of Juan de Fuca and northern Whidbey Basin in early April. Sites located north in the Strait of Georgia or south of Admiralty Inlet did not begin capturing megalopae until mid-May.



Total annual abundance of Dungeness crab megalopae observed at light trap sites from April to September, 2019-2024. Circle size indicates the magnitude of annual abundance; color denotes the month of peak larval delivery at each site.

Periods of peak larval flux also varied by region, with the highest daily abundances occurring in May on the outer coast, June in Whidbey Basin and Hood Canal, and July in the northern and southern Salish Sea regions. In WA, monthly totals were similar in June and July (n = 92,326 June; 96,780 July), while sites in BC observed a majority of megalopae in July (n = 43,088 June; 119,478 July). Overall, catches were moderate relative to previous years, except for sites in the Gulf Islands and southern Strait of Georgia, where catches were comparatively higher. Consistent across all sampling years, total larval abundances were highest in the central Salish Sea region.



Timing of larval delivery at light trap sites in 2024, represented by blue bars. Black trendlines show catch per unit effort (CPUE), calculated as catch per night for each trapping period.

The last megalopal catch of 2024 occurred in mid-September, though at a few sites larval delivery ended by mid-June. Duration of larval delivery varied by site, with time between the first and last catch ranging from 12 to 156 days (mean = 81 days). Sites with the longest larval delivery window (>100 days) were generally located in the central Salish Sea, northern Hood Canal, and Willapa Bay. As the megalopal phase is roughly a month, long periods of larval delivery likely indicate that crab larvae are delivered to these sites from multiple natal sources.

Marine Biotoxins

Authors: Tracie Barry, Washington Department of Health, (tracie.barry@doh.wa.gov); Jerry Borchert, Washington Department of Health
Edited by: Elizabeth Lorence (WDOH), Michelle Lepori-Bui and Melissa Petrich (Washington Sea Grant)
Website: https://doh.wa.gov/community-and-environment/shellfish/recreational-shellfish/illnesses/biotoxins; https://doh.wa.gov/shellfishsafety

Highlights

- Marine biotoxins that cause Paralytic (PSP), Diarrhetic (DSP) Shellfish Poisoning caused 20 commercial and 30 recreational shellfish harvest closures.
- PSP reached lethal levels (≥ 1,000 µg/100g tissue) on the Coast, and in Strait of Juan de Fuca, North and Central Sounds and Whidbey Basin.
- There were no ASP/domoic acid closures in 2024

Overview

The Marine Biotoxin Program at the Washington Department of Health prevents biotoxin related illness and death of shellfish consumers. PSP monitoring began in 1957, with the current iteration of the program consisting of over 100 shellfish monitoring sites routinely tested for Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP; domoic acid), and Diarrhetic Shellfish Poisoning (DSP). Samples are submitted by a wide variety of partners and testing is supported by phytoplankton monitoring by SoundToxins and the Olympic Region Harmful Algal Blooms Partnership (ORHAB). Real-time biotoxin status and shellfish closure information is provided to the public on the Shellfish Safety Map at doh.wa.gov/shellfishsafety.

Closure thresholds for biotoxins levels in shellfish are:

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

Narrative

Shellfish closures for PSP toxins began in late May in the North Sound and along the Pacific Coast. During the 2024 coastal event, ORHAB partners reported a rapidly developing *Alexandrium* bloom. PSP in mussels exceeded 1,000 µg/100 g on the southern Washington coast for the first time and reached 150 µg/100 g in oysters from Willapa Bay (Figure 1). No biotoxin-related illnesses were confirmed related to Washington shellfish, but more than 40 PSP intoxications were caused by consuming recreationally harvested Oregon shellfish, primarily mussels (Watson, 2025). Two Washington residents were included in the outbreak. This PSP event caused significant shellfish closures and recalls with losses exceeding $1,000,000 for Willapa Bay alone, and economic hardship for rural coastal communities. Coastal PSP events of this magnitude are infrequent, but were documented in 1942, 1957, 1984, 1992 and 1997. Due to the significance of this event, shellfish growers and managers requested cyst mapping of Grays Harbor and Willapa Bay to support decision making (*see Alexandrium Species Cyst Mapping*).

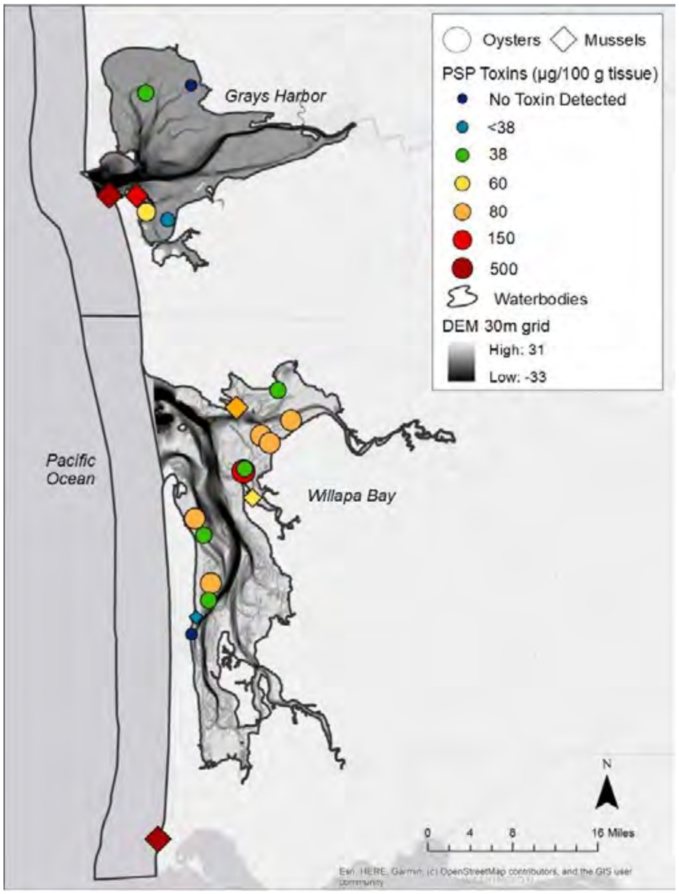


Figure 1 PSP results from south coast shellfish collected during the event peak, May 26 through June 1, 2024. Digital elevation model 30m grid (NCEI, 2018)

By the end of July, coastal PSP levels had declined below safe consumption limits, but PSP levels resulted in shellfish closures in the Strait of Juan de Fuca, North Sound, Central Sound and Whidbey Basin. PSP levels peaked in late August, with widespread lethal levels of toxins (>1,000 µg/100g tissue) (figure 2). The highest level of PSP toxins detected in mussels in 2024 was 1,513 µg/100g from Kingston Marina in the Central Sound on

August 12. The highest PSP detection in 2024 was in rock scallop viscera from the Strait of Juan de Fuca collected July 31 at 5,434 µg/100 g. Adductor meat from the same sample was 206 µg/100 g. PSP impacts were significant in 2024, largely due to the coastal PSP event. The number of PSP closures was consistent with previous years, with 26 recreational shellfish closures and 20 commercial closures. The widespread and high PSP levels in 2024 may indicate significant cyst deposition in the same areas.

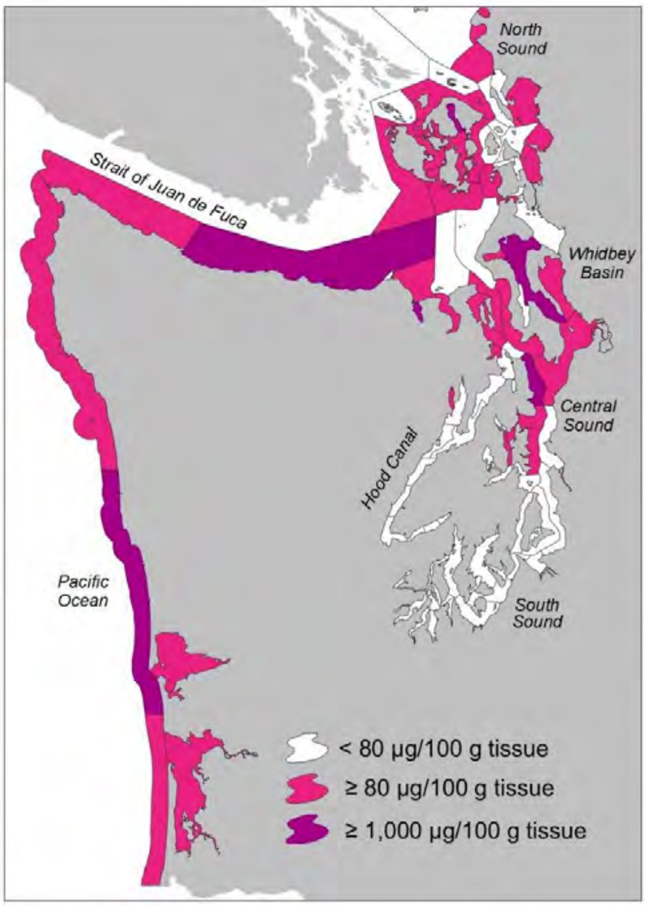


Figure 2. Distribution of shellfish samples where PSP exceeded the closure threshold. Shellfish may not be collected from every area and areas may be closed based on nearby results.

The 2023 DSP event that caused widespread closures in the South Sound continued into early May of 2024. Additional DSP closures occurred in June and July in Sequim Bay, in the Strait of Juan de Fuca and Kilisut Harbor in the Central Sound, respectively. In October DSP impacted Liberty Bay in the Central Sound, and the typical seasonal Budd Inlet DSP event began in mid-November continuing into 2025 (Figure 3). The maximum DSP level was 129 µg/100 g in mussels from Budd Inlet, in the South Sound on January 2, 2024. DSP impacts were reduced from previous years, with four recreational shellfish closures and no commercial closures. There were no ASP/domoic acid closures in 2024, marking the first year without a regulatory exceedance in a decade. The highest ASP level of 2024 was 10 ppm detected in razor clams from Willapa Bay on March 13. The highest level detected within the Salish Sea was 3 ppm in geoduck from Sequim Bay on May 6.

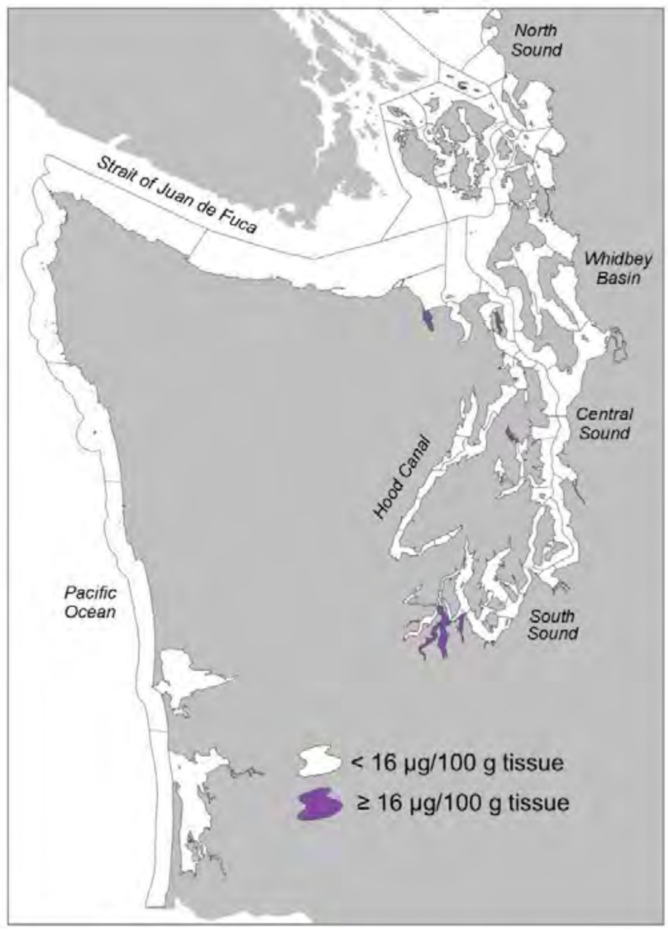


Figure 3. Distribution of shellfish samples where DSP exceeded the closure threshold. Shellfish may not be collected from every area and areas may be closed based on nearby results.

References

National Centers for Environmental Information. 2018. NOAA NOS Estuarine Bathymetry - Willapa Bay (P270). National Centers for Environmental Information, NOAA. doi:10.7289/V5HD7T0G [June 17, 2025]

Madison Watson. 2025. Paralytic Shellfish Poisoning — Oregon, May–July 2024. EIS Conference. CDC. https://www.cdc.gov/eis-conference/php/media-resources/paralytic-shellfish-poisoning.html.

SoundToxins

Authors: Michelle Lepori-Bui (mdtlb@uw.edu) and Melissa Petrich (Washington Sea Grant)
Edited by: Tracie Barry and Jerry Borchert (Washington State Department of Health)
Website: www.soundtoxins.org

Highlights

- The most frequently reported blooms of the year were in the genera *Chaetoceros*, *Rhizosolenia/Sundstroemia*, and *Ditylum*
- A large bloom of *Alexandrium* affected the Pacific Coast in May. Within Puget Sound *Alexandrium* observations peaked about a month later than previous years.
- *Azadinium* and *Karenia* were officially added to the target list after *Karenia* was observed at higher frequencies on the Pacific Coast

Overview

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

Narrative

In 2024, the SoundToxins network had a total of 969 sampling visits across 29 sites. There were 9945 individual observations, 312 of which were blooms. The most frequently reported genus was *Chaetoceros*, which was also most frequent in the first and third quarters of the year (Figure 1). *Rhizosolenia/Sundstroemia* (a genus recently split but still recorded together) was second overall and most frequently reported in April to June. *Ditylum* was third overall and most frequently reported in October to December.

The most notable HAB event of the year was a large *Alexandrium* bloom on the Pacific Coast in May. Multiple people were sickened in Oregon, and Washington experienced the first commercial closure in Willapa Bay since 1997. The bloom was recorded by the Olympic Region Harmful Algal Bloom (ORHAB) partnership which monitors that region. Within Puget Sound, *Alexandrium* observations by SoundToxins peaked about a month earlier than usual, with present and common observations in July, and blooms recorded in August.

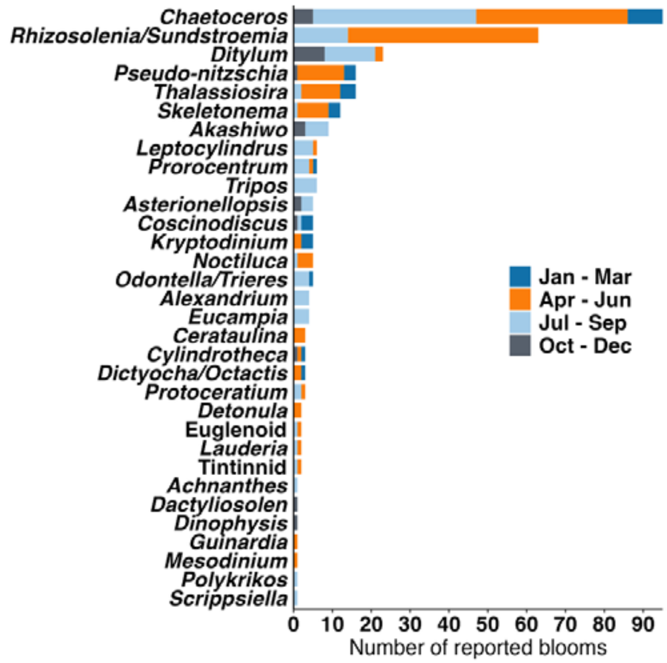


Figure 1. Phytoplankton blooms reported by SoundToxins monitors in 2024 by taxa and quarter observed.

Other HABs that affect human health include *Dinophysis*, *Pseudo-nitzschia*, *Azadinium*, and *Karenia*. For the second year in a row, winter *Dinophysis* blooms spread out of Budd Inlet, where they have historically occurred, into other areas of the South Sound which had not experienced *Dinophysis* blooms until 2023. Although *Pseudo-nitzschia* was observed throughout the year, they did not produce notable levels of domoic acid within Puget Sound. *Karenia* were observed by ORHAB at higher-than-normal frequencies on the Pacific Coast during the summer and have now been added to the target list along with *Azadinium*.

Fish and shellfish killing HABs include *Heterosigma*, *Akashiwo*, *Protoceratium*, and *Phaeocystis*. There were several reports of *Akashiwo* and *Protoceratium* blooms primarily occurring between July and September. The Rapid Response Network, which surveys shellfish beds to collect data on mortality events, reported several notable cockle mortalities in July. Shellfish tissue from Point Julia in northern Hood Canal tested positive for the presence of yessotoxins which are produced by *Protoceratium* and a few other genera of phytoplankton. *Heterosigma*, and *Phaeocystis* were not observed at high abundances.

Emergency Response: *Alexandrium catenella* surface sediment cyst mapping of Willapa Bay and Grays Harbor following toxic algal bloom

Author: Cheryl Greengrove (cgreen@uw.edu), Julie Masura, Peyton Scheschy, Kat Barlow, and Mikayla Mayes, University of Washington Tacoma
Edited by: Tracie Barry, Washington State Department of Health Shellfish Program
Website: https://coastalscience.noaa.gov/news/assessing-paralytic-shellfish-poisoning-risk-in-southern-washington/

Highlights

- May/June 2024 toxic bloom of *Alexandrium catenella* along the WA and OR coast shut down shellfish harvesting in Willapa Bay and Grays Harbor WA.
- Cysts of *A. catenella* found in surface sediments of Willapa Bay and Grays Harbor.

Overview

In May and June of 2024, Washington and Oregon experienced an extreme paralytic shellfish poisoning (PSP) event along their coastal beaches and bays. The Washington State Department of Health (WDOH) Marine Biotoxin Program conducted emergency shellfish sampling following Olympic Region Harmful Algal Bloom (ORHAB) early warning phytoplankton monitoring reports of toxic Alexandrium spp. cells along Washington's coastal beaches and bays. Recreational and commercial shellfish samples tested above regulatory action levels for PSP toxins (see Marine Biotoxins), resulting in shellfish closures in Washington's Willapa Bay and Grays Harbor and large economic losses for rural Washington coastal communities. Coastal events of this magnitude are infrequent with the last event occurring in 1997. Emergency response surface sediment *Alexandrium catenella* cyst surveys were conducted in Willapa Bay and Grays Harbor to determine where the organism had settled, providing early warning of potential future blooms for shellfish growers.

Narrative

Alexandrium catenella is a dinoflagellate known to produce saxitoxin, a neurotoxin harmful to mammals that consume shellfish that bioaccumulate the toxin through filter feeding. *A. catenella* vegetative (swimming) cells produce resting cysts that overwinter in sediments which can germinate in following seasons when environmental conditions that favor growth are met. *A. catenella* cyst concentrations in sediment samples serve as a valuable indicator for predicting the risk of future PSP events. Cyst surveys must be conducted during dormant periods for *A. catenella*, typically during the winter months of December through February in the Pacific Northwest. Cyst mapping has been carried out in Washington's Puget Sound over the past decade with strong correlations between cyst sediment concentrations and *A. catenella* bloom initiation sites (Greengrove *et al*. 2015), but no cyst surveys have been conducted on Washington's shelf or within its coastal bays.

In light of the unprecedented 2024 PSP event, WDOH officials and University of Washington Tacoma (UWT) researchers applied for and received funding for coastal bay cyst surveys from the Harmful Algal Bloom (HAB) Event Response Program at NOAA National Centers for Coastal Ocean Science (NCCOS). Surface sediment samples were collected in Willapa Bay 27-28 January 2025 at 31 stations (Figure 1) and Grays Harbor 1 March 2025 at 11 stations (Figure 2), along with some CTD profiles and phytoplankton net samples. Sediment samples were processed and *A. catenella* cysts enumerated using standard microscopy techniques (Yamaguchi et al. 1995). Maps of *A. catenella* cyst distribution in each area are shown in Figures 1 and 2. Cyst abundances are not particularly high in either bay, but *A. catenella* is present in both bays. In Willapa Bay, cysts are found in the northern part of the bay from the mouth southward to the upper, central part of the bay with the highest cyst abundance at station 20 (Figure 1). Grays Harbor had cysts throughout, both north and south, with greatest number of cysts at stations 56 and 57 (Figure 2). The main channels in both estuaries typically did not have cysts, probably due to high tidal flows and there was a large amount of suspended sediment in the water column throughout these two shallow bays due to tidal mixing and river inflow. We hypothesize that cysts may be buried relatively quickly due to the volume of sediment in these estuaries. But at least for this year (and maybe longer), monitoring the water column for *Alexandrium catenella* will be critical because cysts are present in both estuaries and we do not have a map of cyst distribution on the coastal shelf where the bloom likely originated. Mapping cysts in Washington's coastal bays provided critical information on the likelihood of future PSP events and will aid in contingency planning for shellfish stakeholders.

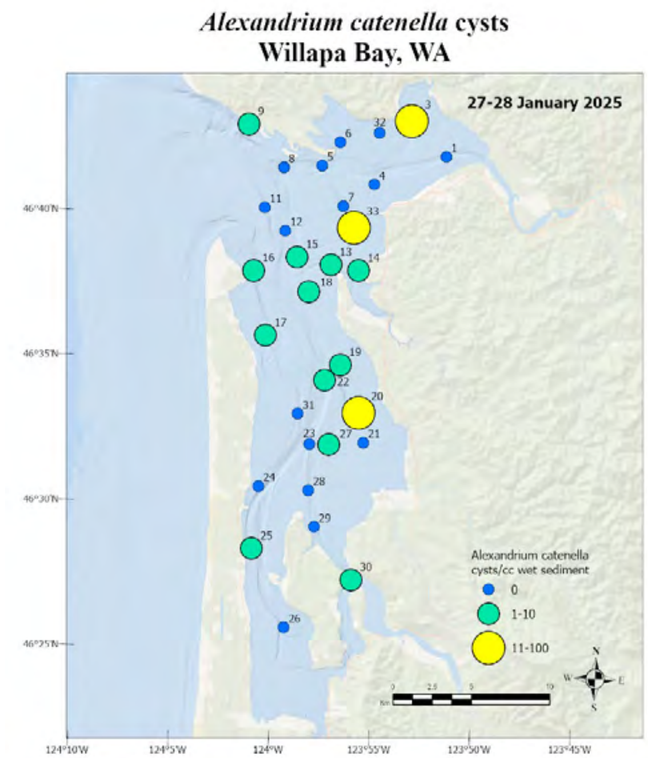


Figure 1 Alexandrium catenella cyst distribution in surface sediments of Willapa Bay, WA (cysts/cc wet sediment) collected 27-28 January 2025.

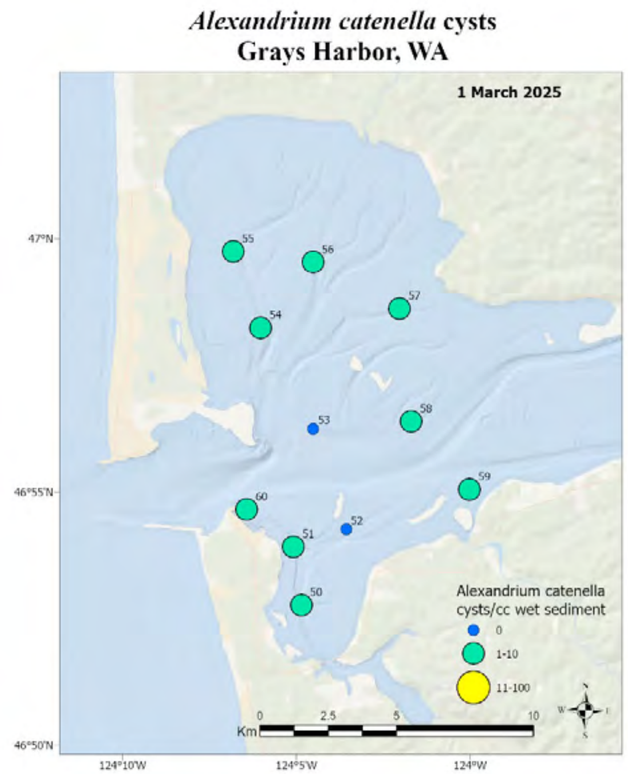


Figure 2 Alexandrium catenella cyst distribution in surface sediments of Grays Harbor, WA (cysts/cc wet sediment) collected 1 March 2025.

References

Greengrove, C.L., Masura, J.E., Moore, S.K., Bill, B.D., Hay, L.R., Eldred, K.C., Banas, N.S., Salathé Jr., E.P., Mantua, N.J., Johnstone, J.A., Anderson, D.M., Trainer, V.L., Stein, J.E., 2015. *Alexandrium* cyst distribution and germination in Puget Sound, WA USA. In: MacKenzie, A.L. (Ed.) Marine and Freshwater Harmful Algae. Proceedings of the 16thInternational Conference on Harmful Algae, Wellington, New Zealand 27th-31st October 2014. Cawthron Institute, Nelson, New Zealand and International Society for the Study of Harmful Algae (ISSHA) ISBN 978-87-990827-5-9. [http://www.cawthron.org.nz/publications/ICHA16-Proceedings.pdf. pp. 163-166](http://www.cawthron.org.nz/publications/ICHA16-Proceedings.pdf)

Yamaguchi, M., Itakura, S., Imai, I., Ishida, Y. 1995. A rapid and precise technique for enumeration of resting cysts of *Alexandrium spp*. (Dinophyceae) in natural sediments. Phycologia 34, 207–214.

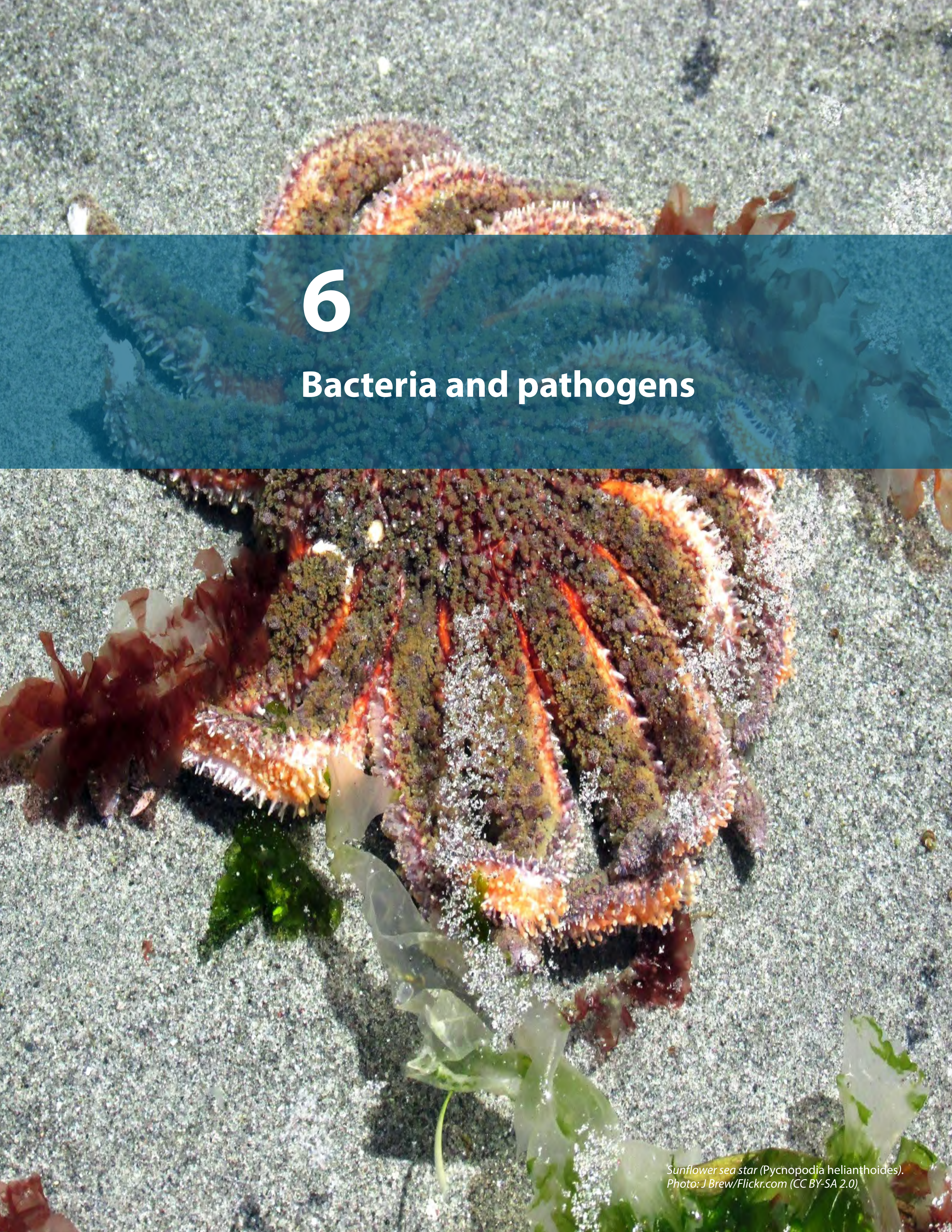
Acknowledgements

Thanks to our WDOH collaborators Jerry Borchert and Tracie Barry and the field teams Zach Forster WDFW and Kyle Deerkop Pacific Seafood for taking us out to collect the samples. Thanks to NOAA/NCCOS for providing these HAB emergency response funds to do this work to help the shellfish growers in Washington State.

Figure 3 Julie Masura (left) and Cheryl Greengrove (right) sampling in Willapa Bay, WA with WDFW.

6

Bacteria and pathogens



Sunflower sea star (Pycnopodia helianthoides). *Photo: J Brew/Flickr.com (CC BY-SA 2.0)*

Central Basin Bacteria Monitoring – 2024

Authors: Wendy Eash-Loucks (King County, wendy.eash-loucks@kingcounty.com)
Edited by: Kimberle Stark, Beth LeDoux, Greg Ikeda
Website: kingcounty.gov/marine-water-quality/beach, kingcounty.gov/marine-water-quality/offshore;
Additional website for data: https://data.kingcounty.gov/d/vwmt-pvjw

Highlights

- Fecal indicator bacteria concentrations at King County beach monitoring stations were generally low to average compared to the historical record with few exceptions.
- 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 evaluate how concentrations are changing over time.

Narrative

Annual geometric mean beach bacteria concentrations were spatially variable in 2024 (Figure 1). However, both *Enterococcus* and fecal coliform geometric mean values were near average to below average at all beach monitoring sites with a few exceptions (Figure 1). *Enterococcus* values were slightly elevated at Carkeek Park near the outflow of Piper's Creek, Fauntleroy Cove, and Dumas Bay sites, while both types of indicator bacteria were above average at the Des Moines Creek sites. All four of these sites have freshwater creeks nearby, which are a potential bacteria source. The highest bacteria values occurred from September–February, when rainfall was highest.

As in previous years, 2024 bacteria concentrations offshore were much lower than those at beach stations due to their distance from various sources. The offshore sites with the highest bacteria concentrations were those located within Quartermaster Harbor (Figure 1), but geometric means of indicator bacteria at these locations were still low. Like beach sites, the highest bacteria concentrations tended to occur in September through winter, but also into April (the rainy season).

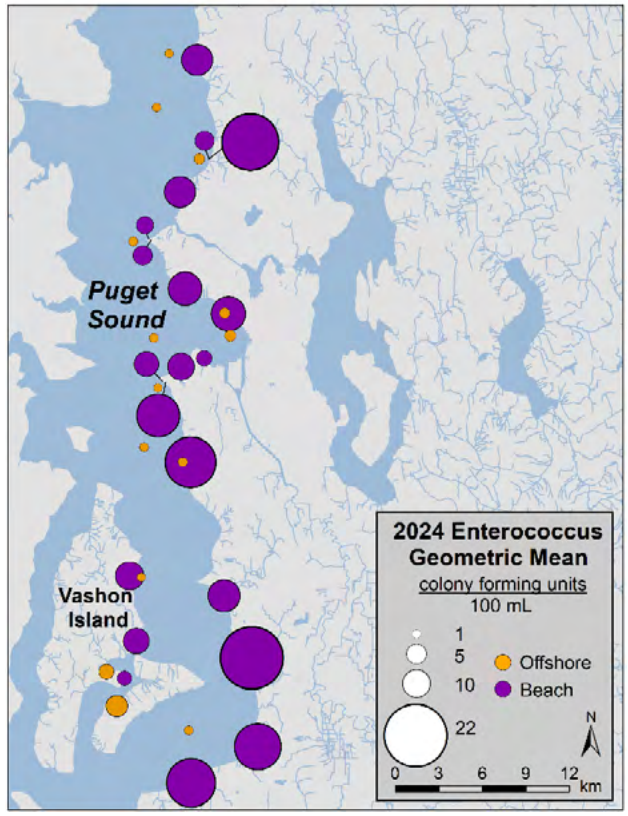


Figure 1 Map of 2024 Enterococcus *annual geometric mean concentrations at King County beach and offshore stations.*

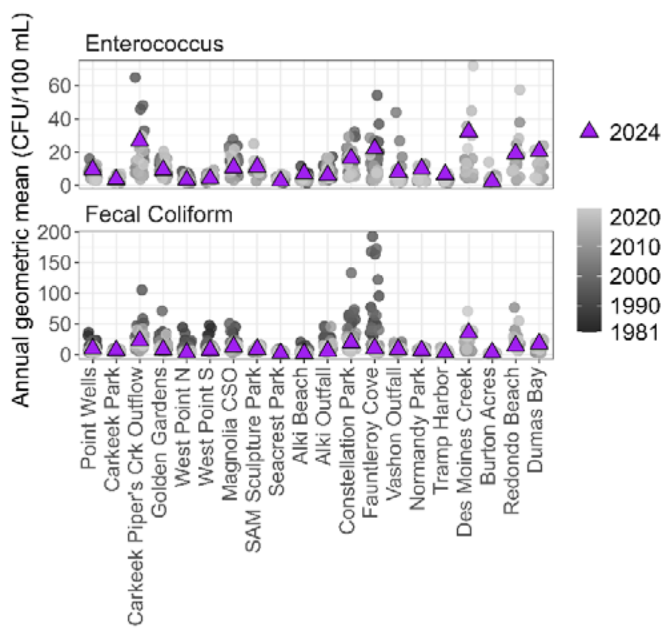


Figure 2 Annual geometric mean Enterococcus *and fecal coliform concentrations at beach stations from 1981 to 2024. 2024 values are shown in purple and older data are shown in a grayscale gradient by year. Note the difference in scales.*

Vibrio spp. Surveillance

Authors: 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

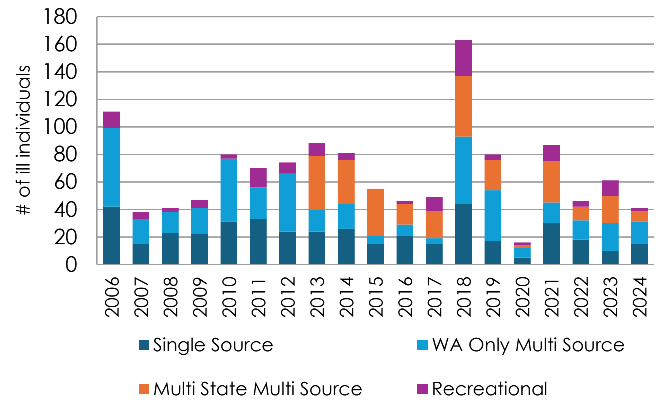
- In 2024 there were a total of 39 laboratory confirmed *Vp* illnesses from commercially harvested oysters.
- 12 samples from three different sites had detectable levels of *Vv*.

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 are monitored in oyster tissue during those warmer months. As waters begin to heat up, we generally see increasing levels of both *Vp* and *Vv*, although no enteric *Vv* illnesses have been reported yet in Washington. Currently, 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.

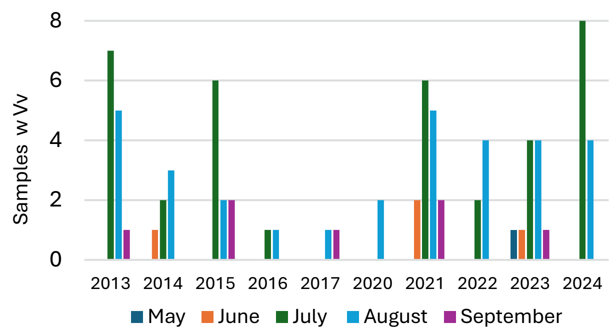
Narrative

In the *Vibrio* control season (May 1-Sept 20) 2024, 39 total confirmed *Vp* illnesses were from commercially harvested oysters and 2 were from recreational harvest (Fig. A). A record-breaking heat wave occurred around the first week of July, and 48.7% of confirmed *Vp* illnesses were related to commercial oysters harvested between 7/2-7/16/2024. In the 2024 control season, there were 15 laboratory-confirmed commercial, single-source illnesses from consumption of oysters contaminated with *Vp*, and 24 commercial multi-source illnesses: 16 were traced back to multiple Washington growing areas and 8 were traced back to multiple Washington growing areas, other states and/or countries. There was one partial closure of the southern portion of Port Townsend Bay.



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

From May to September 2024, WDOH collected 106 samples from 11 sites and analyzed them for the presence of *Vp and Vv*. 12 samples from three different sites had detectable levels of *Vv* through July and August (Fig. B). *Vp* exceeded the upper detection limit of 110,000 MPN/g of tissue, in samples collected on 7/9/2024 from Southern Hood Canal and Hammersley Inlet. Two additional sites had levels of 24,000 MPN/g, also from early July (data not shown). Overall, 14 samples through July and August exceeded 1,000 MPN/g and 87% of samples contained detectable levels of *Vp.* Weather conditions, air, shore, surface water, tissue temperatures, and salinity are also recorded.



(B) Samples with detectable Vv levels 2013-2024

Single-source Illness – *can be traced back to a single growing area.*
Multi-source Illnesses –*cannot be traced back 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.*

References

1. NOAA Climate.gov. (2024, July 1). Climate Change and Environmental Policy. [Accessed June 11, 2025].
2. Howie, Stephen, & O’Neill, Eilis. (2024, July 3) “Get Ready Seattle. Summer ’24 is about to bring the heat.” https://www.kuow.org/stories/seattle-western-washington-heat-hot-weather-july-2024
3. Livingston, Ian. (2024, July 10) “Extreme heat is scorching West and East coasts, and forecast offers little relief”
4. "Heat Wave Provider Alert: “Potentially dangerous heat wave; Remain vigilant for heat related illnesses and deaths."Washington State Department of Health, July 8 2024. doh.wa.gov/sites/default/files/2024-07/HeatWaveProviderAlertJuly2024.pdf

7

Forage fish

Herring spawning biomass in the southern Salish Sea

Authors: Phillip Dionne (WDFW, phillip.dionne@dfw.wa.gov); Erin Jaco (WDFW)
Edited by: Jamey Selleck, Natural Resources Consultants
Website: https://wdfw.wa.gov/fishing/management/marine-beach-spawning#herring;

Highlights

- Estimated Spawning Biomass (ESB) dropped to 11,404 mt, but was still within 500 mt of the 10-year average.
- The ESB declined in most areas and remained concentrated in just a few spawning areas.
- No spawning activity was observed at Cherry Point for the 2nd year in a row, and the ESB in Port Gamble fell below 100 mt for the 1st time since monitoring began in 1976.

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 in Washington, 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 (Figure 1). 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).

Figure 1. Image of 'rake' with herring eggs on eelgrass collected during a 2024 herring survey.

Narrative

The Estimated Spawning Biomass (ESB) of herring in Puget Sound dropped from 17,943 metric tons (mt) in 2023 to 11,404 mt in 2024 (Figure 2). The 2023 ESB was the second highest ESB observed in over four decades, so despite this decline of over 36%, the 2024 ESB is still within 500 mt of the recent ten-year average. Nearly 70% of the total ESB occurred at only three areas, Port Orchard/Port Madison, Purdy Bay, and Semiahmoo Bay, each with over 1,000 mt.

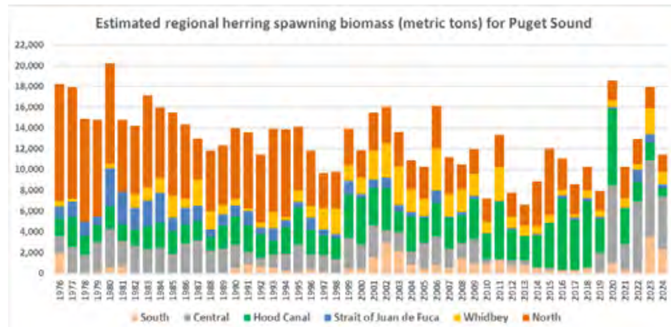


Figure 2. Bar chart of estimated spawning biomass for herring in Puget Sound from 1976 to 2024.

The ESB in most spawning areas either declined or was similar to 2023 levels, and with the decreased spawning we observed few expansions or shifts in spawning distribution. Quilcene Bay's ESB fell below 1,000 mt for the first time in 20 years, and Port Gamble's ESB fell below 100 mt for first time since monitoring began in 1976. We saw no evidence of spawning in five areas, including Cherry Point for the second year in a row.

Bright spots in 2024 included observing spawn in the NW San Juan Islands for the first time since 2003, an increase in Squaxin Pass to over 700 mt for the first time in over a decade, and despite declining from its record high in 2023, the Port Orchard/Port Madison area remained over 5,000 mt for the third year in a row.

References

For more details about the Forage Fish Vital sign and the biomass of Pacific Herring in Puget Sound please visit: https://vitalsigns.pugetsoundinfo.wa.gov/.

Petrou E.L. et al., 2021. Functional genetic diversity in an exploited marine species and its relevance to fisheries management. Proceedings of the Royal Society B 288:20202398. https://doi.org/10.1098/rspb.2020.2398

Early marine survival and marine diet of juvenile Chinook

Authors : Russel Barsh (Kwiaht, russel@kwiaht.org); Madrona Murphy (Kwiaht), Matilda Twigg (Kwiaht) **Edited by:** Madrona Murphy, 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 are also eating fewer forage fish.
- Fraser River-origin Chinook did a little better in response to cooler 2019-2024 conditions than Puget Sound-origin Chinook. They are eating as much forage fish as they did 15 years ago.

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. Fraser origin Chinook dominate 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 10,421 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 4,542 Chinook have been identified thus far. On average, their diet in the San Juan Islands has been 79.8% larval and juvenile Pacific herring and Pacific sand lance, and 1.8% other fishes (Figure 2).

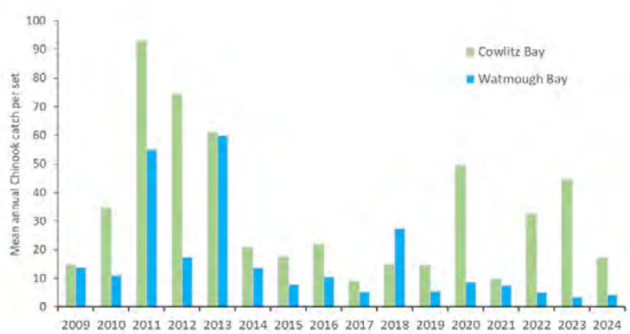


Figure 1. Mean annual catch per seine set of juvenile Chinook outmigrants at stations in the San Juan Islands 2009-2024.

Juvenile Chinook outmigrants were most abundant at both sampling stations in 2009-2013, a cool cycle of the Pacific Decadal Oscillation (PDO), and fell sharply during the 2014-2109 warm cycle of the PDO. When the PDO cooled again in 2020-2024, the abundance of Chinook at Cowlitz Bay rebounded weakly. Chinook abundance at Watmough Bay remained low, however.

Consumption of forage fish biomass by juvenile Chinook outmigrants at Watmough Bay also declined since 2009, while forage fish consumption by outmigrants at Cowlitz Bay has remained the same, on average.

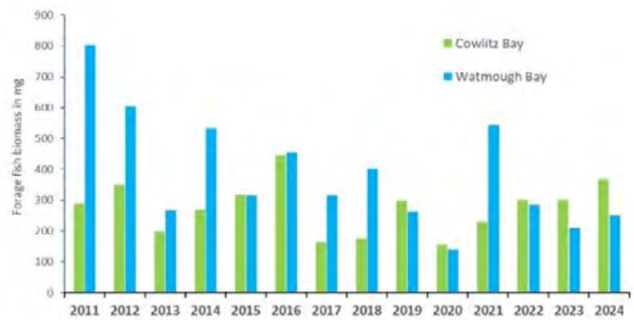


Figure 2. Mean annual consumption of forage fish biomass by unmarked juvenile Chinook outmigrants at stations in the San Juan Islands 2009-2024.

These data suggest that early marine survival of Puget Sound-origin Chinook is mainly influenced by conditions within the Sound, rather than regional marine climate.

One explanation could be a decline in zooplankton taxa on which juvenile Chinook tend to rely on as they transit the Sound on their journey to the San Juan Islands. Declining or changing zooplankton resources could also lead to a reduction in the availability or size of forage fish as prey for Puget Sound-origin Chinook outmigrants.

References

Chamberlin, J., M. Gamble, K. Connelly, J. Gardner, R. Barsh, J. Keister, D. Beauchamp, M. Schmidt, B. Beckman, and K. 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/

8

Bottomfish

Two-year-old Copper Rockfish, Lopez Island. Photo: Russel Barsh

2024 WDFW Puget Sound Bottom Trawl Survey

Authors: Jennifer Blaine (Washington Department of Fish and Wildlife, jennifer.blaine@dfw.wa.gov)
Edited by: James Selleck (Natural Resources Consultants)
Website: https://wdfw.wa.gov/

Highlights

- Survey conducted in spring 2024 sampled all 51 Index stations that have been monitored annually since 2008.
- Most bottomfish species groups were within range of 5-year means for biomass and population estimates.

Overview

The Washington Department of Fish and Wildlife (WDFW) has conducted scientific bottom trawl surveys throughout Puget Sound to monitor bottomfish populations since 1987. There have been a few design changes over the years, but starting in 2008, the survey has sampled the same 51 Index stations annually between April and June (Figure 1). At each site, the net is towed on the bottom for an average 0.4 nautical miles, and the subsequent catch is sorted. All species of bottomfish and benthic invertebrates are identified, weighed, and counted, and select species are also sexed, measured, and have genetics and/or age samples taken.

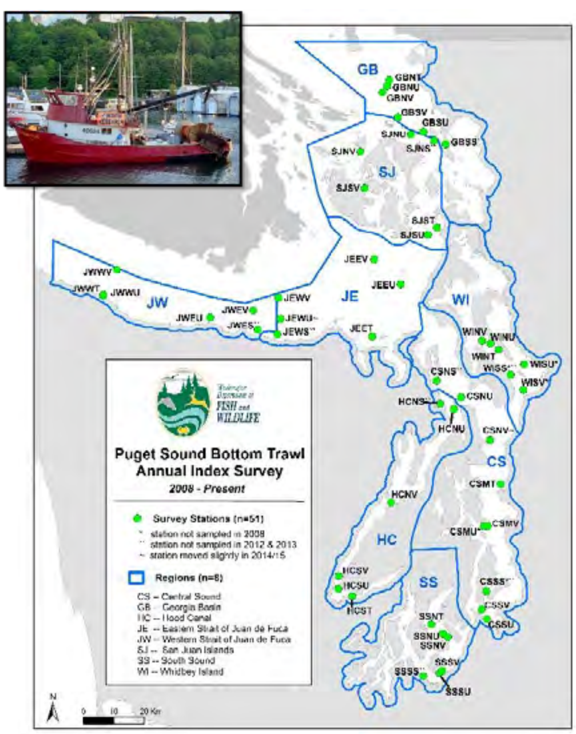


Figure 1: Survey map for the current design of the WDFW Bottom Trawl Survey with 51 Index Stations. Inset picture of the contracted fishing vessel used for the survey, F/V Chasina.

Narrative

The 2024 bottom trawl survey was completed over 15 fishing days from April 29 – May 23. An estimated 53,291 individual fish belonging to 83 species or taxa and weighing 8.8 mt were caught during the survey. Overall, the total estimated bottomfish biomass and abundance for Puget Sound was 99,294 mt and 544.3 million individuals, respectively. Compared to the estimates from the 2023 survey (96,758 mt; 459.6 million individuals), both the biomass and abundance estimates increased (Figure 2). This marks the fourth consecutive survey year that fish biomass estimates have increased. The largest changes of both biomass and population estimates among regions between 2023 and 2024 were in the Georgia Basin (GB) with a 44% increase in biomass and a 78% increase in abundance estimates; these changes can largely be attributed to increases in Spotted Ratfish, Buffalo Sculpin, and a few species of poachers.

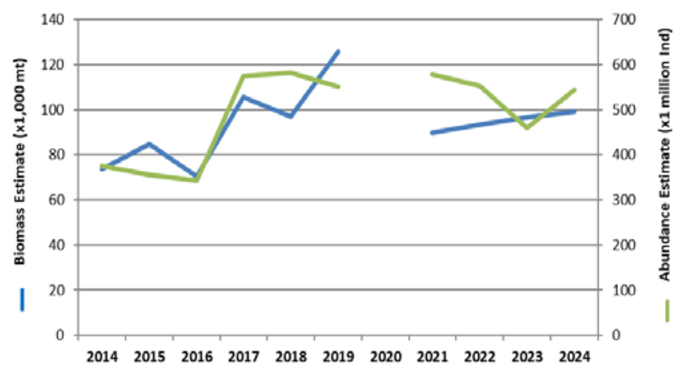


Figure 2: Estimates of bottomfish biomass (x 1,000 mt; primary axis) and abundance (x 1 million individuals; secondary axis) throughout Puget Sound from the annual bottom trawl surveys since 2014. No survey was conducted in 2020.

As in previous years, Spotted Ratfish dominated the catch in terms of biomass, constituting 53.2% of the total fish catch by weight and 25.1% of the total number of individual fish, followed by English Sole at 15.6% and 19.8%, respectively. These catch rates equate to a biomass estimate of 51,050 mt for Spotted Ratfish (up from 47,760 mt in 2023) and 12,727 mt for English Sole (9,172 mt in 2023), and abundance estimates of 145 million and 110 million individuals, respectively (Figure 3). The remaining individual fish species contributed 3% or less each to the total fish catch weight and 6% or less to the total number of individual fish (aside from

Blackbelly Eelpout at 10% and Pacific Hake at 7%) and were categorized into larger species groups for comparisons. Overall, all species groups fell within or above one standard deviation of their 5-year-means for both biomass and abundance estimates, with the lone exception of codfish abundance, which fell below.

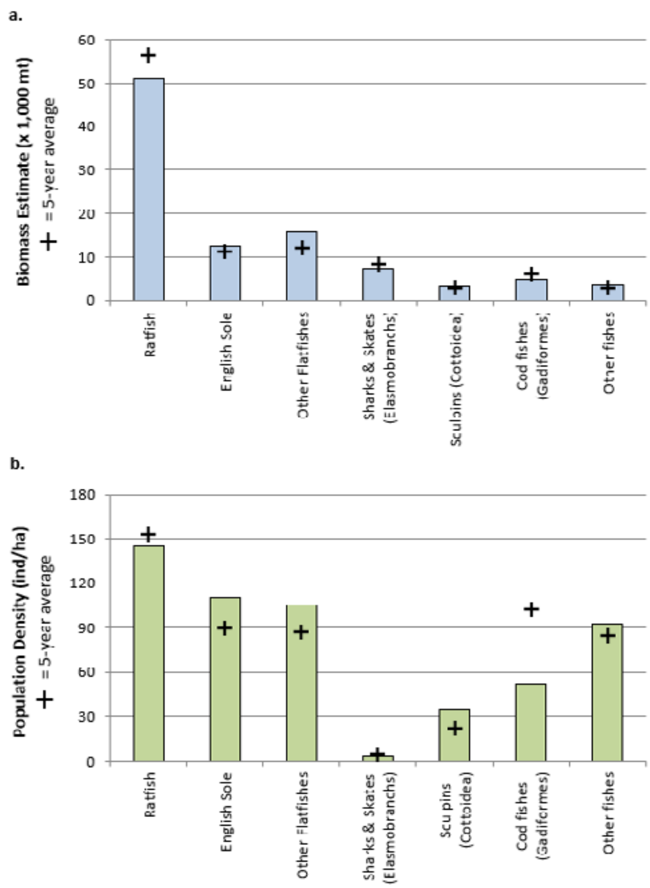


Figure 3: Estimates of bottomfish biomass (x 1,000 metric tons; graph a.) and abundance (x 1 million individuals; graph b.) from the 2024 survey. Species were combined into groups by taxa, with the exception of Spotted Ratfish and English Sole, the two most prominent species. Plus signs indicate the mean from 2018-2023, excluding 2020.

One particularly interesting catch note was that more Sablefish (aka Black Cod) were caught in the 2024 survey than in any other year in the history of the trawl survey (dating back to 1987). Sixty-eight individuals, compared to 14 in the 2023 survey and six in the 2022 survey, were caught in six regions (mostly JW), with an average length of 37.8 cm.

While the primary objective of the bottom trawl survey is to gather population data for bottomfish, the regularity and scope of the survey, and the vast number of fish handled, provide a unique opportunity to assist and inform other research. In total, we collected 185 genetic samples from Pacific Cod, Spiny Dogfish, Sablefish, Cabezon, Red Brotula, and seven species of rockfish. We also collected 123 age samples (otoliths) from rockfish and Pacific Cod; all samples were sent to labs at the WDFW for analysis or to partner researchers for ongoing, collaborative projects. Additionally, 632 whole fish or other samples were preserved for other researchers.

To obtain the full 2024 Puget Sound Bottom Trawl survey report, which includes results on benthic invertebrates as well, please contact the author.

WDFW staff begin to sort a tow's catch, comprising mostly of flatfish and shrimp species, onboard the F/V Chasina*.*

Concluding Notes

The WDFW bottom trawl survey is the largest, most geographically expansive, methodologically consistent, and longest-running, fishery-independent survey of benthic organisms in Puget Sound. The data, samples, and estimates from the trawl survey are not only important for the WDFW's marine fish monitoring efforts but are also used by other entities both within and outside the agency. Recently, the bottom trawl dataset was selected to inform the Puget Sound Partnership's Groundfish and Benthic Invertebrates Vital Sign as part of the Thriving Species and Food Webs Recovery Goal. Due to ongoing budget and staffing cuts, however, the WDFW bottom trawl survey was not conducted in 2025 and will now operate on a biennial basis in even years.


PSEMP
PUGET SOUND ECOSYSTEM
MONITORING PROGRAM
PUGET
SOUND
INSTITUTE
UNIVERSITY of
WASHINGTON
PSEMP
PUGET SOUND ECOSYSTEM
MONITORING PROGRAM
PUGET
SOUND
INSTITUTE
UNIVERSITY of
WASHINGTON