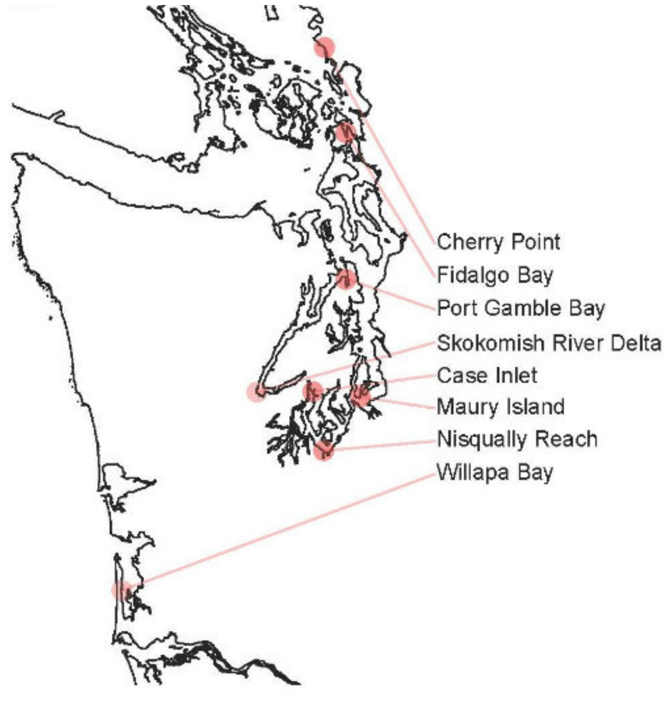
Acidification **Ne**arshore **Mo**nitoring **Ne**twork

2019 State of ANeMoNe

Abbreviations

ANeMoNe .... The Acidification Nearshore Monitoring Network
B / E .... Bare (Unvegetated) / Eelgrass
chl .... Chlorophyll
CI .... Case Inlet
cm .... Centimeters
CP .... Cherry Point
FB .... Fidalgo Bay
L .... Liter
mg .... Milligrams
MI .... Maury Island
NR .... Nisqually Reach
ppb .... Parts Per Billion
PG .... Port Gamble Bay
PSU .... Practical Salinity Units
SD .... Standard Deviation
SK .... The Skokomish River Delta
Temp. .... Temperature
WB .... Willapa Bay
WDFW .... Washington State Department of Fish and Wildlife
WDNR .... Washington State Department of Natural Resources

Overview



The Acidification Nearshore Monitoring Network (ANeMoNe) was established in 2015 to study climate change and ocean acidification in nearshore environments and to test practical management options to reduce the negative impacts of changing ocean conditions on state-owned aquatic lands. Across Washington State, ANeMoNe uses sensors to measure temperature, pH, dissolved oxygen, chlorophyll, and salinity inside and outside of eelgrass at eight sites. Biological data on eelgrass and shellfish are collected in the summer to explore the effects of warming and acidification on critical natural resources.

This report is the first to collate and visualize ANeMoNe data. For 2018 comparisons, observations were excluded when there was evidence of sensor failure. For site summaries, all observations were included to illustrate the frequency of sensor failure and the improvement in data quality following the initiation of Site Guardian efforts. These data are rooted in thousands of hours of work by Site Guardians and WDNR staff. The environmental data encompass more than 12,000,000 observations, and biological data cover shellfish and eelgrass situated amid diverse habitats and environmental pressures.

<u>Short-term goals</u>

- ANeMoNe intends to increase public engagement with ocean warming and acidification via Site Guardians, educational programs, and public presentations by WDNR staff.
- ANeMoNe aims to be a resource for experimental research. Learn more under 'Publications.'

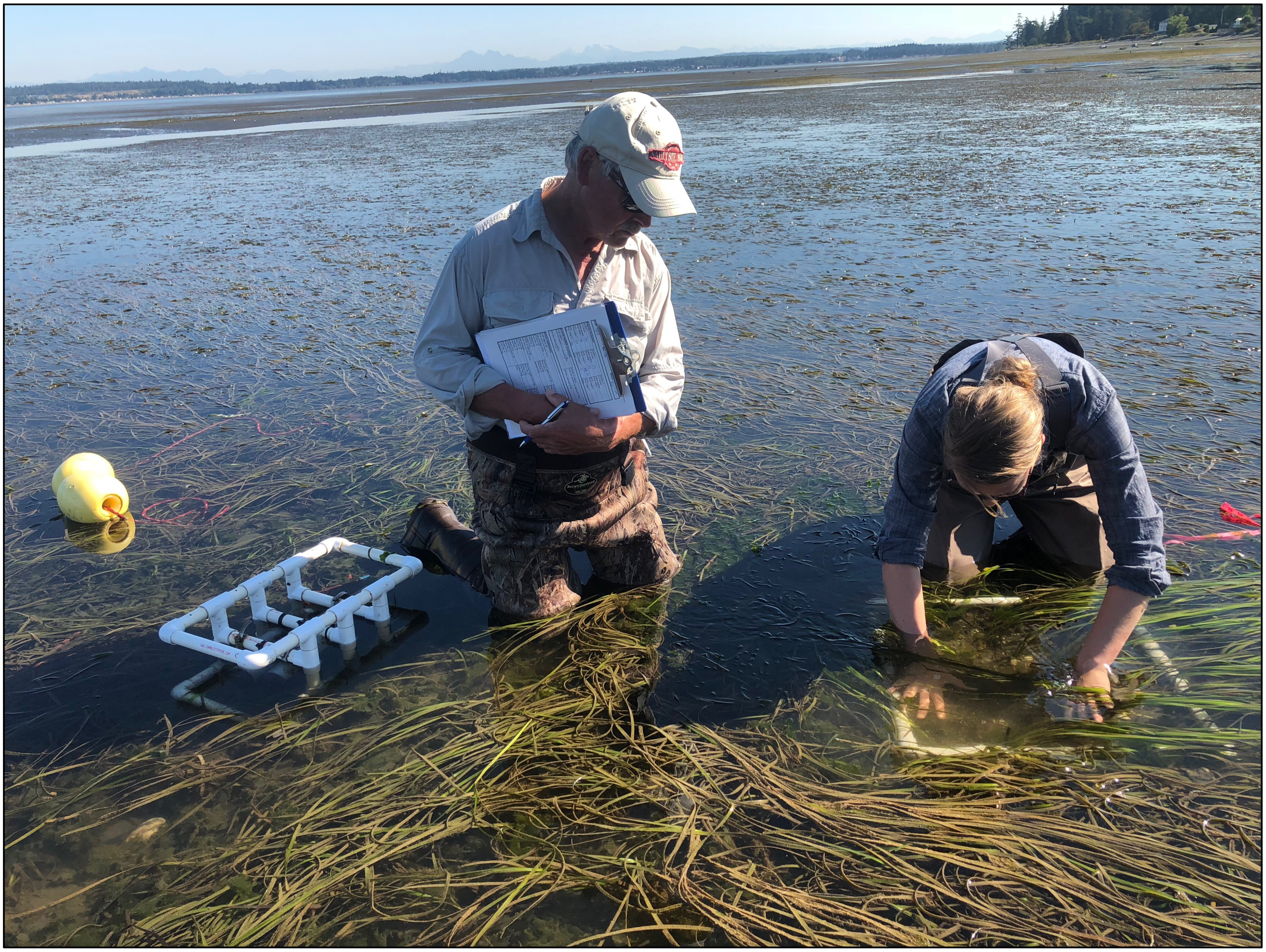
<u>Long-term goals</u>

- Ocean warming and acidification are slow-moving problems, and detecting their impacts will require many years of data. ANeMoNe is designed to generate data that can tease apart short-term and long-term variation in nearshore conditions, and delineate the effects of ocean warming and acidification.
- Regional differences could prove crucial in a changing ocean. Cooler or less acidic sites might provide refuge to sensitive organisms, while warmer or more acidic sites could merit special protections. Sites that are variable in pH or temperature could contain valuable genetic diversity, while more stable sites might be especially vulnerable to rapid shifts in environmental conditions. ANeMoNe hopes to explore these possibilities and develop management options for maintaining resilient ecosystems.

<u>New directions</u>

ANeMoNe is expanding in 2019. New sites have been established in Elliot Bay and in Sequim Bay, in partnership with the Port of Seattle and the Jamestown S'Klallam Tribe. WDNR is excited to broaden the scope of the network to include its first urban site and its first site on the Olympic Peninsula.

WDNR and WDFW co-manage the fishery for geoduck, a shellfish with enormous cultural and economic value. Partnering with WDFW, and Site Guardians, WDNR will study geoducks at their most sensitive life stage, as microscopic larvae. By measuring DNA in seawater, this project will determine when and where geoduck larvae occur, and identify areas and conditions that are critical for the future of the population.



Site Guardian and WDNR coordinator count eelgrass shoots at Cherry Point

Site Guardians

In 2018, WDNR partnered with the first cohort of Site Guardians: volunteers who collect biological data and maintain sensors. In May, WDNR hosted a summit at the Nisqually Reach Nature Center, where prospective Site Guardians got updates on ANeMoNe science and practiced survey methods and sensor maintenance.

Early on, WDNR discovered that the major obstacle to collecting environmental data was fouling: the growth of algae, barnacles, and other marine life on sensors. WDNR staff could not travel to ANeMoNe sites frequently enough to counteract fouling, and sensors often returned to Olympia with compromised data. Site Guardians have solved this problem. Through frequent visits and early removal of fouling, Site Guardians have vastly improved the quality of environmental data and our understanding of nearshore habitats.

Site Guardians bring their valuable understanding of local conditions, and serve as ambassadors to their communities on issues of climate change and ocean acidification. In 2019, WDNR hopes to retain current Site Guardians and recruit new volunteers. WDNR intends to listen to Site Guardians and re-evaluate survey methods and practices when necessary, and to collaborate on new research projects based on local interest.

At WDNR, Erica Bleke is the coordinator for Site Guardian activities. Contact her at erica.bleke@dnr.wa.gov.

Publications

ANeMoNe is a scientific resource to Pacific Northwest researchers, and Site Guardians help maintain this resource. By collecting synchronous environmental and biological data at many sites, the network is designed to support replicated experiments that pursue pressing questions: how do we limit the impacts of warming and acidification? will certain habitats provide refuge? can we develop tools to detect stress in sensitive species? Tribal biologists, university researchers, and agency scientists have teamed up to lead experiments looking for answers, and published their findings in the papers below.

Biologists from the Swinomish Indian Tribal Community explored whether recycled oyster shells could protect juvenile Manila clams by buffering local waters against ocean acidification. At two ANeMoNe sites, juvenile Manila clams were grown with and without recycled shells, and with and without kelp or eelgrass present. Recycled shells were effective in reducing acidity and increasing pH in the sediment where the clams live, but had no effect on clam growth. Clams grew more slowly in the presence of kelp or eelgrass. This study improves our understanding of the tools available to counteract acidification at small scales.

Greiner C.M., Klinger T., Ruesink J.L., Barber J.S., and Horwith M.J. (2018) Habitat effects of macrophytes and shell on carbonate chemistry and juvenile clam recruitment, survival, and growth, Journal of Experimental Marine Biology and Ecology, doi.org/10.1016/j.jembe.2018.08.006

Smithsonian scientists examined how interactions between oysters and eelgrass shift across the river-to-ocean zones of an estuary, including a mid-estuary ANeMoNe site. Native and non-native oysters grew faster in eelgrass near the ocean, but not near the river. Eelgrass appeared to increase shell strength for native oysters, and decrease shell strength for non-native oysters. The lack of consistent effects across the estuary shows that any beneficial effects of eelgrass may depend upon the local environment and proximity to freshwater sources.

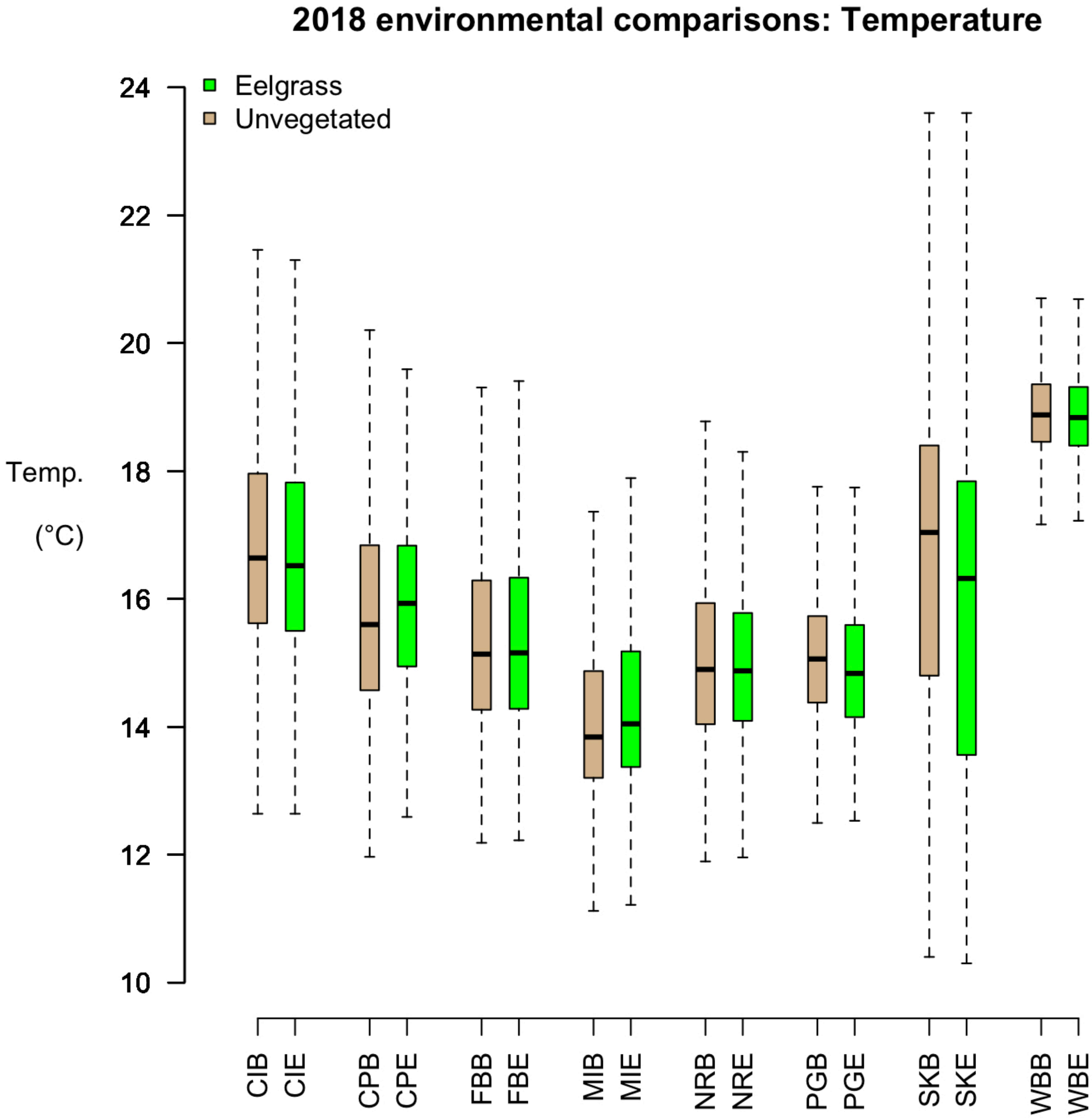
Lowe A.T., Kobelt J., Horwith M.J., and Ruesink J.L. (2018) Ability of eelgrass to alter oyster growth and physiology is spatially limited and offset by increasing predation risk, Estuaries and Coasts, doi.org/10.1007/s12237-018-00488-9

WDNR and University of Washington scientists measured how Pacific oyster physiology responds to temperature, pH, and the presence of eelgrass. Juvenile Pacific oysters were moved from a hatchery to five ANeMoNe sites. After 29 days, the oysters were collected, dissected, and the proteins in their gill tissue were analyzed using novel laboratory techniques. Pacific oyster physiology differed between Puget Sound and a Washington coastal estuary, perhaps reflecting that oysters in the estuary experienced more heat stress. These results help us understand differences in shellfish stress across Washington State, and the potential for particular areas to provide refuge from climate change and acidification.

Venkataraman Y.R., Timmins-Schiffman E., Horwith M.J., Lowe A.T., Nunn B., Vadopalas B., Spencer L.H., and Roberts S.B. (2019) Characterization of Pacific oyster Crassostrea gigasproteomic response to natural environmental differences, Marine Ecology Progress Series, doi.org/10.3354/meps12858

WDNR and University of Washington scientists tested the response of geoduck physiology to temperature, pH, and the presence of eelgrass. Juvenile geoducks were transplanted from a hatchery to five ANeMoNe sites. Over the following 29 days, eelgrass appeared to reduce acidity and increase local pH, but this had no effect on the geoducks. Instead, geoducks appeared to respond to temperature and dissolved oxygen. This study helps us predict how geoducks and their fishery may respond to warmer and more acidic waters.

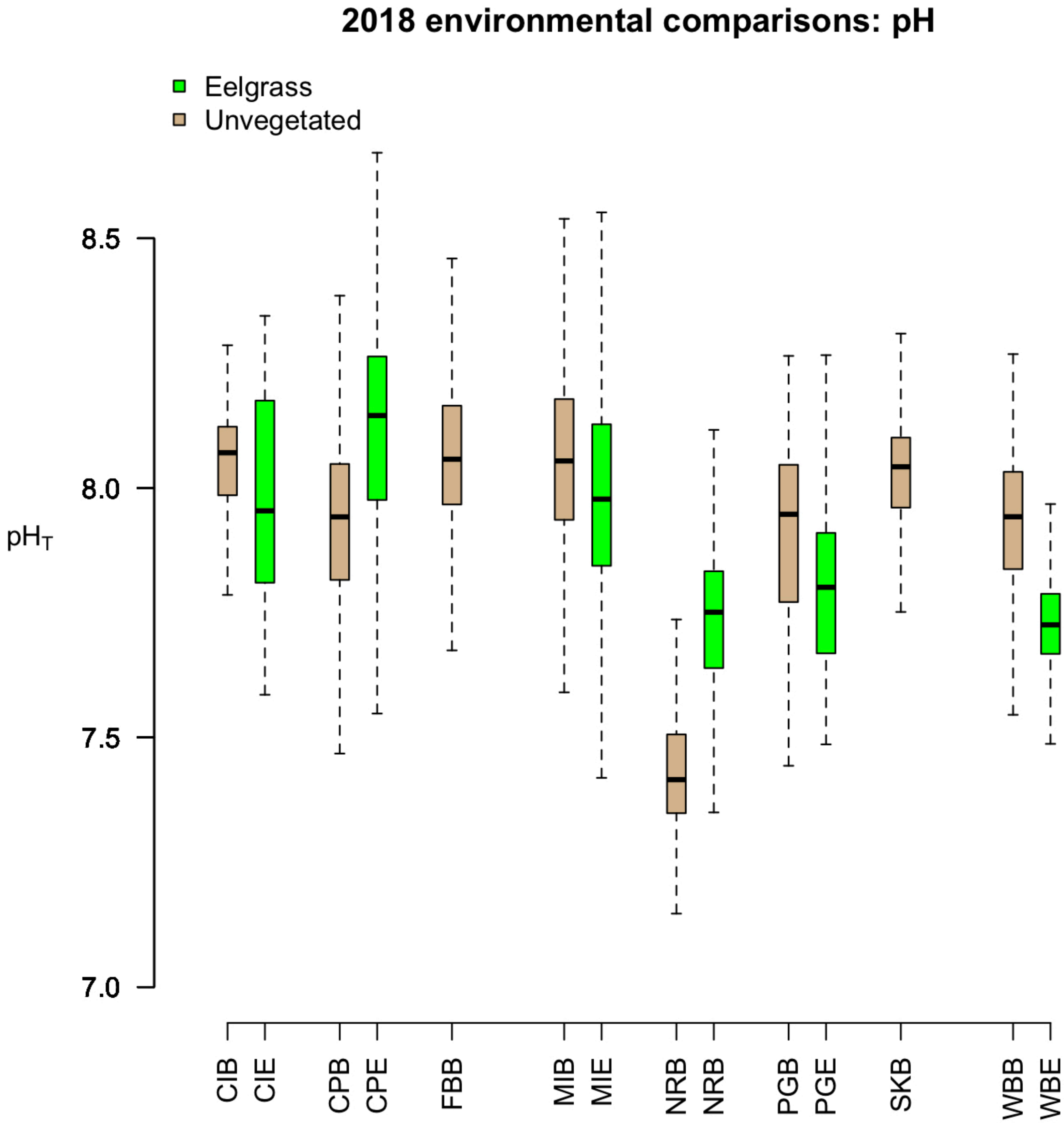
Spencer L.H., Horwith M.J., Timmins-Schiffman E., and Roberts S.B. (2019) Pacific geoduck (Panopea generosa) resilience to natural pH variation, Comparative Biochemistry and Physiology – Part D: Genomics and Proteomics, doi.org/10.1016/j.cbd.2019.01.010



Carbon emissions by human activities are driving climate change, and ANeMoNe is designed to measure the intensity and variation of warming waters in nearshore environments. Ocean temperatures have increased by about 0.8 to 1.0°C or 1.4 to 1.8°F since preindustrial times.

Water temperature affects virtually all aspects of biology, from respiration to reproduction. Warming waters may increase stress on native species, and allow invasive species to colonize. Climate change could also alter the timing of biological events, such as algae blooms and shellfish spawning.

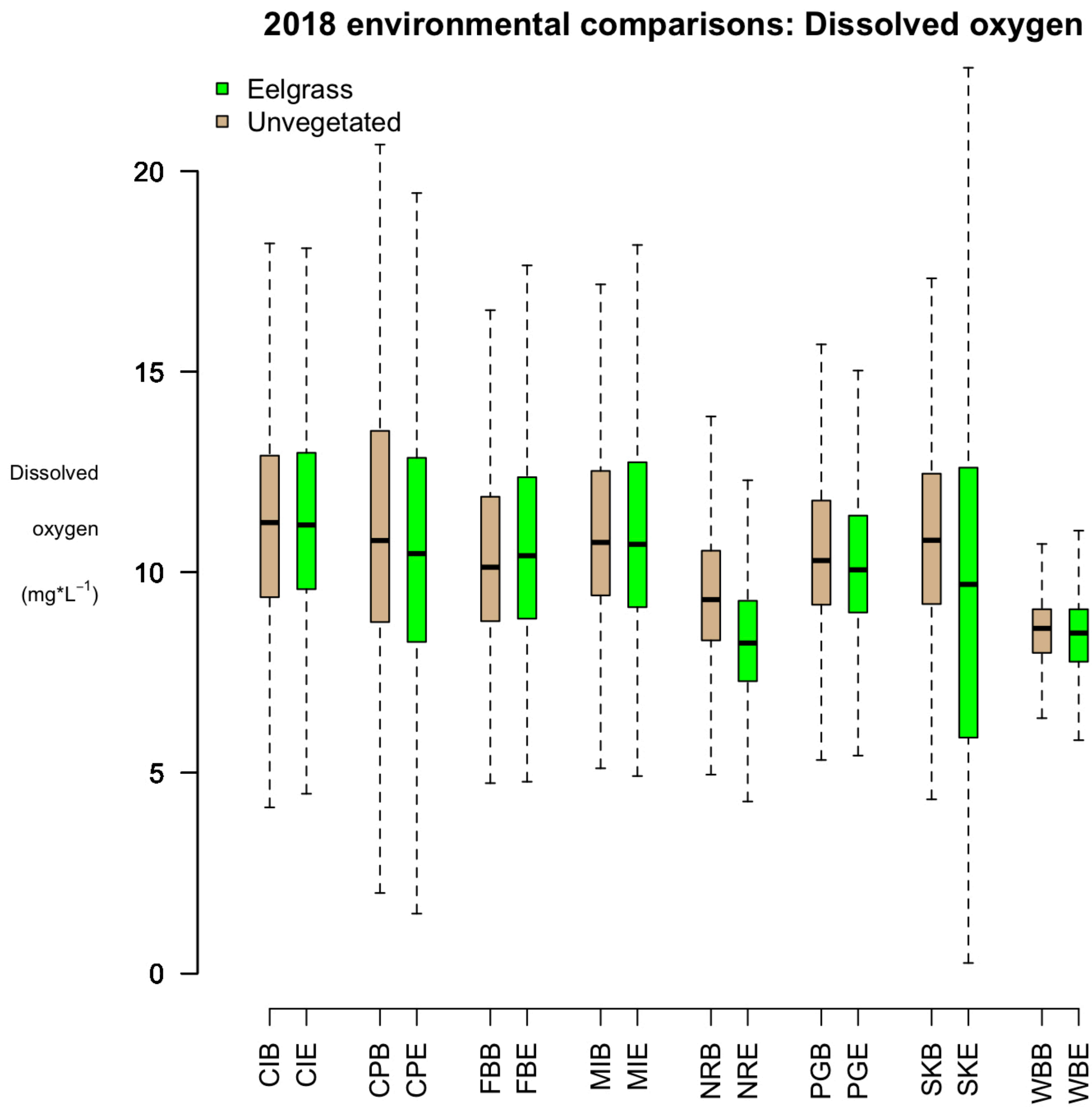
From June 19th to September 5th 2018, temperature was highest at Willapa Bay and lowest at Maury Island. The Skokomish River Delta was the most variable site and Willapa Bay the most stable.



Ocean acidification is another consequence of carbon emissions. As seawater absorbs excess carbon dioxide from the atmosphere, its pH declines. Ocean acidity has increased by about 25% since preindustrial times.

Shell-building animals are at risk from acidification: lower pH can dissolve shells, and make it harder to build new shell. Shellfish larvae have shown greater sensitivity to acidification than adult shellfish.

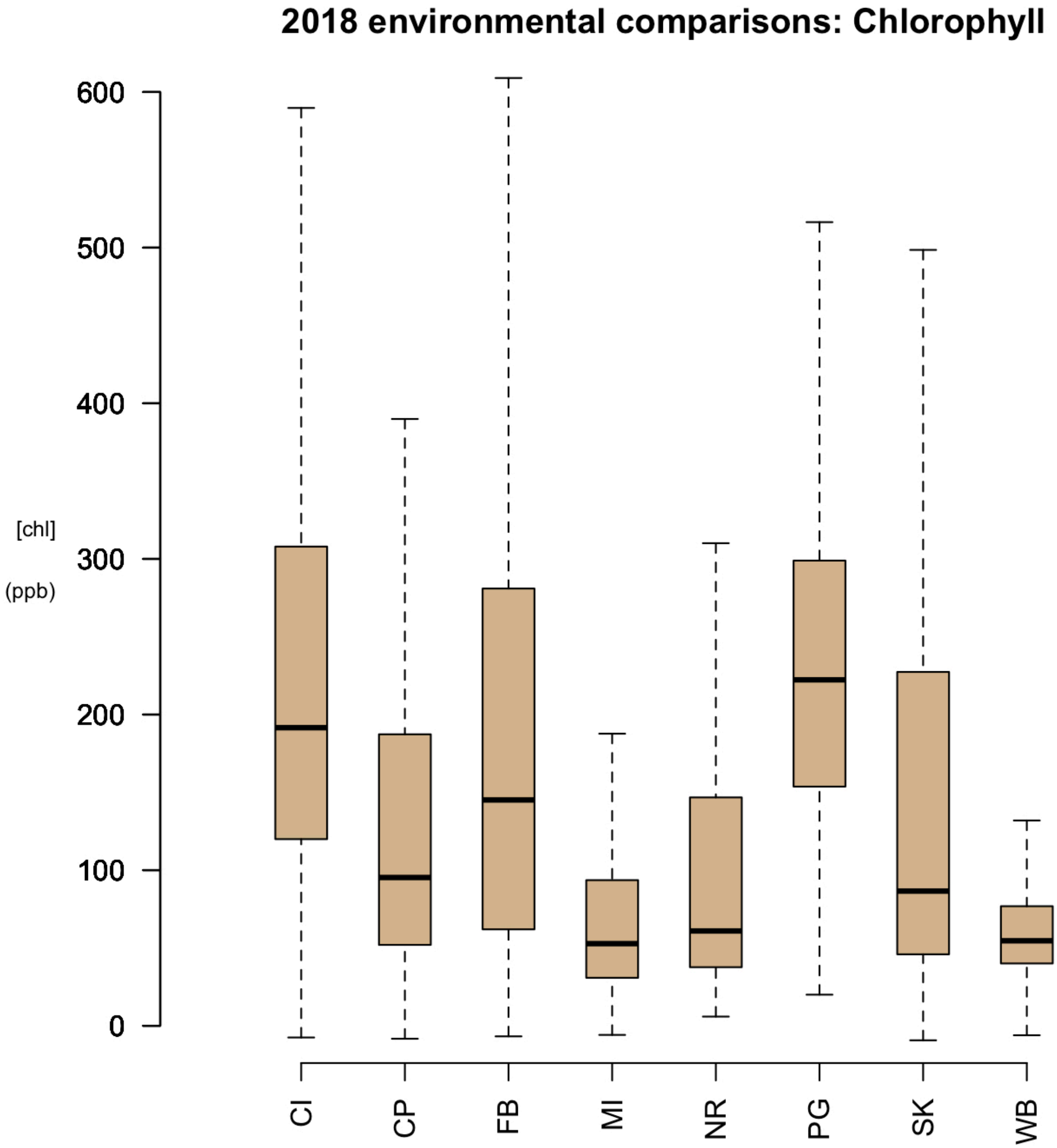
From June 19th to September 5th 2018, pH was similar across sites, but highest at Fidalgo Bay and lowest at Nisqually Reach. Cherry Point and Maury Island were the most variable sites and Case Inlet and the Skokomish River Delta the most stable. Eelgrass did not have a consistent effect on pH. The pH sensors in eelgrass at Fidalgo Bay and at the Skokomish River Delta failed over the relevant time period.



Warm water holds less oxygen than cold water. Projections suggest that climate change will cause dissolved oxygen in the oceans to decrease by 3 to 6% by the end of the 21st century.

Marine animals need oxygen to breathe. Hood Canal and South Puget Sound naturally experience periods of extreme low oxygen, resulting in the dramatic appearance of dead fish, crabs, and other animals. Ocean warming could increase the frequency or duration of these events and disrupt ecosystems.

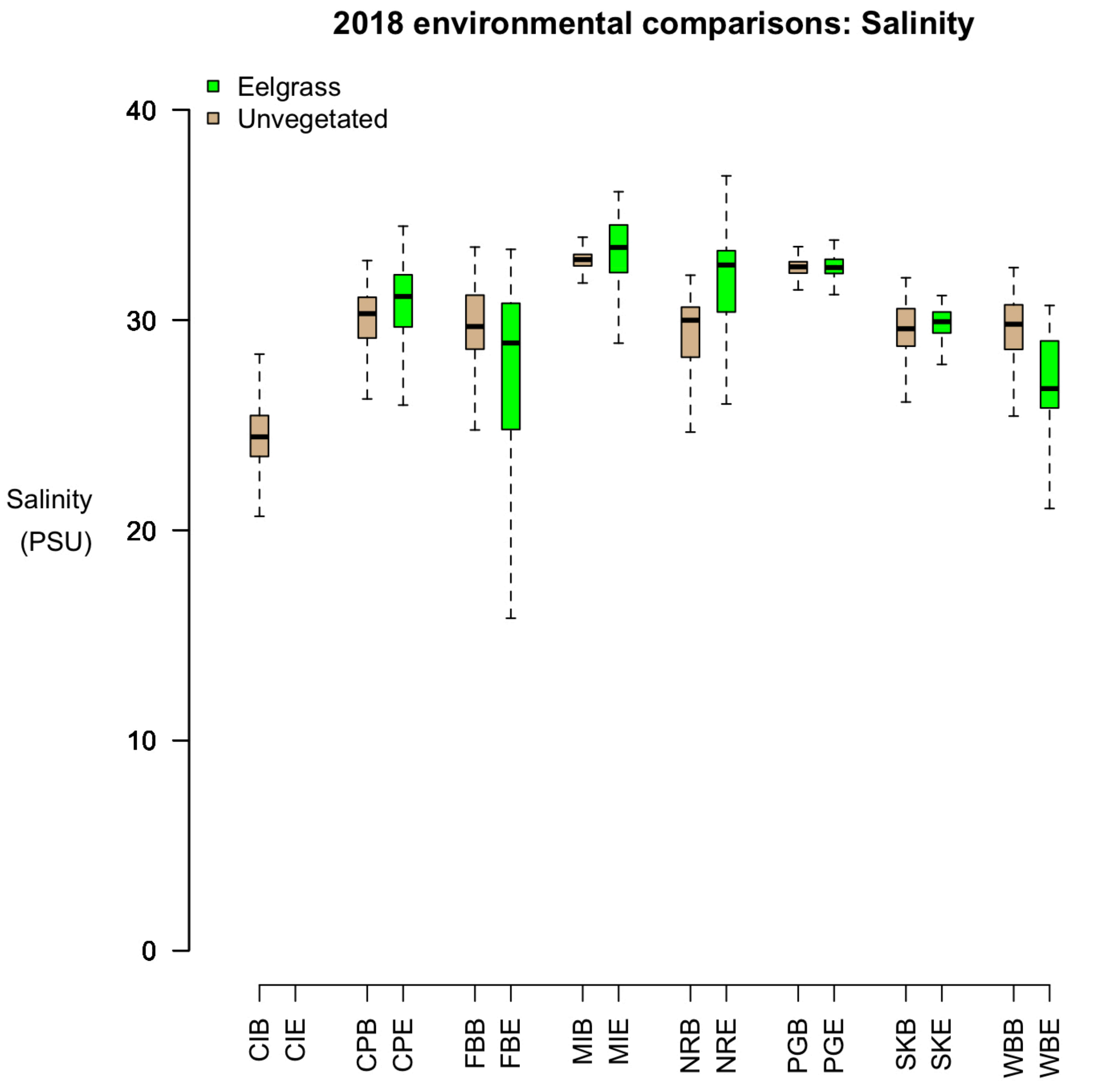
From June 19th to September 5th 2018, dissolved oxygen was similar across sites, but lowest at Nisqually Reach. Cherry Point and the Skokomish River Delta were the most variable sites and Nisqually Reach and Willapa Bay the most stable.



Phytoplankton form the base of oceanic food webs. Their cells contain chlorophyll, which is used as an indirect measure of phytoplankton abundance. The impacts of climate change on chlorophyll remain unclear.

ANeMoNe measures chlorophyll to gauge the food environment for shellfish, which eat phytoplankton, and to explore the effects of overlapping stressors. For example, a well-fed oyster may tolerate warmer water, while that same warm water could be lethal to an oyster starved of food.

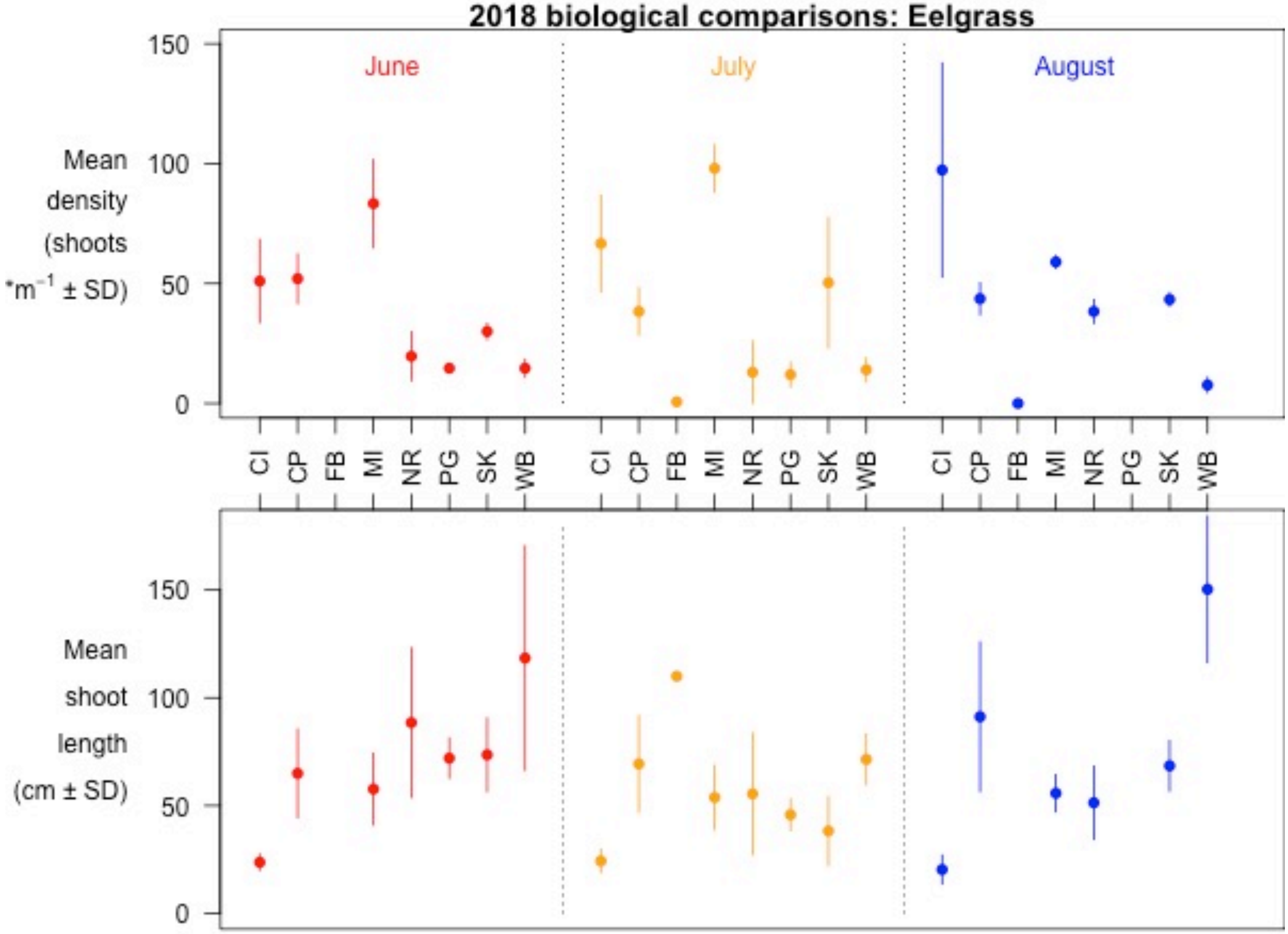
From June 19th to September 5th 2018, chlorophyll was highest at Case Inlet and Port Gamble Bay and lowest at Maury Island and Willapa Bay. Fidalgo Bay was the most variable site and Willapa Bay the most stable.



Lower salinities indicate a nearby source of freshwater. In the Pacific Northwest, climate change is projected to decrease mountain snowpack and increase rainfall, which will change the timing and intensity of freshwater inputs in the nearshore environment.

Changes in salinity are often stressful for marine animals and plants. Freshwater input also decreases pH, making local conditions more acidic.

From June 19th to September 5th 2018, salinity was similar across sites, but highest at Maury Island and lowest at Case Inlet. Fidalgo Bay was the most variable site and Port Gamble Bay the most stable. The salinity sensor in eelgrass at Case Inlet failed over the relevant time period.

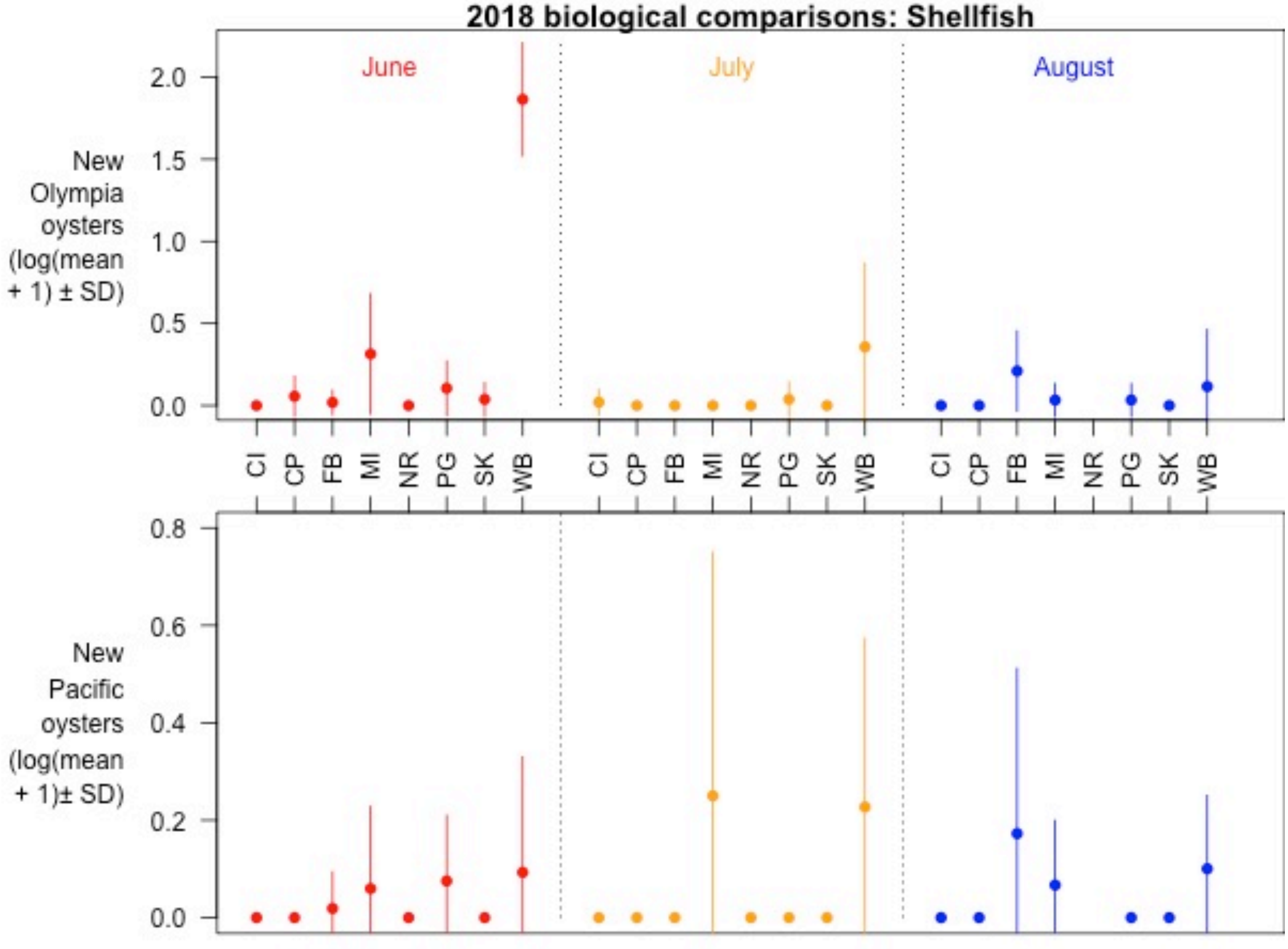


Eelgrass occurs across the northern hemisphere and provides habitat for many species. Like all plants, eelgrass performs photosynthesis, which absorbs carbon dioxide from surrounding waters. ANeMoNe tests whether eelgrass absorbs enough carbon dioxide to increase pH and locally counteract acidification.

Denser eelgrass is typically shorter, and sparser eelgrass is typically longer. Dense eelgrass is more effective at slowing waves and reducing erosion. Shorter and longer varieties of eelgrass shelter different species.

Eelgrass was most dense at Case Inlet and Maury Island and least dense at Fidalgo Bay and Willapa Bay. Eelgrass was longest at Fidalgo Bay and Willapa Bay and shortest at Case Inlet.

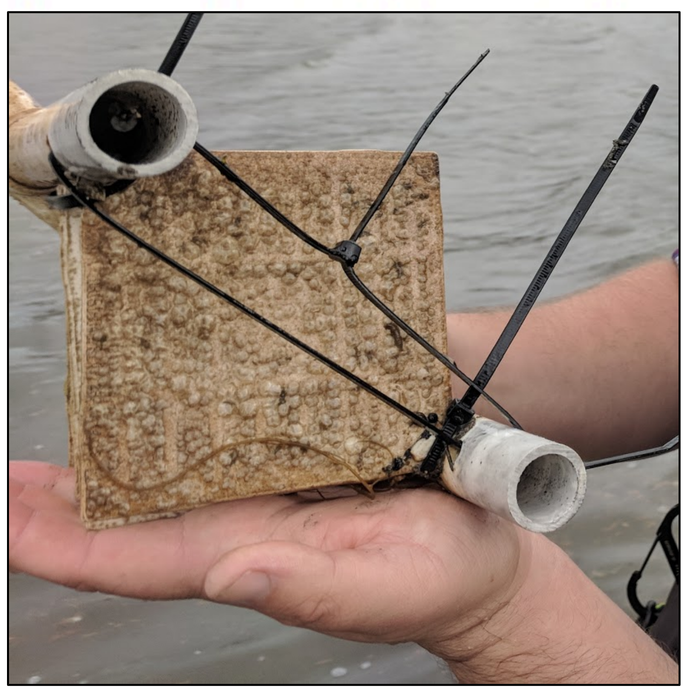
Cherry Point eelgrass meadow on a receding tide



Shellfish are at risk from acidification, along with other shell-builders like coral. Ocean warming is likely to harm some species and benefit others.

Native Olympia oysters have declined from their historical abundance. Pacific oysters are non-native and grown on farms across Washington State. As filter feeders, shellfish can improve water quality, and their shells can provide habitat for other species.

New Olympia oysters appeared most often in June, and were most common at Willapa Bay. New Pacific oysters appeared throughout the summer, and were most common at Maury Island and Willapa Bay.



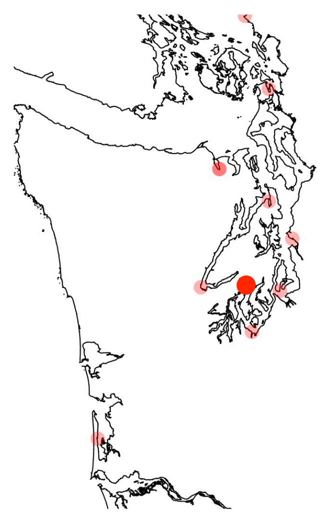
New juvenile invertebrates on a collected tile

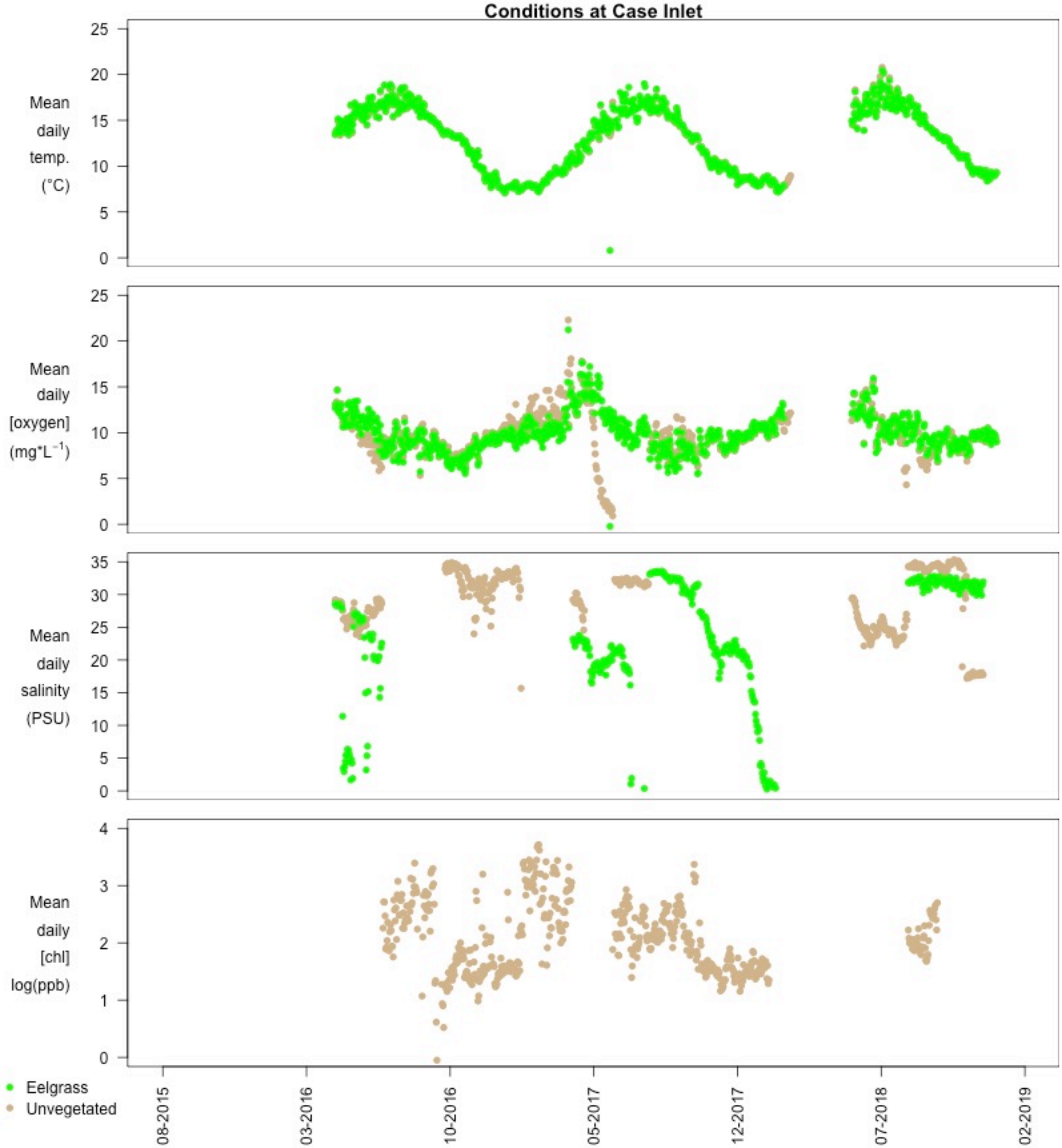
Case Inlet

Site Guardian and WDNR scientists collecting tiles at Case Inlet

In south Puget Sound, Case Inlet supports commercial oyster and geoduck aquaculture. Beds of sand dollars occur here in the intertidal zone, and great blue heron and double-crested cormorants are common. This site has a large tidal amplitude: waters can rise or fall almost 20 feet in seven hours.

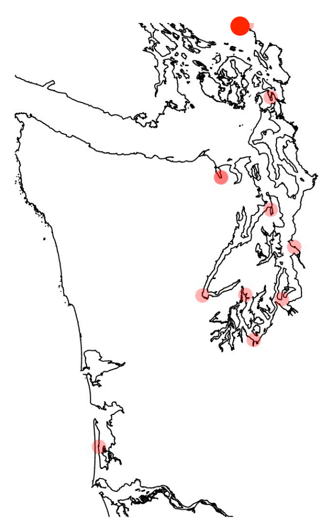
ANeMoNe measurements began in May of 2016.




Conditions at Case Inlet
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L⁻¹)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

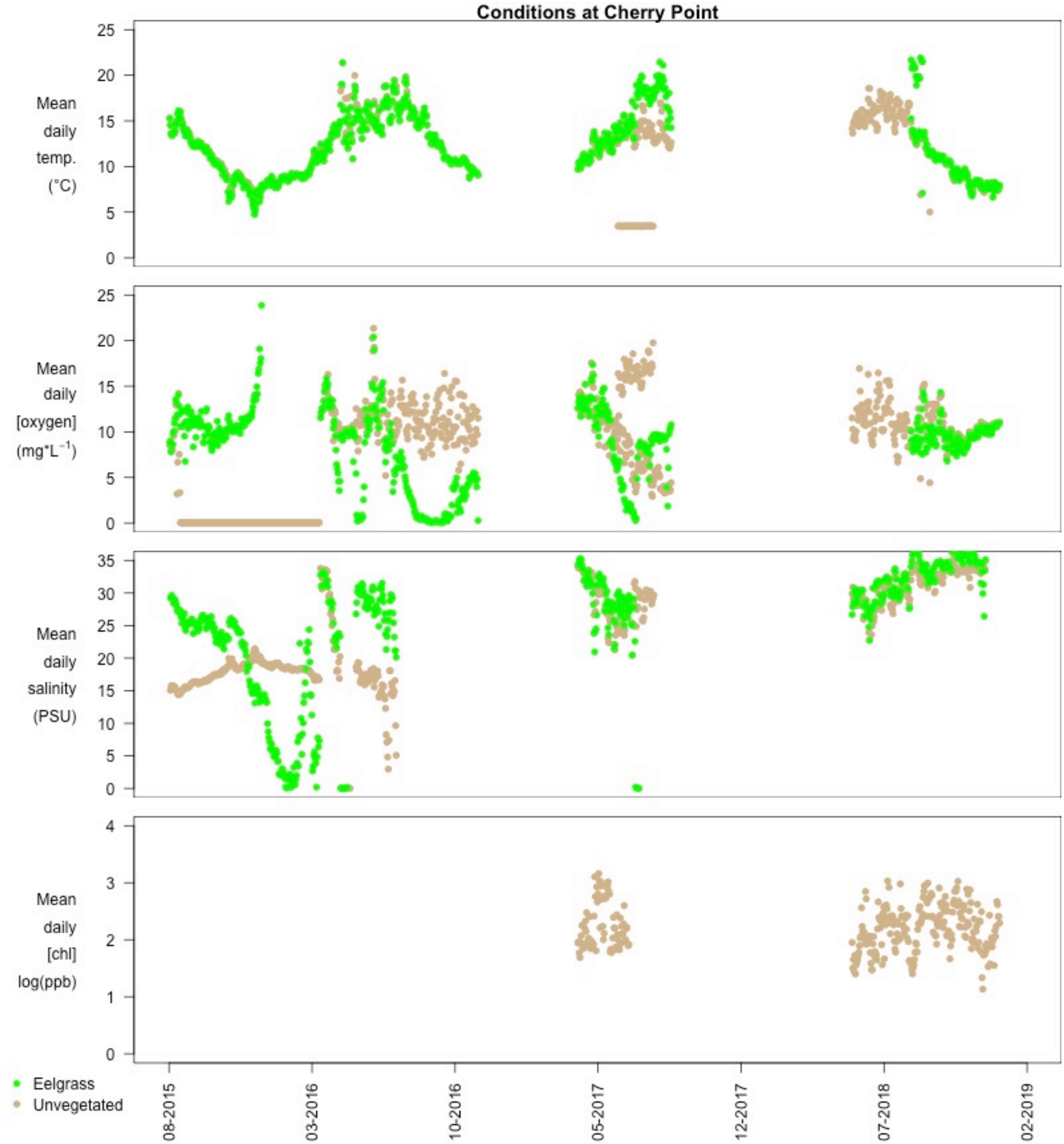
Cherry Point

Cherry Point Site Guardians head out to maintain sensors and assess eelgrass



Near the Canadian border, Cherry Point is a WDNR Aquatic Reserve encompassing 3,050 acres. This site has historically supported substantial populations of Pacific herring and surf smelt, which are forage for salmon, seabirds, and marine mammals. Cherry Point is the most exposed ANeMoNe site, facing strong waves and winter storms.

ANeMoNe measurements began in August of 2015, but sensors were removed through the winters of 2016 and 2017 to avoid storms.

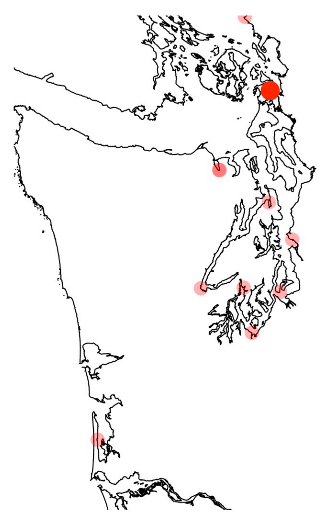

Conditions at Cherry Point
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L⁻¹)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

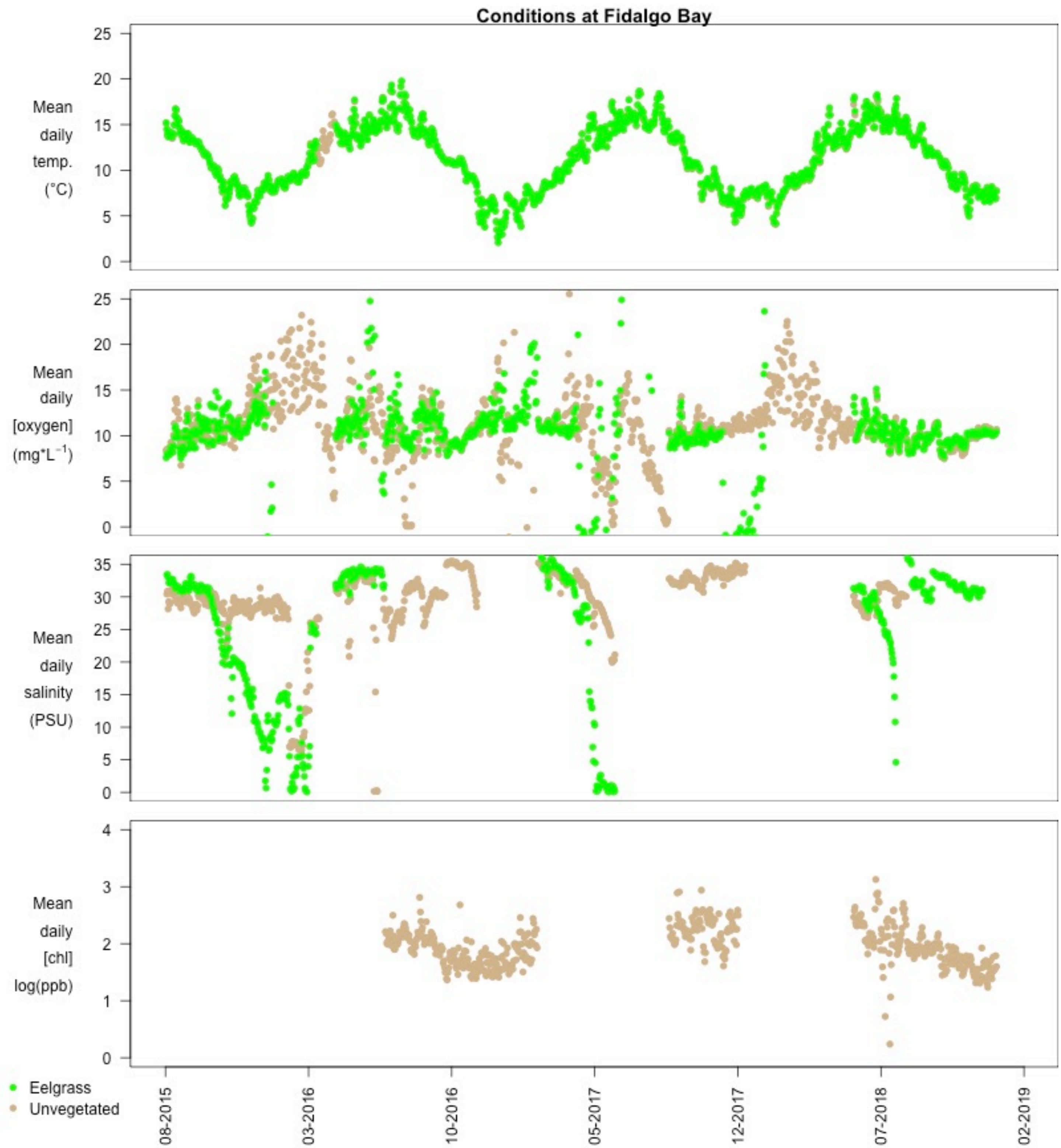
Fidalgo Bay

Fidalgo Bay Site Guardians counting eelgrass shoots and collecting tiles to assess shellfish reproduction

Fidalgo Bay is a WDNR Aquatic Reserve north of Puget Sound, covering 781 acres. Olympia oyster restoration has helped to establish a viable population of native shellfish here. Surf smelt and Pacific herring spawn within the reserve, and birdlife is particularly diverse and abundant.

ANeMoNe measurements began in August of 2015.



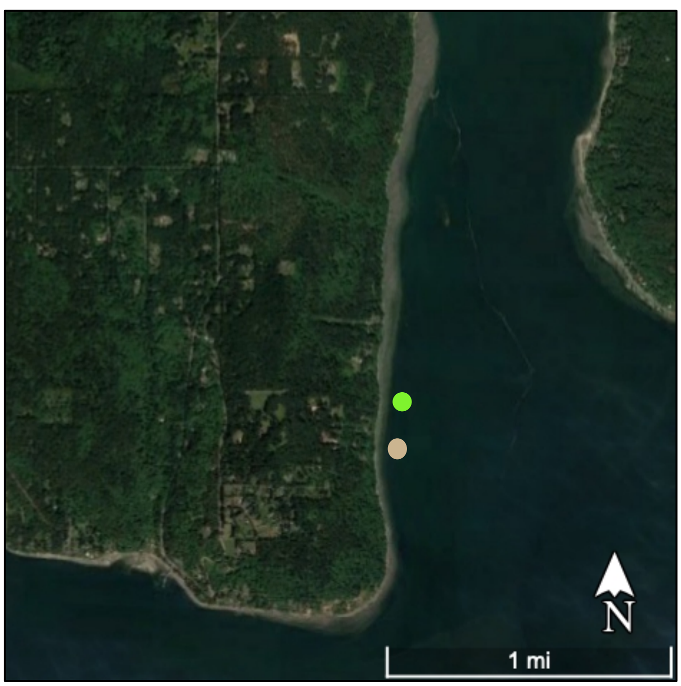

Conditions at Fidalgo Bay
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L^-1)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

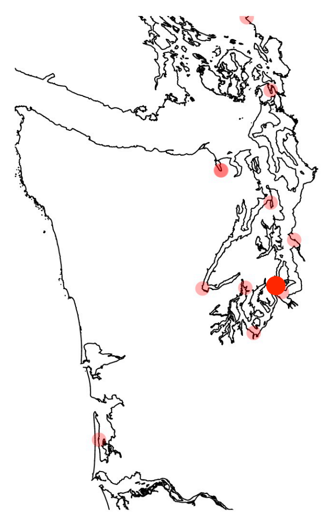
Maury Island

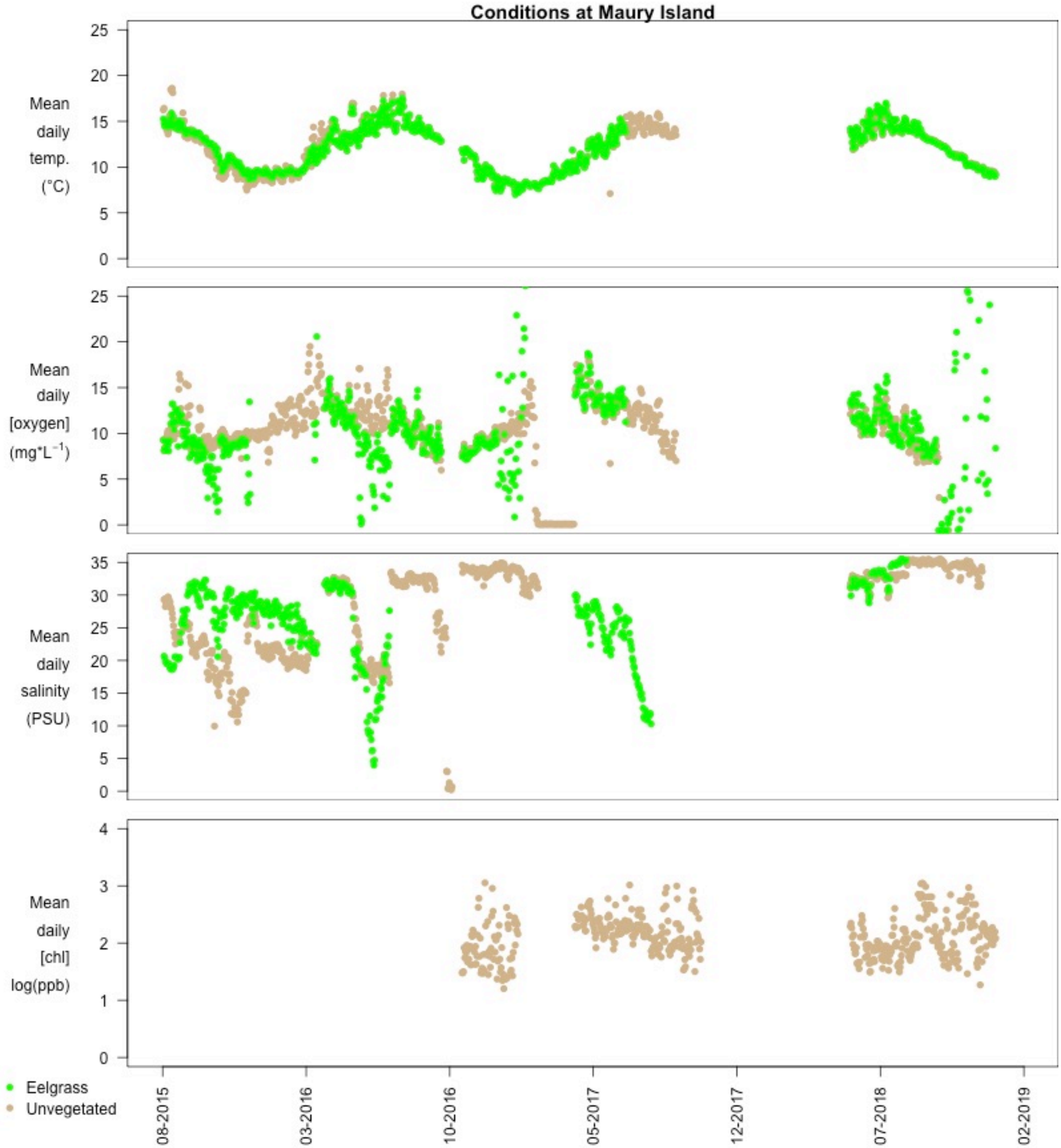
Maury Island Site Guardians and WDNR scientist swapping collecting deployed sensors

Maury Island is a WDNR Aquatic Reserve in central Puget Sound that spans 5,530 acres. Designated by the Audubon Society as an Important Bird Area, this site is frequented by resident and migratory species. Although eelgrass flourishes here, it has vanished to the north in Quartermaster Harbor, for reasons that remain unclear.

ANeMoNe measurements began in August of 2015.





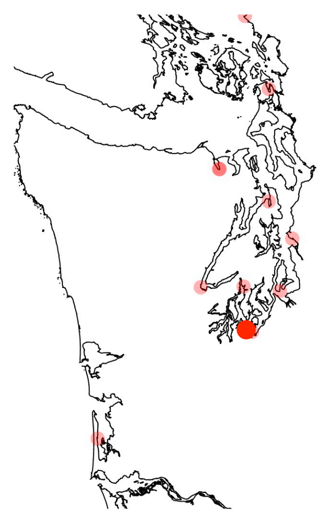

Conditions at Maury Island
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L⁻¹)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

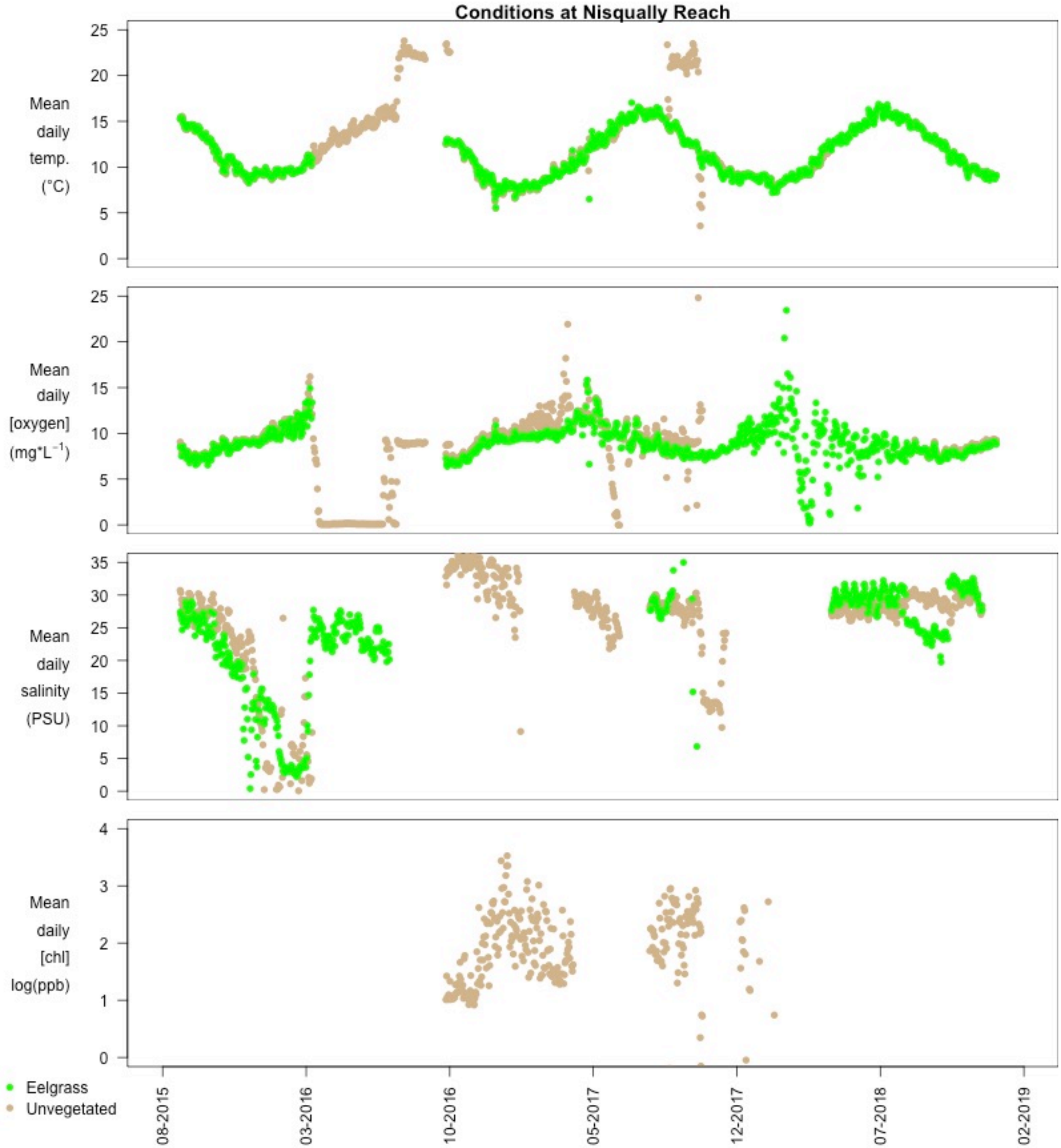
Nisqually Reach

Nisqually Reach eelgrass station with sensors exposed at low tide

Nisqually Reach is a WDNR Aquatic Reserve that stretches over 14,826 acres in south Puget Sound. This site experiences strong seasonal freshwater inputs from the Nisqually River. Salmon migrate through the reserve as juveniles and as adults, prior to their upstream migration.

ANeMoNe measurements began in September of 2015.



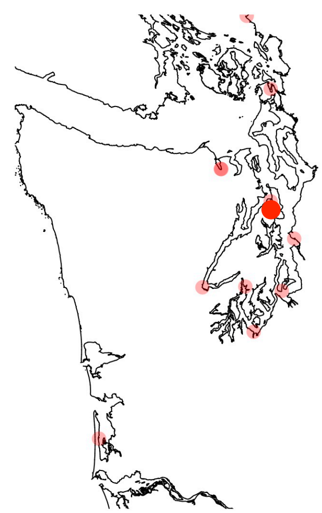

Conditions at Nisqually Reach
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L⁻¹)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

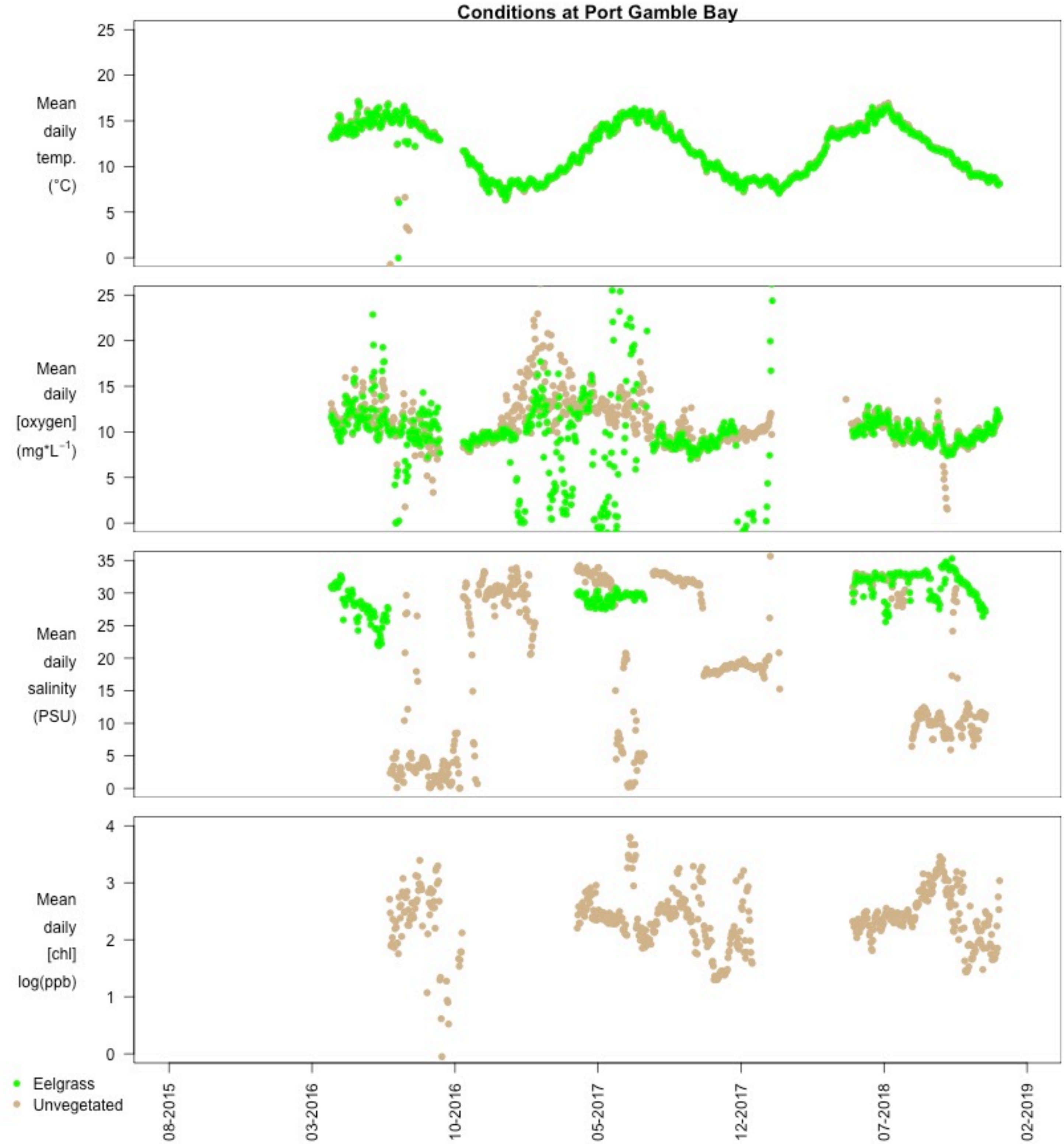
Port Gamble Bay

WDNR and University of Washington scientists setting up an experiment in Port Gamble Bay

Just north of Hood Canal, Port Gamble Bay has experienced substantial restoration in recent years with the removal of a derelict mill, contaminated sediment, wood waste, and creosote-treated pilings. The Port Gamble S'Klallam harvest fish and shellfish in their usual and accustomed areas in and outside of the bay.

ANeMoNe measurements began in April of 2016.



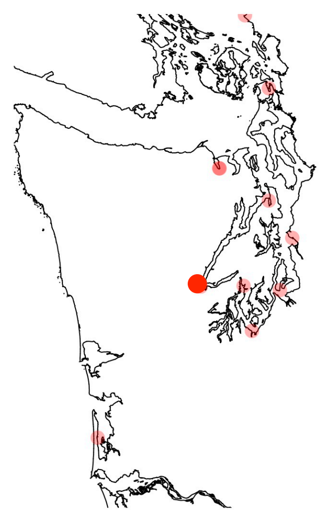

Conditions at Port Gamble Bay
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L^{-1})
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

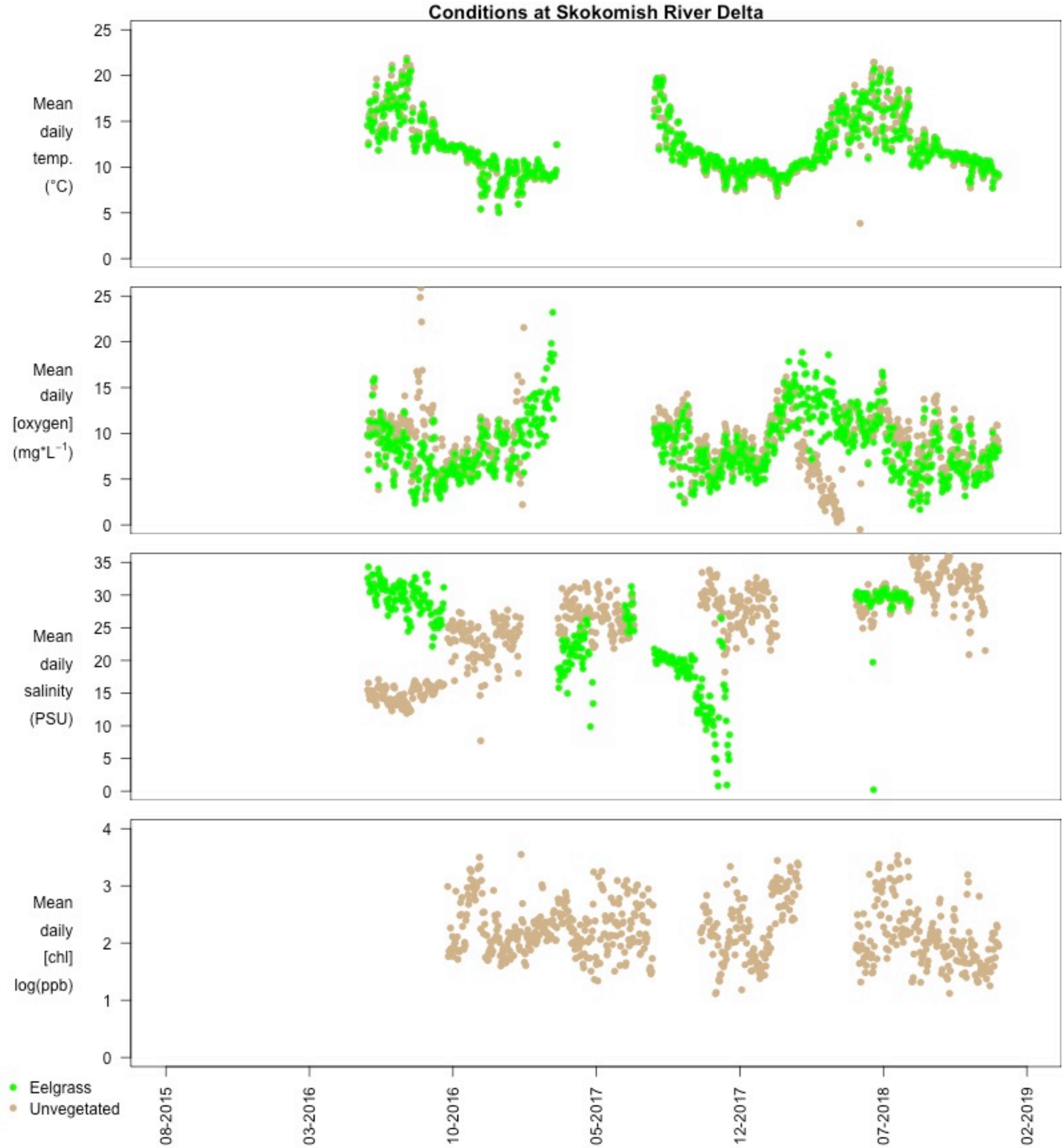
Skokomish River Delta

Skokomish River Delta Site Guardians ready to assess eelgrass

In south Hood Canal, the Skokomish River Delta naturally experiences periods of low oxygen and seasonal freshwater inputs. The Skokomish harvest intertidal shellfish across their usual and accustomed areas in the Delta.

ANeMoNe measurements began in June of 2016.




Conditions at Skokomish River Delta
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L⁻¹)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
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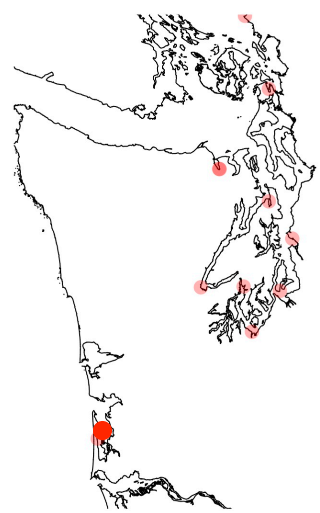
07-2018
02-2019

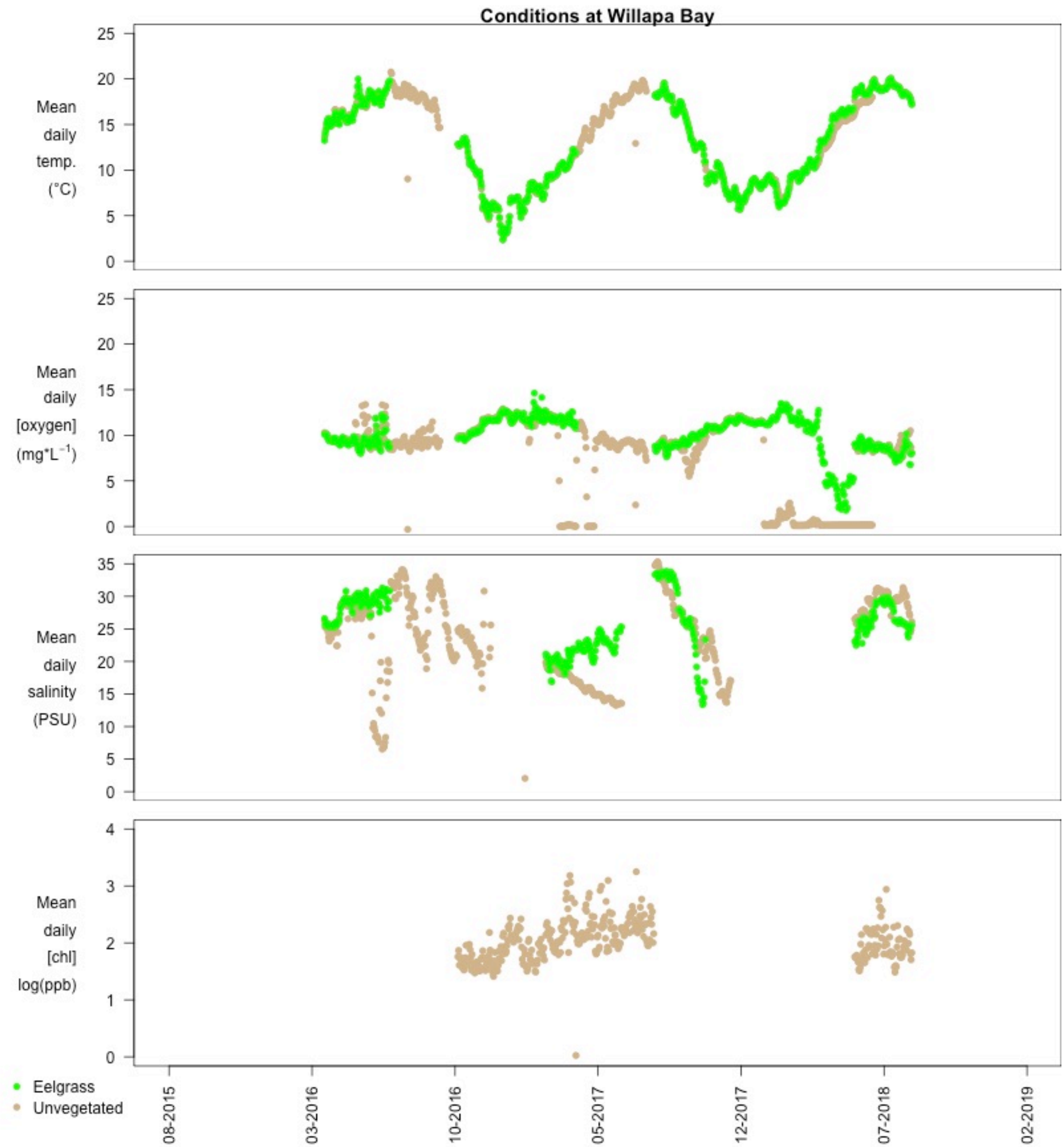
Willapa Bay

Willapa Bay tideflats, with oyster farm in the distance

Willapa Bay is an enormous coastal estuary in southwestern Washington. The bay supports commercial shellfish aquaculture and produces roughly one out of every five oysters in the United States. Birds and marine mammals feed and rest in the bay on their coastal migrations.

ANeMoNe measurements began in April of 2016.




Conditions at Willapa Bay
Mean daily temp. (°C)
Mean daily [oxygen] (mg*L⁻¹)
Mean daily salinity (PSU)
Mean daily [chl] log(ppb)
Eelgrass
Unvegetated
08-2015
03-2016
10-2016
05-2017
12-2017
07-2018
02-2019

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Julian Sammons served as a 2018 Site Guardian at the Skokomish River Delta.

Collaborators: Julie Barber, Courtney Greiner, Terrie Klinger, Julia Kobelt, Alex Lowe, Brooke Nunn, Steven Roberts, Jennifer Ruesink, Laura Spencer, Emma Timmins-Schiffman, Brent Vadopalas, and Yaamini Venkataraman contributed to published scientific studies that drew data from ANeMoNe.

George Blomberg, Randy Edwards, and Jon Sloan at the Port of Seattle and Sarah Sandstrom at The Watershed Company led efforts to add a new ANeMoNe site at Elliott Bay.

Liz Tobin at the Jamestown S'Klallam Tribe led efforts to add a new ANeMoNe site at Sequim Bay.