Northeast Pacific Update: Summer 2021 low oxygen event on the west coast of North America

Tetjana Ross, Ana C. Franco, John A. Barth, Akash Sastri, Marie Robert, Debby Ianson, Charles Hannah, Francis Chan, Richard Feely, Richard Dewey, and Angelica Peña

While hypoxic events are known to occur seasonally in coastal bottom waters along the west coast of North America, 2021 was more severely hypoxic. The onset of low oxygen water was the earliest in 35 years (NOAA, 2021), lasted longer (Lundeberg, 2021), was anomalously low (Figures 1 and 4), and covered a larger extent, reaching north into Canadian waters (Figure 5) where hypoxia is rare (Figure 6; Crawford and Peña, 2013).

The seasonal near-bottom hypoxia was observed as early as mid-May (Figure 1) on the Washington shelf. Low-oxygen water was observed near the seafloor over the Washington, USA, continental shelf for much of the summer 2021. Oxygen levels continued to decrease throughout the summer, reaching "severe" hypoxia (O_2< 0.5 ml/l) – that can harm important marine species like Dungeness crab (Keller et al, 2015) – at the end of July and even approached anoxia, zero oxygen, in late August/early September. This seasonal decrease in near-bottom DO is consistent with similar measurements off central Oregon (Adams et al., 2013), but these 2021 levels are lower than typical. The return of near-bottom DO to levels above hypoxia occurred in mid-late September (not shown) as early-season storms swept across the region.

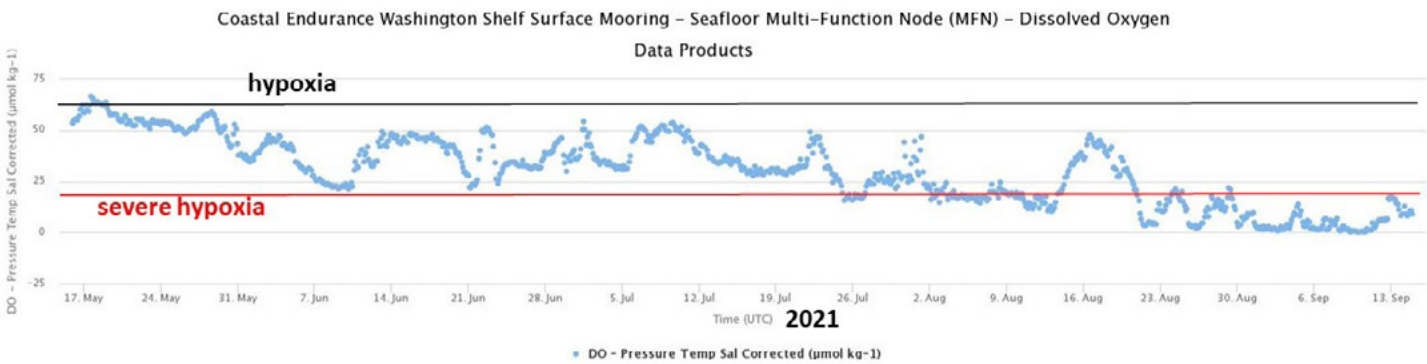

Figure 1. Near-bottom dissolved oxygen measured at the mid shelf off Grays Harbor, WA, USA, by an Ocean Observatories Initiative instrumented bottom platform in approximately 90 m of water. Black and red lines indicate the thresholds of 1.4 ml/l (equal to 62.2 µmol kg^{-1}) for hypoxia and 0.5 ml/l (equal to 22.2 µmol kg^{-1}) for severe hypoxia. Data are available at https://oceanobservatories.org/).

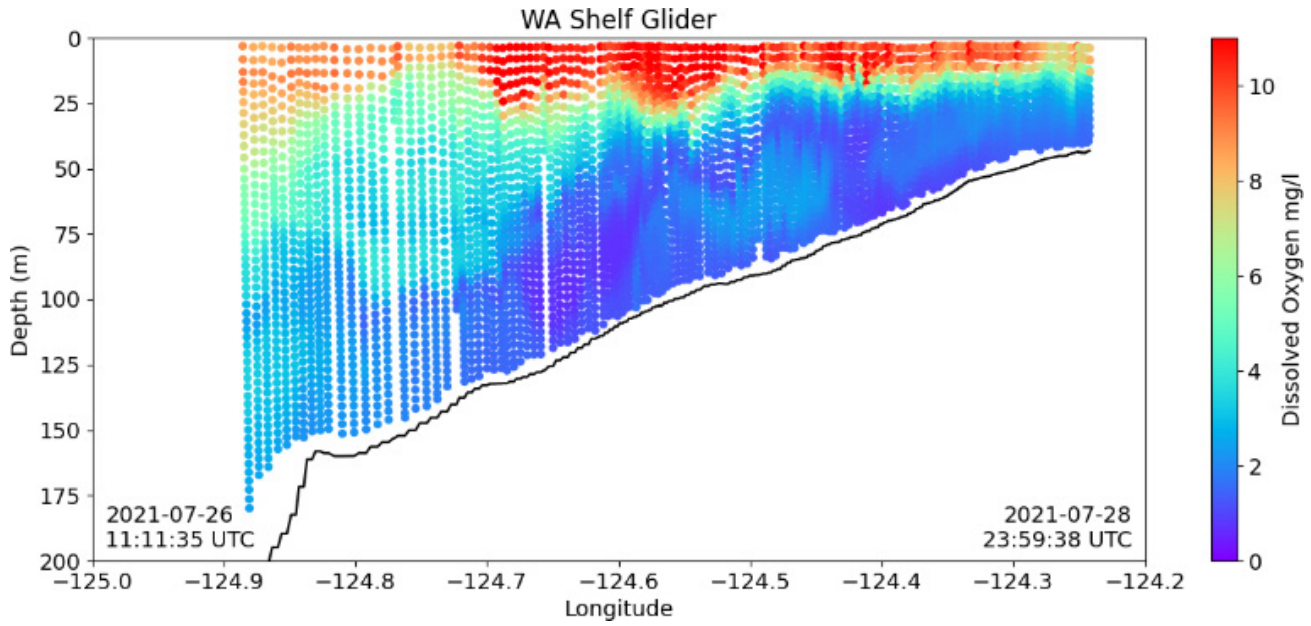

Figure 2. Dissolved oxygen measured from an underwater vehicle glider operated by Oregon State University on a cross-shore transect off Grays Harbor, Washington, USA (plots available at http://nvs.nanoos.org and data available at the U.S. Integrated Ocean Observing System Glider Data Acquisition Center, http://gliders.ioos.us). Hypoxic water occupies the lower three-quarters of the water column near the mid-shelf mooring location (~80 m isobath) and stretches from the outer continental shelf, shoreward to at least the 50-m isobath.

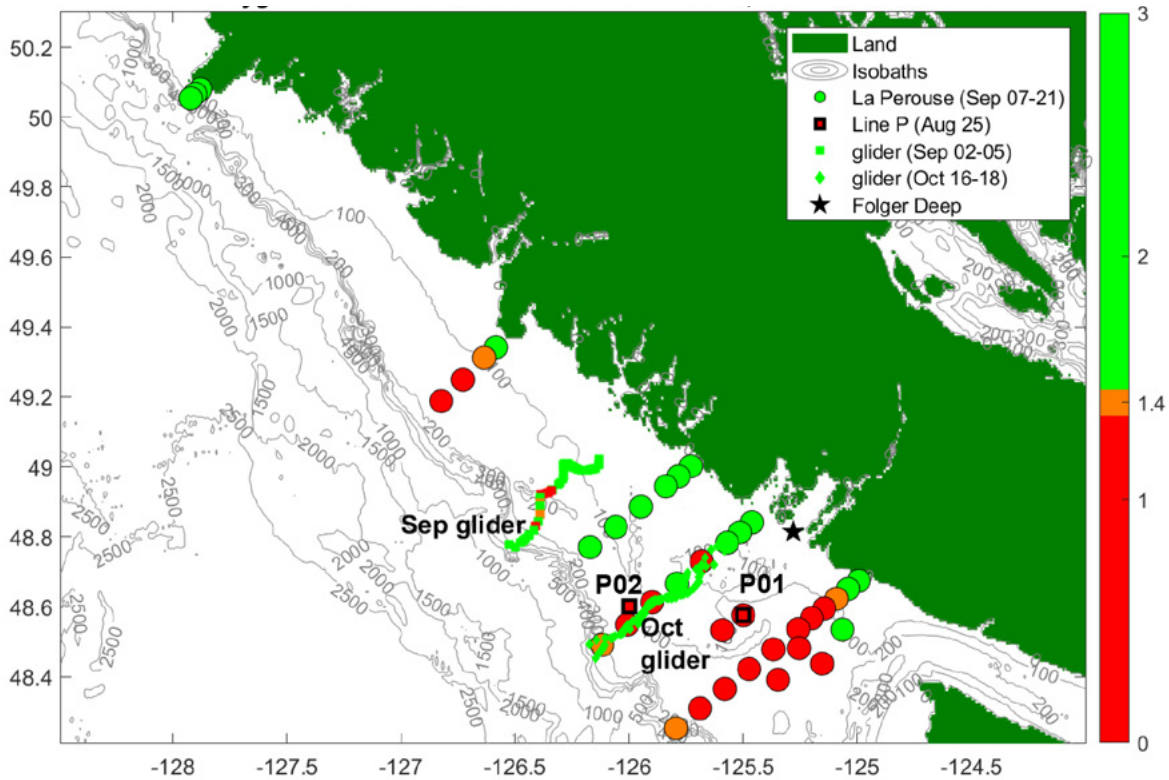

Figure 3. Map of near bottom oxygen along Vancouver Island using cruise and glider data collected between Aug 25 – Oct 18, 2021. The colour bar (in ml/l) is red for hypoxic waters (<1.4 ml/l, or approx. 62 µmol kg^{-1}), orange for 1.4 ml/l, and green for > 1.4 ml/l.

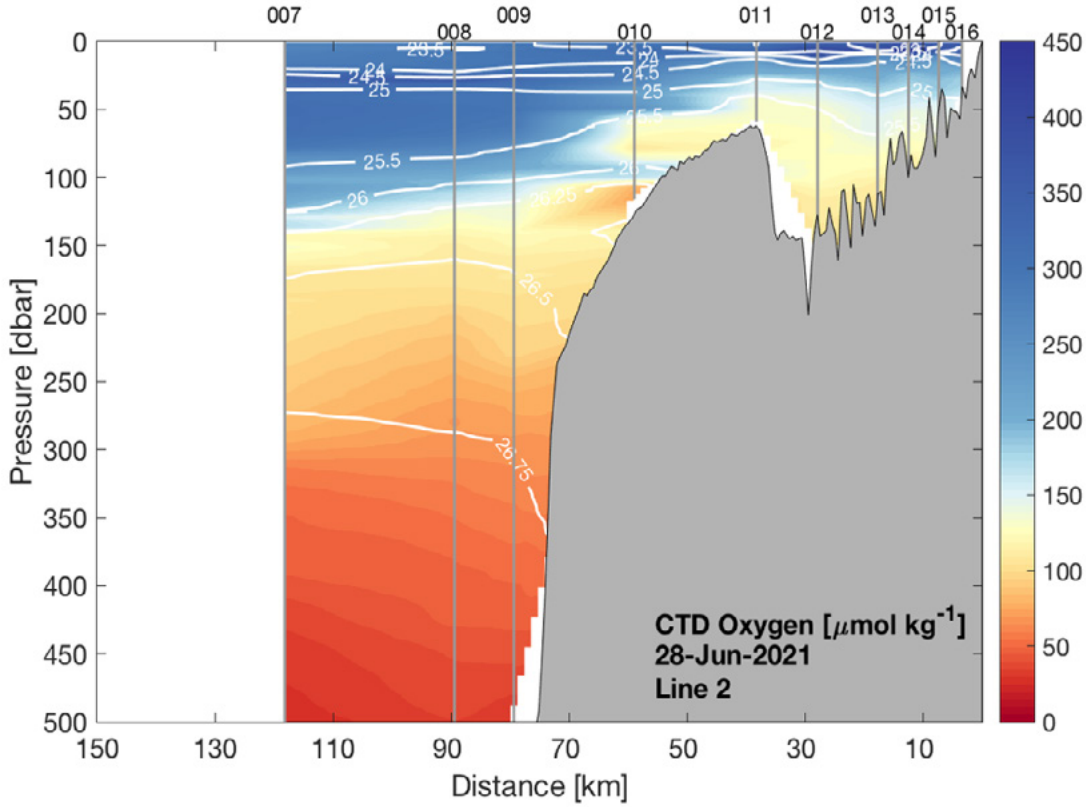

Figure 4 Section of dissolved oxygen concentrations off the Vancouver Island coast (near Barkley sound or ~49˚N). The thin white lines indicate isopycnals. All oxygen concentrations on the shelf are above 62 µmol kg^{-1} (approx 1.4 ml/l). Credit: NOAA Pacific Marine Environmental Laboratory/Richard Feely.

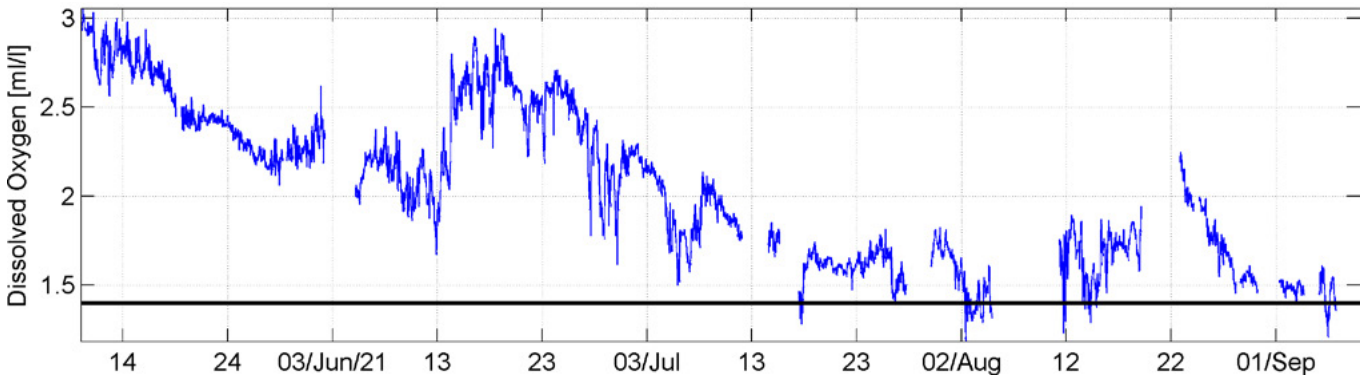

Figure 5. Time series of oxygen sensor data from Ocean Network Canada's Folger Deep mooring situated at 96 m depth near Barkley Sound on the west coast of Vancouver Island, British Columbia, Canada. The black line indicates hypoxia (oxygen below 1.4 ml/l).

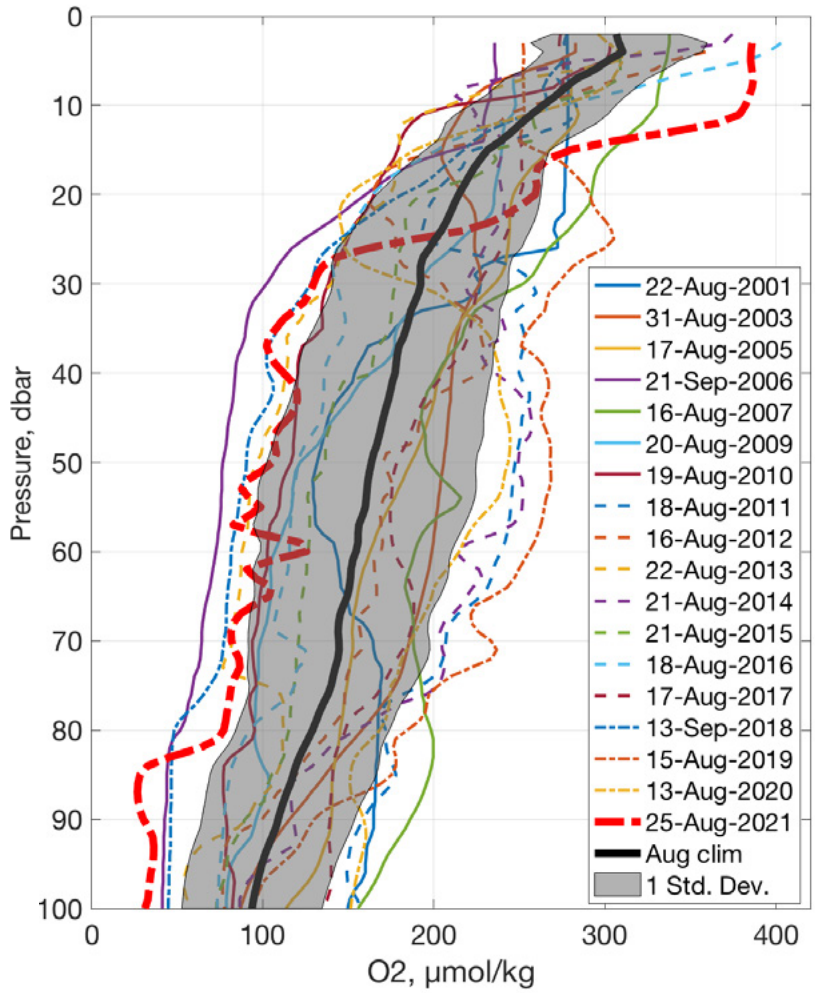

Figure 6. Vertical profiles of dissolved oxygen (µmol kg-1) collected at station P02 (Figure 5) during late summer cruises (August and September) as part of DFO's Line P monitoring program. Gray shading indicates one standard deviation from the climatological (2001-2021) summer mean. In 2021 (red thick dot-dash line), the bottom oxygen was the lowest observed in two decades and one of only two recent years where bottom waters reached hypoxic levels at this location.

The seasonal low-oxygen bottom waters in the Northeast Pacific coastal areas are typically linked to upwelling, both driven by the sinking and decomposition of primary production fueled by upwelled nutrients (Connolly et al 2010) or sometimes upwelled low oxygen waters. The separation of the coastal hypoxic waters from deep hypoxic water in the offshore in a glider transect collected near the OOI bottom platform (Figure 2) suggests that increased coastal productivity was responsible for the low oxygen on the Washington shelf in July 2021. An early onset of upwelling may be responsible for this productivity, though it could also be caused by an increase

in stratification trapping phytoplankton nearer the surface, as they may be light limited earlier in the growing season due to deeper mixing (Thomson and Fine 2003).

Initially, the hypoxic area was south of the Canada-USA border, but in late summer it expanded north onto the Vancouver Island shelf (Figure 3). In May, oxygen concentrations were lower than the climatological value off Vancouver Island at the P01 (observations not shown), but they were not yet hypoxic. The NOAA West Coast Ocean Acidification Cruise in late June/early July found hypoxic waters offshore of Washington, but not off Vancouver Island (Figure 4). Oxygen data from a sensor near the bottom (96 m) at Ocean Network Canada's Folger Deep mooring (Figure 5; black star in Figure 3) had some data loss in 2021, but suggests that hypoxic bottom water was present close to shore on the Vancouver Island starting in mid-July. By late summer, Fisheries and Oceans Canada (DFO)'s routine summer surveys observed hypoxic bottom waters over much of the Vancouver Island shelf (Figure 3), including a Line P station (P02) where the bottom oxygen was lower than ever observed before (Figure 6; see also Crawford and Peña, 2013).

By mid-October, the bottom waters on the Vancouver Island shelf had returned to normal (oxic) oxygen levels, as observed by an ocean glider (diamond symbols in Figure 3).

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Dr. Tetjana Ross is a Research Scientist at the Institute of Ocean Sciences, Fisheries and Oceans Canada, in Sidney, BC. She is an ocean physicist who develops new ways to observe the ocean – from observing ocean mixing using sound to taking photographs of zooplankton in turbulence. Nowadays, she rarely goes to sea, sending robots out to do the work for her: both gliders and Argo floats (i.e., she currently leads the Pacific component of DFO's Argo and glider programs). In PICES she is member of the Technical Committee on Monitoring and the Working Group on Mesoscale and Submesoscale Processes (WG-38).

Ana C. Franco is a postdoc at the Earth, Ocean and Atmospheric Sciences department at the University of British Columbia. She focuses on marine inorganic carbon and oxygen dynamics, specifically on the drivers of deoxygenation and ocean acidification at different time scales with the combined use of long-term observations and computational tools. Currently, she is working on estimating the potential impact of future climate change scenarios on oxygen and suitable habitat availability for Pacific halibut in the Northeast Pacific.

Dr. Jack Barth is a Professor of oceanography in Oregon State University's College of Earth, Ocean, and Atmospheric Sciences and the Executive Director of OSU's Marine Studies Initiative. He received a Ph.D in Oceanography from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution Joint Program in Oceanography. His research seeks to understand how coastal ocean circulation and water properties shape and influence coastal marine ecosystems. He has led a number of research, technology development, and ocean observing system projects off Oregon and around the world. He presently Co-Chairs the Oregon Ocean Acidification and Hypoxia Coordinating Council. He is a Fellow of The Oceanography Society and the American Meteorological Society. In PICES, he is a member of Governing Council, AP-NPCOOS, MONITOR, and SG-SciCom.

Dr. Akash Sastri is an oceanographer with Fisheries and Oceans Canada at the Institute of Ocean Sciences in Sidney, British Columbia, Canada, where he leads the Plankton Ecology program. He has a background in biological oceanography with a focus on the roles of marine plankton communities in changing environments. His Ph.D. (2007) thesis at the University of Victoria focused on the development and application of novel ways to measure zooplankton productivity routinely at sea. In PICES he is the Chair of the Biological Oceanography Committee, co-chairs the Working Group on Zooplankton Production Methodologies, Applications and Measurements in PICES Regions (WG 37), and is a member of the Advisory Panel on North Pacific Coastal Ocean Observing Systems.

Marie Robert is an oceanographer with the Institute of Ocean Sciences of Fisheries and Oceans Canada, and co-ordinates the Line P program. She leads three cruises per year sampling the Line-P long-term observation program, and in between these cruises she coordinates products and future research of this program.

Debby Ianson is an interdisciplinary oceanographer who works in the field and develops numerical models focused on climate change issues. She is a federal research scientist at the Institute of Ocean Sciences in Sidney BC and an Adjunct Professor at the University of British Columbia, Simon Fraser University and the University of Victoria. Debby was also a member of the West Coast Ocean Acidification and Hypoxia Panel convened by the California Ocean Science Trust.

Dr. Charles Hannah is a senior Research Scientist for Fisheries and Oceans Canada based at the Institute of Ocean Sciences in Sidney, BC. His research program is focused on the oceanography of the central and north coast of British Columbia and he is currently leading a program of moored observations along the British Columbia continental shelf. Within PICES he is member of the Advisory Panel on North Pacific Coastal Ocean Observing Systems (AP-NPCOOS).

Francis Chan is an ecologist in the Department of Integrative Biology at Oregon State University (OSU). His research is focused on the dynamics of ocean deoxygenation and ocean acidification in the coastal ocean. He is also the Director of the Cooperative Institute for Marine Ecosystem and Resources Studies (CIMERS). The Institute is a partnership between the United States National Oceanic and Atmospheric Administration (NOAA) and OSU to advance management-focused ocean science.

Dr. Richard Feely is the group leader of the Ocean Carbon Group at the NOAA Pacific Marine Environmental Laboratory in Seattle, WA. He has more than forty years of experience working with large-oceanographic data sets for the study of long-term changes in the ocean carbon system. He is the co-chair of the U.S. CLIVAR/CO2 Repeat Hydrography Program, and has published more than 220 peer-reviewed publications on the carbon cycle in the oceans, including his most recent research on ocean acidification processes in the South Pacific, including the Southern Ocean.

Richard Dewey Richard is the Ocean Networks Canada Associate Director, Science. Richard is responsible for coordinating and assisting all scientists and researchers using the observatories, from planning to publication. He works with the Staff Scientists to support the science community. He has a B.Sc. in Physics from UVic and a Ph.D. in Oceanography from UBC. His research interests are coastal flows, mixing, turbulence, waves, and tides. He has conducted research throughout the Pacific from Japan to California, and along the B.C., Alaskan, and Arctic coasts. He has used a variety of profilers and ROVs, and deployed more than 150 moorings on over 100 oceanographic expeditions. He is author of the Mooring Design and Dynamics MATLAB package, and specializes in time series analysis.

Dr. Angelica Peña is a Research Scientist at the Institute of Ocean Sciences, Fisheries and Oceans Canada, in Sidney, BC. Her research focuses on processes influencing phytoplankton ecology and biogeochemical cycles. She develops circulation-biogeochemical models and uses long-term observations to study the impacts of natural variability and climate change on ocean productivity and biogeochemistry of the northeast Pacific. In PICES, she is a member of the Biological Oceanography Committee and the Section on Climate Change Effects on Marine Ecosystems.