Oceanographic Data across Oregon's Marine Reserves

John A. Barth[1], Anatoli Erofeev[1], and Francis Chan[2]

[1]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University
[2]Department of Integrative Biology, Oregon State University

December 15, 2021

This report summarizes the results from oceanographic sampling by the Oregon Department of Fish and Wildlife's Marine Reserve Ecological Monitoring team in Oregon's five marine reserves (**Figure 1**). In this section, a summary of oceanographic sampling and results are presented. Appendix A contains information about data collection methods, Appendix B describes oceanographic conditions at and among Oregon's Marine Reserves, while Appendix C contains a comprehensive set of plots of oceanographic measurements by reserve, from north to south, and by year. This summary includes some lessons learned and recommendations for the future.

Figure 1. Map showing the location of Oregon's marine reserves and associated protected areas (from https://oregonmarinereserves.com).

Data from oceanographic sensors deployed in Oregon's marine reserves (MR) by the ODFW Ecological Monitoring team since 2010 both expand the amount of oceanographic information from Oregon's state waters as well as confirm the basic summertime patterns created by wind-driven upwelling. The measurements in Oregon's MR extend the routine ocean observations made by other programs (NOAA, Ocean Observatories Initiative - OOI, Partnership for Interdisciplinary Studies of Coastal Oceans - PISCO) well north and south beyond those programs' focus off central Oregon (Newport to Coos Bay). Specifically, the Oregon MR program adds seasonal measurements from four additional along-shelf locations in state waters to the only existing year-round mooring in state waters maintained by OOI off Yaquina Head, and to the seasonal measurements at Cape Perpetua maintained by PISCO. In turn, the analysis of Oregon MR oceanographic data benefits greatly from the availability of data from the year-round OOI buoy off Yaquina Head near the Otter Rock MR and from the summertime PISCO moorings in and just offshore of the Cape Perpetua MR.

The ODFW MR Ecological Monitoring team has established effective mooring and platform designs and the ability to deploy them through use of research and fishing charter vessels near each marine reserve. For the most part, they follow best practices for sensor preparation and calibration, and for metadata documentation. However, there is room for improvement as their limited staff must always deal with the operational, at-sea sampling first. It is recommended that more attention be paid to sensor and data quality assurance and quality control (QA/QC).

Oceanographic sampling by the ODFW MR Ecological Monitoring team has not been able to be done simultaneously in all five marine reserves due to a lack of equipment. Their measurements have been most effective for temperature, with modest success measuring salinity and dissolved oxygen due to the added complexity of those measurements. Note that both OOI (since 2014) and PISCO (since 1999) moorings are in place each year, although the PISCO sampling at Cape Perpetua is in danger of being stopped due to funding. Both the shortfall in total equipment and lack of sensors for salinity and dissolved oxygen may be helped through the availability of funding through Oregon House Bill 3114 (HB3114), but likely only for the 2021-2023 biennium. The ODFW MR and state should address these equipment shortfalls and the ongoing support for oceanographic measurements.

The ability to compare oceanographic measurements from inner-shelf waters, less than 50 m in depth, taken during the same summer season along nearly 350 km of coastline spanning two distinct oceanographic and biogeographic regions is unprecedented. Because the dominant summertime forcing is by wind-driven upwelling, separated by wind relaxation or, less frequently, downwelling, and these wind patterns extend across Oregon state waters, oceanographic measurements are well correlated between the marine reserves. The correlation holds best for temperature. The next best correlation is for salinity, where local sources of freshwater contribute to decorrelation, although there are very few salinity measurements available from the OR marine reserves outside of Cape Perpetua (PISCO sampling) and Otter Rock (using OOI as a proxy). Lastly, dissolved oxygen is correlated along the coast even in the face of potentially patchy, biological processes that may further lead to decorrelation. Again, this all reinforces the point that the large-scale, wind-driven upwelling of deep, cold, salty, low-oxygen water – separated by period of wind relaxation and wind downwelling when offshore surface waters move shoreward and into the marine reserves -- dominates the summertime response off Oregon.

The extensive coverage across years offers the chance to look for interannual variability in oceanographic conditions in the marine reserves. This can be done for Cape Perpetua where there are 18 years of data to compute a season climatology (see Appendix C). One notable time when the data from the marine reserve are anomalous is when anomalously warm, fresh, high-

DO water from offshore is advected into the marine reserve during wind relaxation or downwelling. This is evident during the late summer of 2015 as the Warm Blob waters of the Northeast Pacific lurked offshore. The upwelling tends to shield inshore state waters from the large-scale, near-surface heating that occurred during the warm blob years. It is also notable that dissolved oxygen is anomalously low during upwelling events in late 2020.

Intertidal sampling of pH (see Appendix B) shows that waters in Oregon's marine reserves are exposed to low-pH and low aragonite saturation state, especially during late summer. Initial data highlight 1) the propagation of low pH signals across the continental shelf and into the intertidal environment, 2) extremely high temporal variability in pH reflecting time variations in upwelling winds, and 3) spatial differences in the severity of exposure to low pH, corrosive waters between reserves. Subsequent deployments suggest the persistence of 1) fine-scale spatial differences in OA exposure between reserves in addition to regional differences reflecting, in part, region-specific water mass properties that vary temperature vs. pH.

In some of the Oregon MR (CF, OR, RR), ODFW measured oceanographic parameters in nearby "comparison areas" to support biological sampling in the comparison areas compared with the marine reserves. Based on comparisons presented in Appendix B, mostly using temperature but also using some limited salinity and dissolved oxygen measurements, the general conclusion is that the comparison areas are similar oceanographically to each of the MR sites. Another way to say this is that the marine reserves and their nearby comparison areas are exposed to the same large-scale oceanographic processes allowing biological sampling to be compared without influence of differing oceanographic conditions between the MR and nearby comparison area.

In summary, oceanographic sampling in Oregon's marine reserves has extended our knowledge of oceanographic processes in state waters in space, time, and in the number of regularly measured parameters (temperature, salinity, dissolved oxygen, pH). They provide useful data for characterizing the ocean habitat during the biological sampling in and near the reserves. A good baseline has been established, but more concerted effort is needed to measure each of the oceanographic parameters simultaneously at each of Oregon's marine reserves. This will require both more equipment and personnel time focused on oceanographic data collection, data QA/QC, and analysis. The support of increased monitoring through HB3114 for ocean acidification and hypoxia in the subtidal and intertidal of Oregon's marine reserves is promising.

Acknowledgements

This report would not have been possible without the committed work of the ODFW Marine Reserves Ecological Monitoring Team. We also thank the oceanographic technicians from the PISCO program and for support of the PISCO program and allied observing projects from the David and Lucile Packard Foundation, the Gordon and Betty Moore Foundation, Oregon Sea Grant, the National Science Foundation, and the Educational Foundation of America. Thanks also to the captains and crews of the various research and fishing vessels that deployed and recovered instruments up and down the coast in Oregon's marine reserves. We appreciate the volunteers who help maintain the intertidal pH instruments in Oregon's marine reserves. This report was produced with support from the Oregon Department of Fish and Wildlife.

Appendix A: Oceanography Methods Development

Oceanographic measurements in Oregon's marine reserves were collected using a variety of platforms including bottom landers, water-column moorings, and instrumented crab pots. For all but the Cape Perpetua Marine Reserve where measurements were made by the Oregon State University Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO – Menge et al., 2019) team, oceanographic measurements were made by the ODFW Ecological Monitoring Team. The sampling approach and monitoring activities being employed at each site are described in the ODFW Marine Reserve's Ecological Monitoring Plan (ODFW, 2017). Sensors include a Sea-Bird Scientific SBE16+ conductivity-temperature-depth instrument equipped with a Sea-Bird SBE43 dissolved oxygen (DO) sensor. Other sensors are Onset Tidbit sensors for temperature and Onset HOBO Dissolved Oxygen Data Loggers (U26-001) for both DO and temperature. These sensors are factory calibrated before each sampling season. In addition, the DO sensors are calibrated in the laboratory by cross checking against known, calibrated DO sensors and/or against Winkler titrations done at zero and saturated oxygen levels.

Because the ODFW Marine Reserves Ecological Monitoring Team does not have sufficient oceanographic sensors to make simultaneous observations at all five marine reserve at once, the team used an alternating years approach. That is, they deployed oceanographic sensors in the marine reserves during summer upwelling seasons that were targeted for biological sampling via hook and line surveys, scuba surveys, and/or video cameras deployed on bottom landers or a remotely operated vehicle (ROV). The data reported here for each reserve and by year reflect that choice of sampling strategy (ODFW, 2017).

In recent years, for example 2019, the ODFW Ecological Monitoring Team deployed crab pots instrumented with an Onset T/DO sensor during the days there were doing biological sampling. These 1-2 day long records can be used to compare oceanographic conditions during biological sampling in the marine reserves and comparison areas.

Oceanographic sampling in the Cape Perpetua Marine Reserve has been conducted by PISCO since 1999 following methods described in Kirincich and Barth (2009) for temperature and salinity, and in Adams et al. (2013) for dissolved oxygen. Measurements are made at the 15-m isobath (SH15) using an oceanographic mooring equipped at various depths with sensors measuring temperature and salinity with a Sea-Bird Scientific SBE 16+ conductivity-temperature-depth instrument, and dissolved oxygen using a Sea-Bird Scientific SBE43. Data from the 70-m isobath (SH70), outside of the CP MR but indicative of upwelled source waters and used in this report, were collected from an instrumented bottom lander described in Adams et al. (2013) using the same set of Sea-Bird Scientific sensors used at the 15-m site. Temperature, salinity, and DO sensors are factory calibrated before and after each field season. In addition, calibration casts were performed on the DO sensor at the end of each deployment. During a calibration cast, the moored DO instrument is attached to a profiling instrument with a laboratory-calibrated (via Winkler titrations) DO sensor and data are collected for 5 min at a few depths through the water column. Data from calibration casts were plotted against each other to determine inaccuracies in the moored instrument measurements, e.g., drift. Final DO data are corrected for any observed drift, usually zero or small especially at the SH70 site.

The Otter Rock (OR) Marine Reserve is close (~7.5 km) to a year-round mooring maintained in 25 m of water off Yaquina Head by the Ocean Observatories Initiative (OOI) (https://oceanobservatories.org). The OOI mooring has a seafloor platform with sensors that measure temperature, salinity and dissolved oxygen, among a number of other oceanographic parameters. Comparing the OR and OOI temperatures during 2018 shows they are highly correlated in time (**Figure A1**) and that OR average temperatures over the upwelling season are slightly cooler (0.3-0.5° C) when compared at similar depths (**Figure A2**). Interestingly, the average OR 15-m temperature is nearly identical to the OOI 25-m temperature. Therefore, when temperature measurements are not available from the OR MR, the OOI 25-m data will be used.

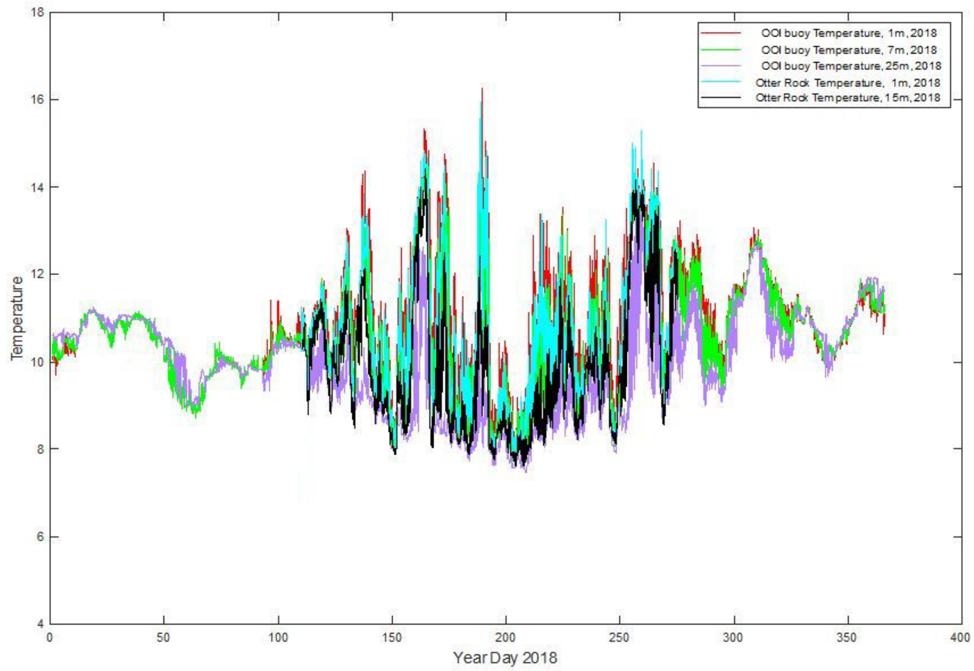


Figure A1. Time series of temperatures from the Otter Rock Marine Reserve and from an OOI mooring in 25-m of water off Yaquina Head about 7.5 km to the south of the OR MR.

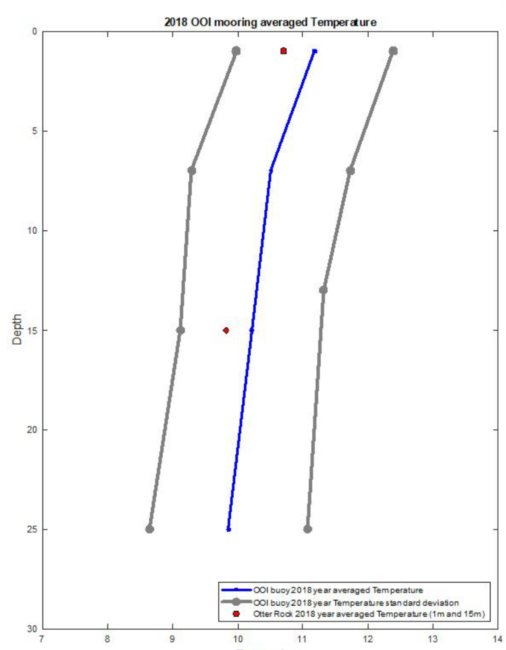


Figure A2. Vertical structure of temperature averaged over the 2018 upwelling season from the OOI mooring in 25-m off Yaquina Head (average in blue, +- 1 standard deviation in gray) and from the Otter Rock Marine Reserve (red).

To compare oceanographic parameters to the wind, we use north-south wind stress derived from winds measured at Newport, Oregon, available at http://damp.coas.oregonstate.edu/windstress/ .

Each time series was cleaned by removing values from before the sensor was in the water and after it was removed from the water. Erroneous values, often spikes or negative values, were removed using a two standard deviation filter.

When comparing oceanographic parameters across the marine reserves, each time series is smoothed using a low-pass filter with a half-power width of 40 hours in order to remove tidal and higher frequency fluctuations. This allows the subtidal variations, primarily driven by the wind, to be more easily seen.

The focus of this report is on near-bottom data from each reserve, chosen to be as close to 15 m as possible, as it is the most available across the reserves. While the ODFW Ecological Team collected data higher in the water column at some locations, that data is not fully reported here. For Cape Perpetua, data collected by PISCO at the surface (1 m) are plotted.

A summary of available data (T = temperature, S = salinity, DO = dissolved oxygen) for each marine reserve is, from north to south:

- Cape Falcon: T and DO for 2018, 2019, 2020
    - Cape Meares comparison area: T and DO for 2020

- Cascade Head: T, S and DO for 2013, 2014, 2018, 2019, 2020.

- Otter Rock: T, S and DO 2010, 2011; T only for 2012, 2013, 2018, 2019.
    - Cape Foulweather comparison area: T only for 2010, 2011, 2012, 2013, 2018, 2019.

- Cape Perpetua: T, S and DO 2003 to 2020.
    - SH70 near-bottom data: T, S and DO for 2009-2020

- Redfish Rocks: T, S and DO for 2010, 2012, 2013; T and S for 2011; T only for 2014, 2018, 2019.
    - Humbug comparison area: T only for 2010, 2011, 2012, 2013, 2014, 2018, 2019
    - Orford comparison area: T only for 2011, 2012, 2013

Through leadership by OSU and a citizen science team, intertidal pH data were sampled from 2016-2020 using a custom enclosure housing a stable and precise solid state Durafet pH sensor. Aragonite saturation state was calculated from pH (total scale) and temperature and assumptions of conservative salinity and alkalinity ranges according to a method described in Chan et al. (2017). For more details, see Chan et al. (2017).

Appendix B: Oceanography Conditions at and among Oregon's Marine Reserves

The Oregon coastal ocean is subject to seasonal wind forcing that drives summertime upwelling and wintertime downwelling along the Oregon coast (Huyer, 1983). Summertime upwelling, generally lasting from April to September each year, brings cold, salty, and low-oxygen water close to shore and into Oregon's marine reserves. Offshore water that is warmer and higher in oxygen moves shoreward and into the marine reserves when the wind relaxes from upwelling with periods of about 5-10 days, the typical "weather" event time scale. The strength of summertime, upwelling winds increases slightly from north to south along the Oregon coast down to the Cape Blanco region where alongshore winds increase by a factor of 4 (Samelson et al., 2002).

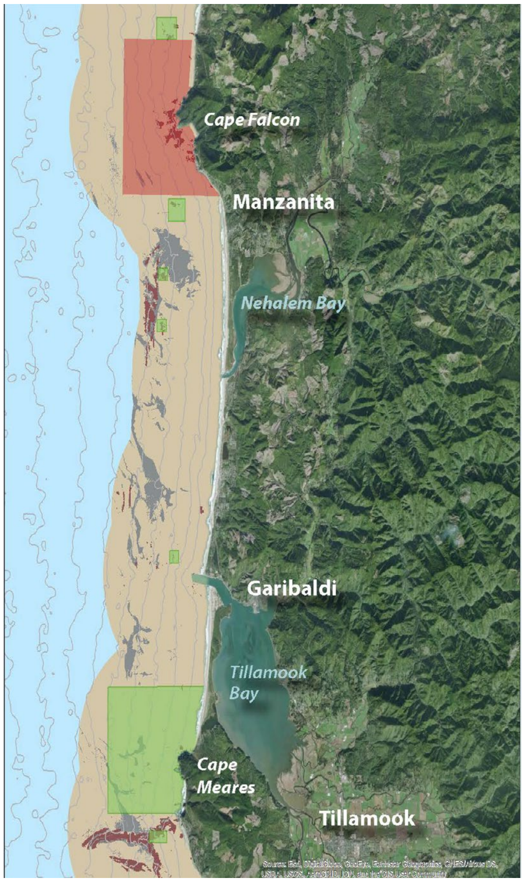
During summer, the Columbia River plume turns south with the prevailing winds and currents and is found offshore of the coastal upwelling front found over the mid to outer shelf (Barnes et al., 1972). Upwelling generally keeps these lower in salinity waters offshore of the Oregon territorial sea and Oregon's marine reserves, except during relaxation from upwelling-favorable (southward) winds and during active downwelling. Other major rivers along the Oregon coast have weaker inputs to the coastal ocean during summer, but their input during winter is substantial with the total of Oregon's coastal rivers approaching that of the Columbia (Mazzini et al., 2014). During winter, a strong (0.5 m/s or greater), northward current driven by freshwater input to the coastal ocean is found within about 20 km of the coast (Mazzini et al., 2014).

Oregon coastal waters are exposed to low-oxygen and low pH (high pCO_2) waters during summertime when southward winds drive upwelling of deep, offshore waters low in oxygen and high in CO_2 toward shore (Chan et al., 2019). In the plots of dissolved oxygen below, hypoxia (DO < 1.4 ml/l) is indicated by a horizontal cyan line and severe hypoxia (DO < 0.5 ml/l) is indicated by a horizontal black line.

Overall oceanographic conditions, and exceptions from the general patterns described above, at each marine reserve from north to south are as follows.

Cape Falcon (CF)

As Oregon's northernmost marine reserve, Cape Falcon (**Figure B1**) is subject to the same seasonal wind forcing that drives summertime upwelling and wintertime downwelling along the Oregon coast. Cape Falcon is the closest Oregon marine reserve to the Columbia River, about 50 km to the north, so is expected to have the lowest salinity, especially at the surface and during relaxations from summer upwelling winds, of all of Oregon's marine reserves. It is also near to the Tillamook Bay entrance, about 23 km to the south, an additional potential source of lower salinity water. Unfortunately, salinity is not yet measured regularly at the CF MR (see future sampling recommendations). An example of seasonal temperature and dissolved oxygen time series are shown in **Figure B2**. Not the excellent agreement between the temperature and dissolved oxygen measurements in the CF MR and the nearby comparison site at Cape Meares.



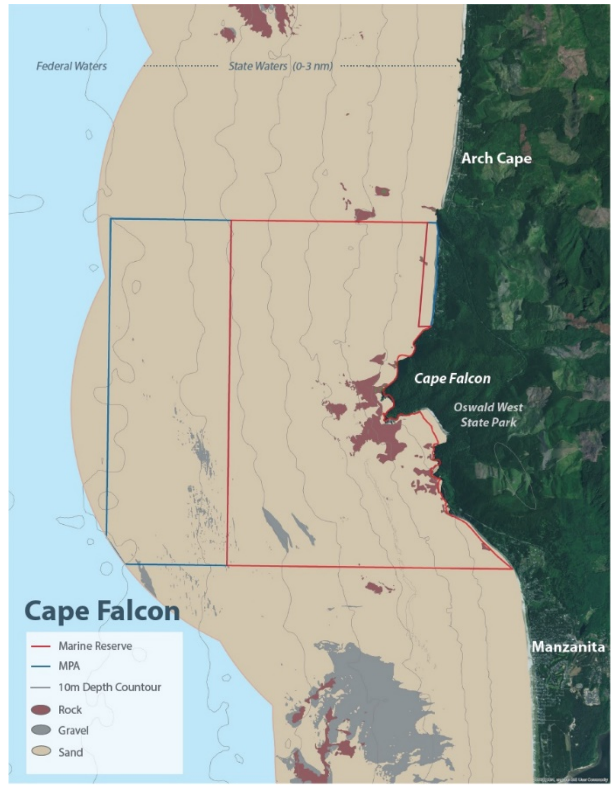


Figure B1. Map of the Cape Falcon Marine Reserve (red) and nearby comparison areas (green). From Cape Falcon Marine Reserve Site Management Plan (2021) and https://oregonmarinereserves.com .

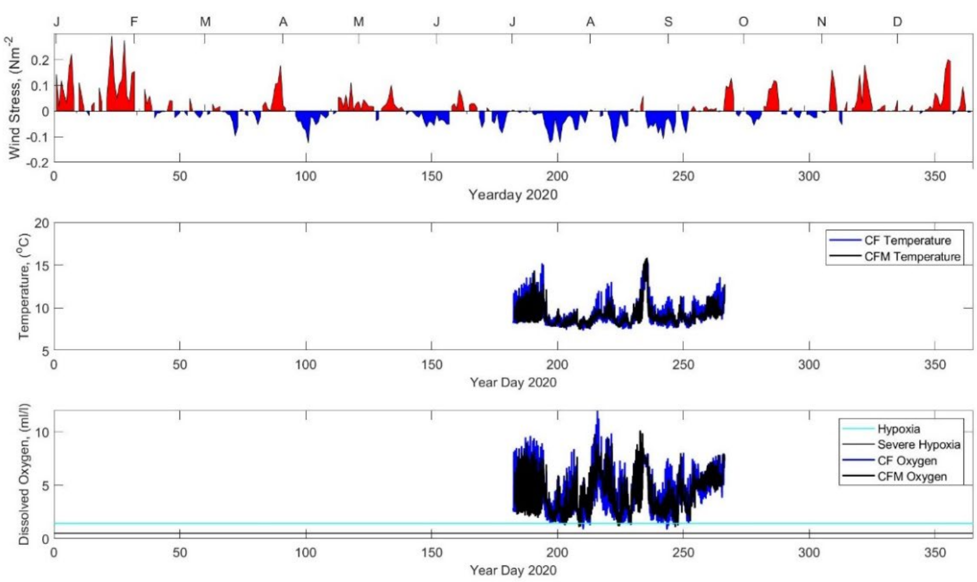


Figure B2. (top) North-south wind stress from Newport, Oregon, and (middle) temperature and (bottom) oxygen in the Cape Falcon (CF) MR (blue) and nearby Cape Meares (CFM) comparison area (black). In this and all other dissolved oxygen plots, hypoxia (DO < 1.4 ml/l) is indicated by a horizontal cyan line and severe hypoxia (DO < 0.5 ml/l) is indicated by a horizontal black line.

Cascade Head (CH)

The Cascade Head (CH) Marine Reserve is located on the central Oregon coast, onshore of where the continental shelf is one of the narrowest along the entire Oregon coast, about 20 km offshore (**Figure B3**). Thus, the CH MR is likely to be highly influenced by nearby oceanic water, both deep waters during upwelling and surface waters during wind relaxation and downwelling. An example of seasonal temperature and dissolved oxygen time series from the CH MR are shown in **Figure B4**.

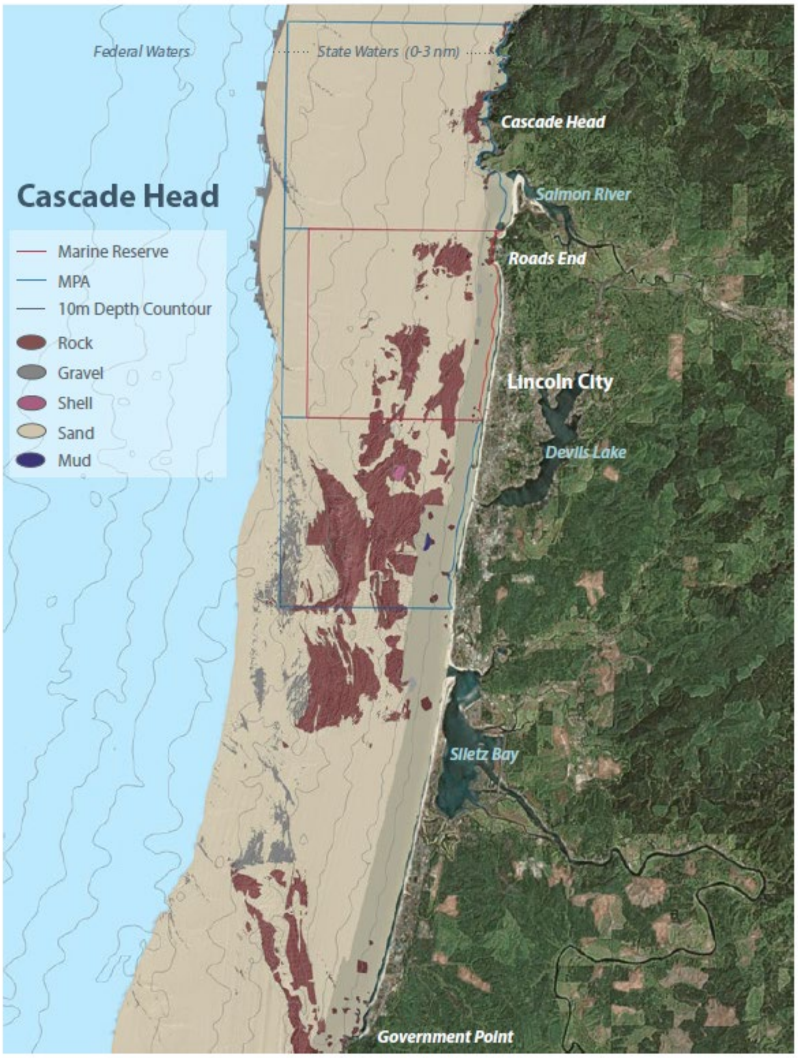


Figure B3. Map of the Cascade Head Marine Reserve (from https://oregonmarinereserves.com).

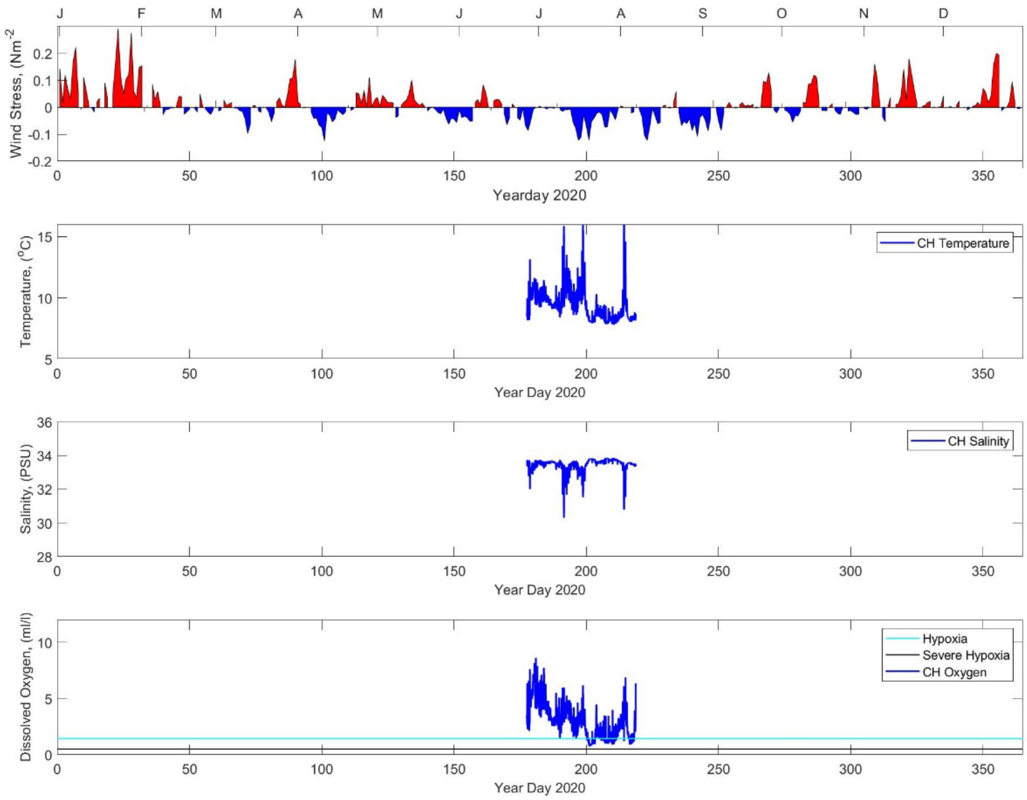


Figure B4. (top) North-south wind stress from Newport, Oregon, and (middle) temperature and (bottom) oxygen in the Cascade Head (CH) marine reserve.

Otter Rock (OR)

The Otter Rock (OR) marine reserve is located on the central Oregon coast, onshore of where the continental shelf begins to widen at the top of the Heceta Bank complex (**Figure B5**). A comparison site exists at nearby Cape Foulweather (CRF). An example of seasonal temperature, salinity, and dissolved oxygen time series from the OR MR and CRF comparison site (temperature only) are shown in **Figure B6**.

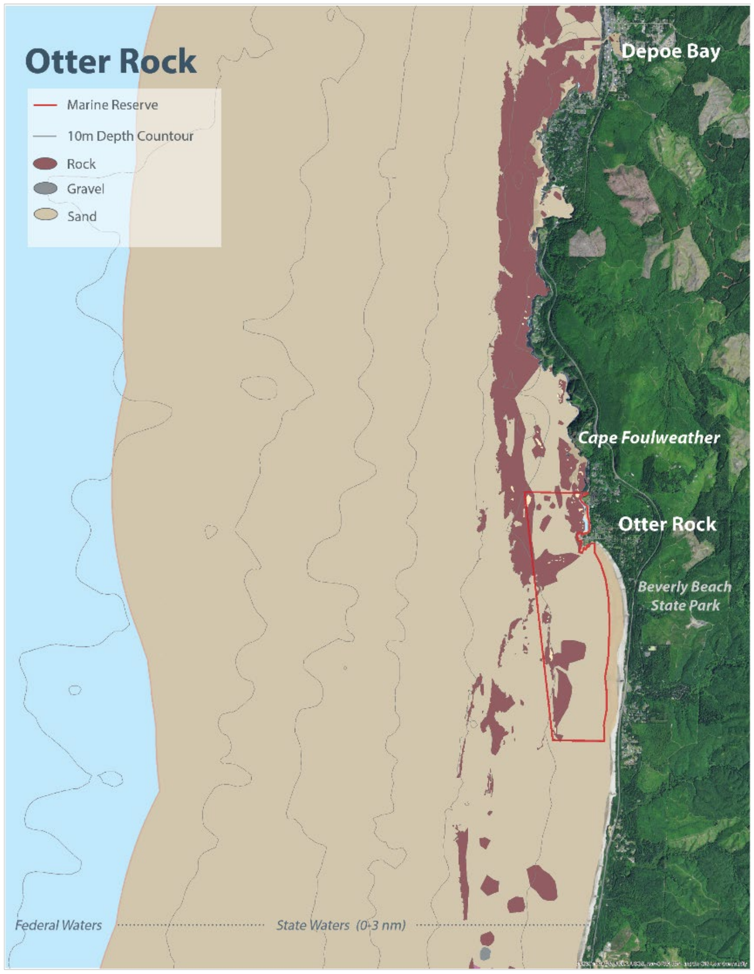


Figure B5. Map of the Otter Rock Marine Reserve (from https://oregonmarinereserves.com).

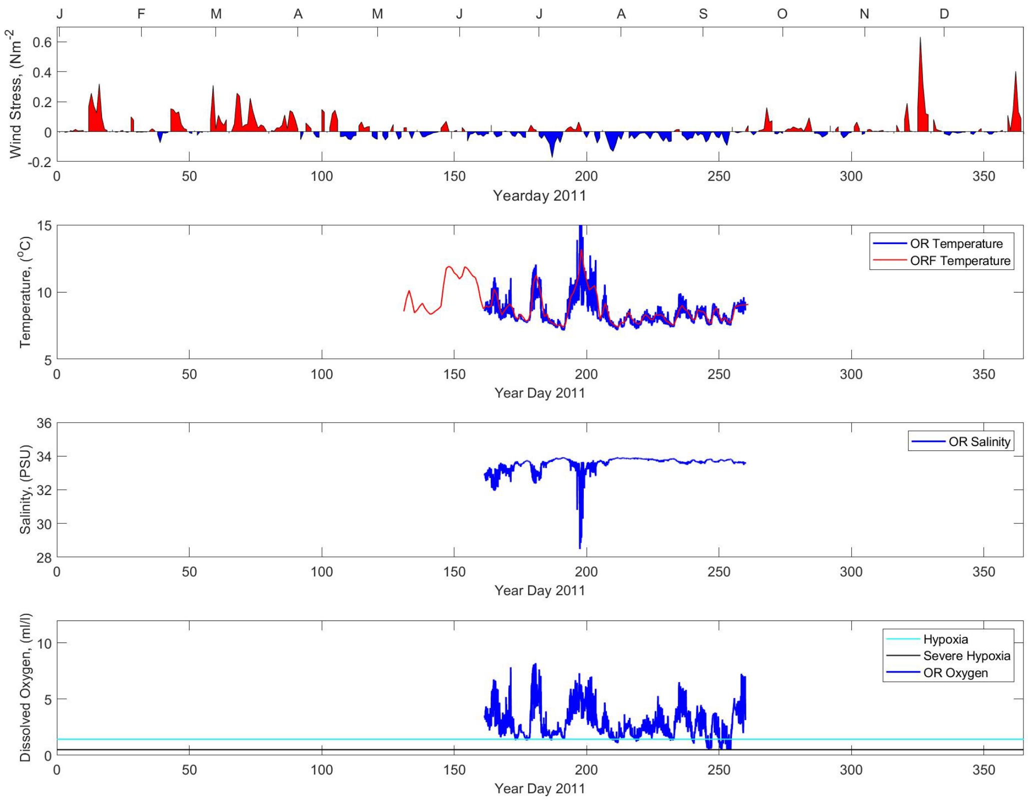


Figure B6. (top) North-south wind stress from Newport, Oregon, during 2011 and (middle) temperature and (bottom) oxygen in the Otter Rock (OR) MR (blue) and nearby Cape Foulweather (ORF) comparison area (red).

Cape Perpetua (CP)

The Cape Perpetua Marine Reserves is located on the central Oregon coast on the inshore side of the Heceta Bank complex where the continental shelf is about 65 km wide, the widest along the entire Oregon coast (**Figure B7**). During summertime, the southward coastal upwelling jet and front located on the mid shelf (~70-80 m isobath) is pushed offshore by the Heceta Bank complex and a region of weaker flow is formed inshore and over the Bank (Barth et al., 2005). In addition, the clockwise turning of the coastal upwelling jet around the southern end of the Bank causes enhanced upwelling leading to colder, saline and more nutrient rich water to be upwelled onto the Bank compared with north and south of the Bank (Barth et al., 2005). Lastly, the low-flow inshore region is known for high amounts of phytoplankton that, when they fall toward the sea floor and decompose, draw oxygen out of the lower water column leading to hypoxia over the Bank (Barth et al., 2005; Keller et al., 2010). Cape Perpetua is one of the best monitored marine reserve areas in the country, having been a study sight for PISCO since 1999 (Menge et al., 2019). An example of seasonal temperature, salinity, and dissolved oxygen time series from the CP MR and the SH70 bottom lander offshore of the CP MR are shown in **Figure B8**.

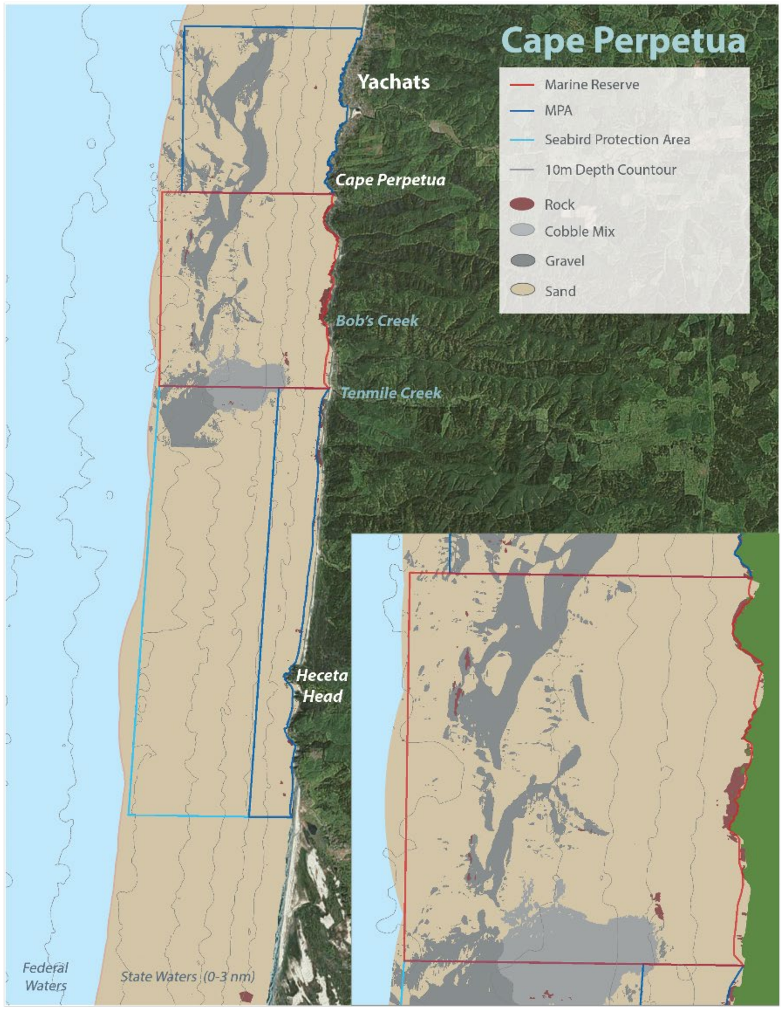


Figure B7. Map of the Cape Perpetua Marine Reserve (from https://oregonmarinereserves.com).

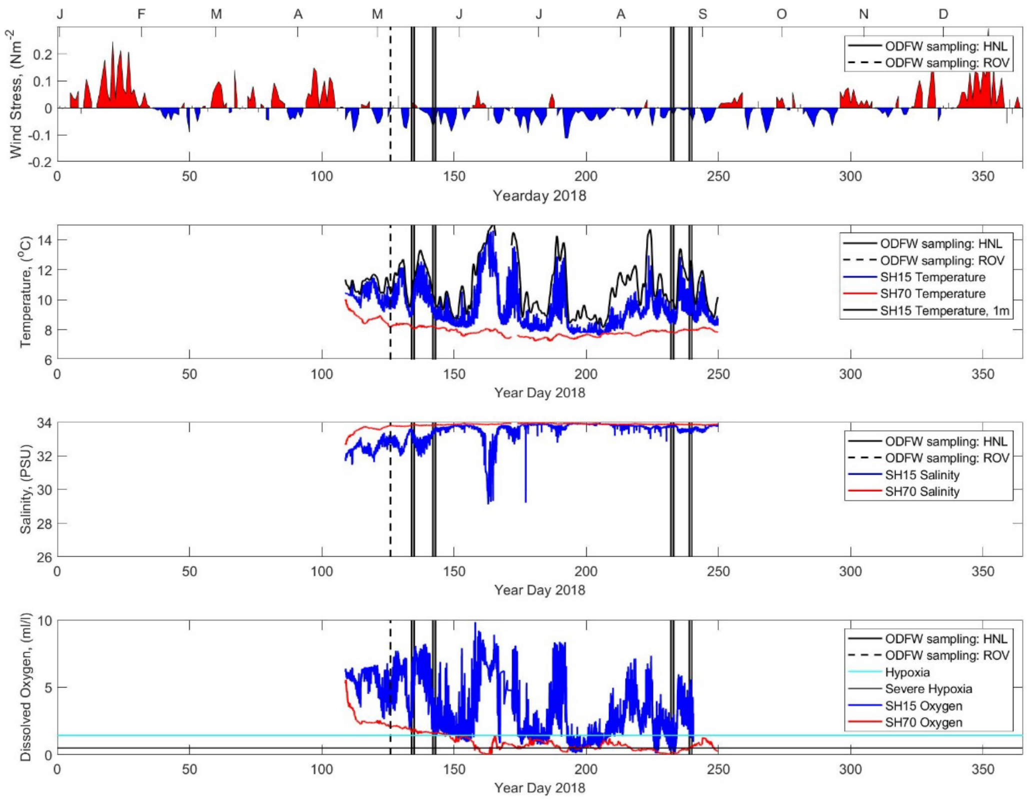


Figure B8. North-south wind stress measured at Newport, Oregon, (top) and temperature, salinity and oxygen from the Cape Perpetua MR, labeled “SH15” following the PISCO naming convention for this site. Parameters are also plotted from the SH70 site (red), offshore of the CP MR.

Redfish Rocks (RR)

The Redfish Rocks Marine Reserve is located just south of Cape Blanco, Oregon, a major coastal promontory (**Figure B9**). Redfish Rocks MR is the only Oregon marine reserve south of the biogeographical break at Cape Blanco (Heppell et al., 2008). During the upwelling season, the strong, southward coastal upwelling jet is directed offshore by Cape Blanco so that it “separates” from the continental shelf (Barth et al., 2000). The southward, upwelling-favorable coastal winds also increase in this region due to the overall North Pacific High Pressure system’s isobars aligning better with the coast than farther north and increases due to orographic intensification (Samelson et al., 2002). These stronger winds can lead to increased upwelling in the RR region and have also been implicated in the separation of the coastal upwelling jet (Castelao and Barth, 2006). Sometimes during upwelling-favorable winds and usually during wind relaxation or downwelling-favorable winds, the near-coast flow, inshore of the separated coastal upwelling jet can be northward. An example of seasonal temperature, salinity, and dissolved oxygen time series from the RR MR and the nearby Humbug (RRH) and Orford (RRO) comparison areas are shown in **Figure B10**.

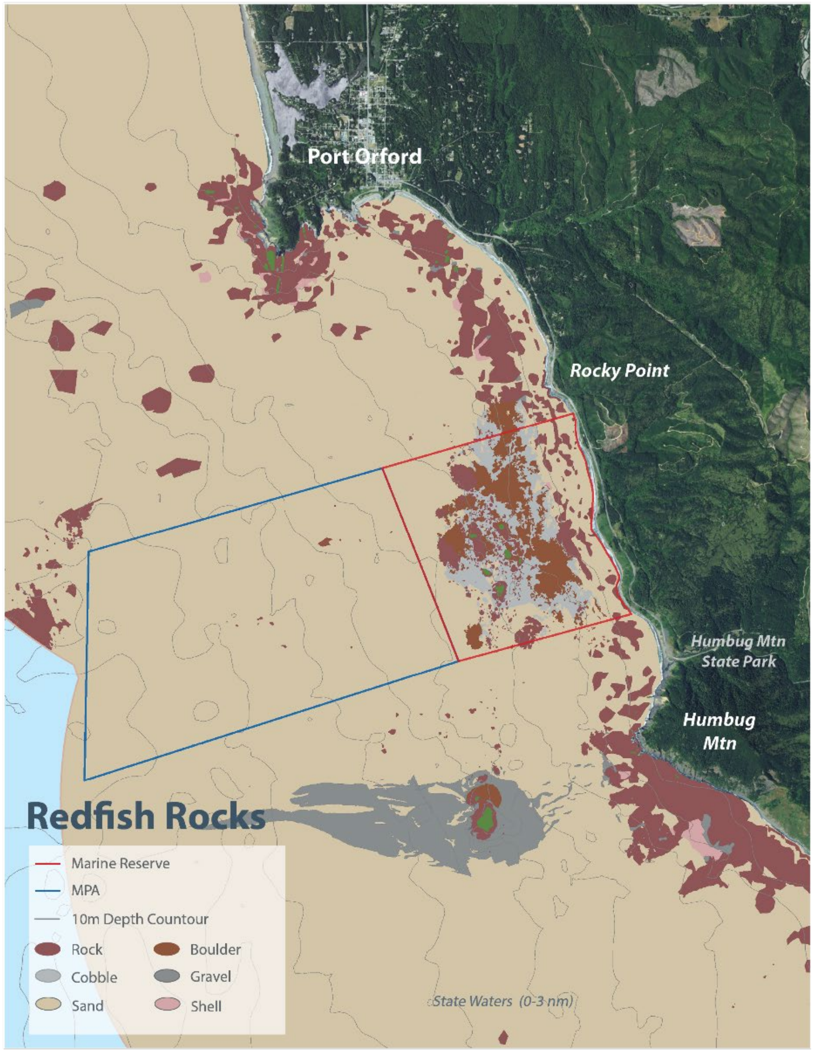


Figure B9. Map of the Redfish Rocks Marine Reserve (from https://oregonmarinereserves.com).

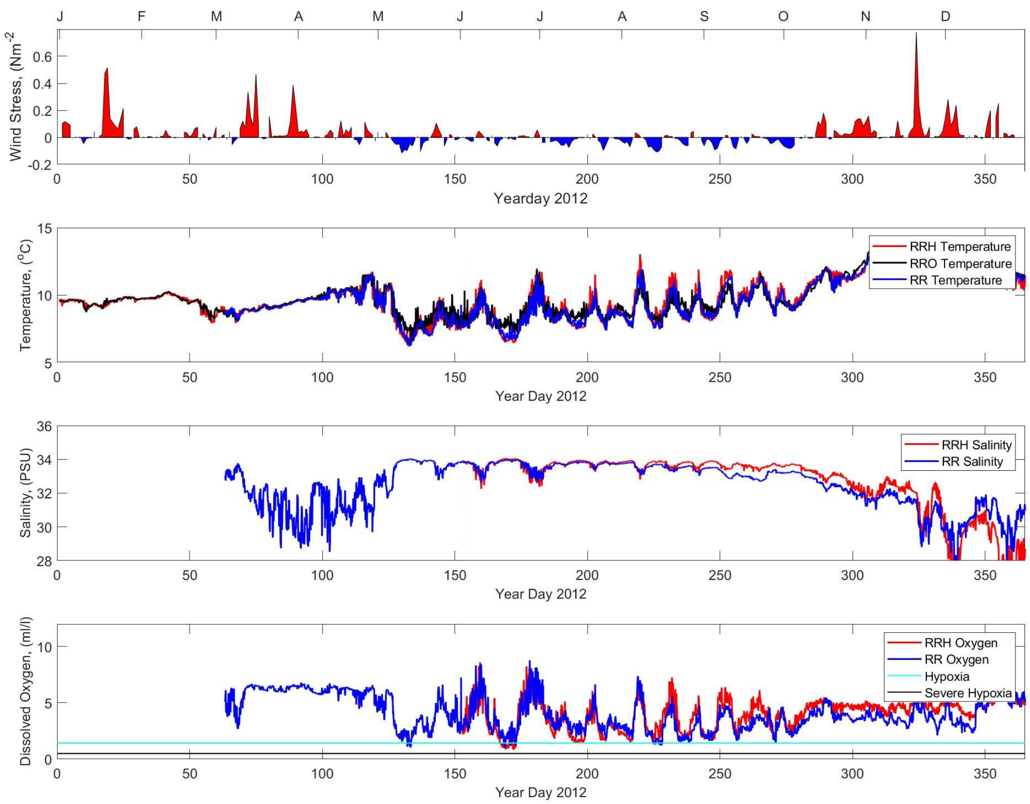


Figure B10. North-south wind stress measured at Newport, Oregon, (top) and temperature, salinity and oxygen from the Redfish Rocks MR (RR, blue). Oceanographic parameters from nearby comparison areas, Humbug (RRH, red) and Orford (RRO, black), are also plotted.

Variation of Oceanographic Conditions along the Oregon Coast

Temperature along the Oregon coast during the spring-summer-fall season covaries as forced by the alongshore winds (**Figure B11**) (Kirincich and Barth, 2009). This is because the dominant source of temperature variability is upwelling of cold, subsurface water during southward winds and onshore movement of warm, offshore, surface waters during wind relaxation or downwelling. The temperature time series among Oregon's marine reserves are significantly correlated. On average, for the years when overlapping data are available (2013, 2014, 2018, 2019, and 2020), the 95% significant correlations are (values in **bold** significant at 99% significance level):

	CF	**CH**	**OR**	**CP**	**RR**
CF	1.0000	0.6876	0.6973	**0.8337**	0.6977
CH	0.6876	1.0000	**0.7520**	**0.8491**	---------
OR	0.6973	**0.7520**	1.0000	**0.8573**	0.5885
CP	**0.8337**	**0.8491**	**0.8573**	1.0000	---------
RR	0.6977	--------	0.5885	0.5383	1.0000

Note that the three marine reserves in close proximity along the central Oregon coast, CH, OR and CP, are very highly correlated. Cape Falcon in the north is slightly less correlated with the remainder of Oregon's marine reserves and Redfish Rocks is least correlated with other marine reserve, reinforcing that it is south of the major biogeographical break at Cape Blanco.

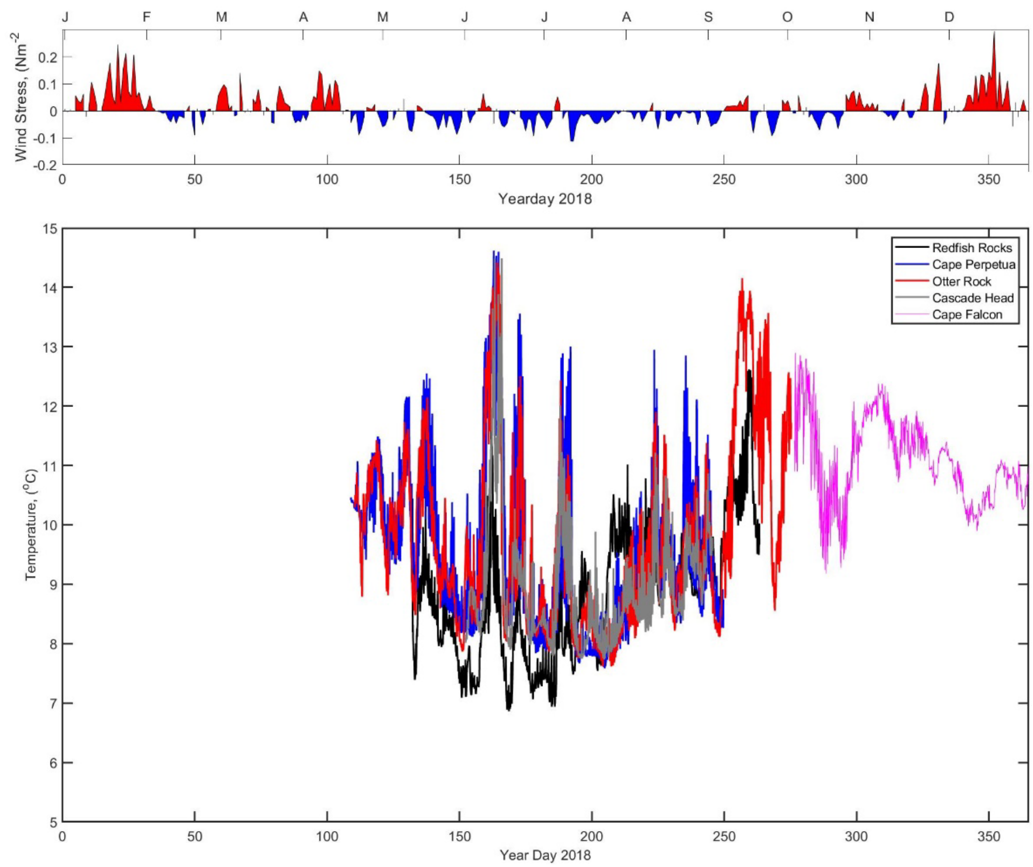


Figure B11. (top) North-south wind stress during 2018 derived from winds measured at NOAA's National Data Buoy Center Station NWPO3, Newport, Oregon (https://www.ndbc.noaa.gov/station_page.php?station=nwpo3). Blue (red) shading indicates upwelling (downwelling) favorable, southward (northward) winds. (bottom) Near-bottom temperature from 2018 from all five of Oregon's Marine Reserves.

Computing the average temperature for each marine reserve during periods of overlapping data during 2018-2020 reveals that CF is consistently warmer by 0.5-0.9° C than the average of the three central Oregon marine reserves (CH, OR, CP). The average temperature at RR is consistently colder by 0.5-1.3° C than the average of the three central Oregon marine reserves (CH, OR, CP) due to the increased upwelling-favorable wind stress south of Cape Blanco and the attendant coastal jet separation (Barth et al., 2000).

Salinity along the Oregon coast during the spring-summer-fall season also covaries as forced by the alongshore winds (**Figure B12**). This is because the dominant source of salinity variability is upwelling of salty, subsurface water during southward winds and onshore movement of fresh, offshore surface waters – fresh because of Columbia River influence in the southward trending Columbia River plume during summer -- during wind relaxations or downwelling. There is insufficient data to compute quantitative correlation coefficients.

Salinity is more variable along the coast than temperature because of the presence of rivers including the dominant Columbia River and the many coastal rivers in Oregon. During winter, a fresh, swift, northward current, the Oregon Coastal Current, exists across state waters near the coast (Mazzini et al., 2014). Salinity differences along the coast are notable during spring and summer when winds are relaxed or downwelling favorable (northward), when offshore waters of variable salinity are brought closer to shore. Note that salinity at Cascade Head spikes to lower values during relaxed or northward winds compared with marine reserves farther south, because of CH's closer proximity to the Columbia River mouth.

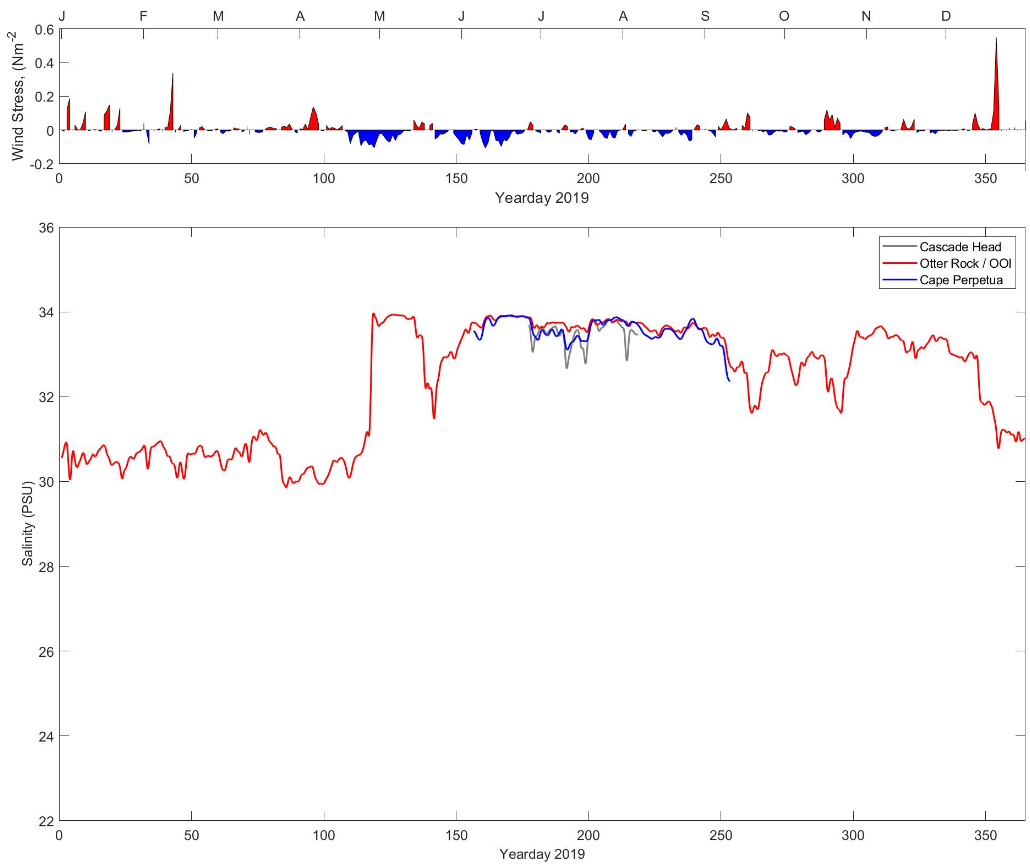


Figure B12. (top) North-south wind stress from Newport, Oregon, for 2019. (bottom) Near-bottom salinity from 2019 from two of Oregon's marine reserves, Cascade Head and Cape Perpetua, along with a proxy for Otter Rock Marine Reserve salinity from the Ocean Observatories Initiative (OOI) Oregon Inshore Mooring located nearby off Yaquina Head. Note the onset of summertime upwelling and the increase in salinity in mid-late April.

Computing the average salinity for the three marine reserves with overlapping data during 2018-2020 – note that CF and RR do not have enough salinity data overlapping in time with the other reserves to be included in this calculation – reveals no significant differences between reserves. This is likely because the average salinity during summer is controlled by salty, upwelled water; differences in salinity between reserves is more evident during wind relaxation or downwelling as noted earlier.

Dissolved oxygen along the Oregon coast during the spring-summer-fall season covaries as forced by the alongshore winds (**Figure B13**) (Adams et al, 2013). This is because the dominant source of dissolved oxygen variability is upwelling of low-oxygen, subsurface water during southward winds and onshore movement of higher-oxygen, offshore surface waters during wind-relaxation or downwelling. The dissolved oxygen time series among Oregon's marine reserves are significantly correlated. On average, for the years when overlapping data are available during the summer upwelling season (2018-2020) – note that there is no DO data available from RR to include in the analysis -- the 95% significant correlations are (values in bold significant at 99% significance level):

	CF	CH	OR	CP
CF	1.0000	0.6962	0.5792	**0.8409**
CH	0.6962	1.0000	0.6809	0.6767
OR	0.5792	0.6809	1.0000	0.5972
CP	**0.8409**	0.6767	0.5972	1.0000

Note that the differences between DO levels at the marine reserves decreases during upwelling-favorable winds when deep, low-oxygen waters are upwelled toward the coast. Larger differences are observed during wind relaxations or downwelling when offshore waters with different levels of oxygen reach the marine reserves. The high values at CP during wind relaxation or downwelling could be attributed to onshore movement of surface waters high in oxygen due to the greater phytoplankton productivity observed there. Averages computed from overlapping data segments from 2018-2020 show CP DO levels on average about 1.4 ml/l greater than at OR/OOI, likely again due to high-oxygen waters during wind relaxation or downwelling dominating the average.

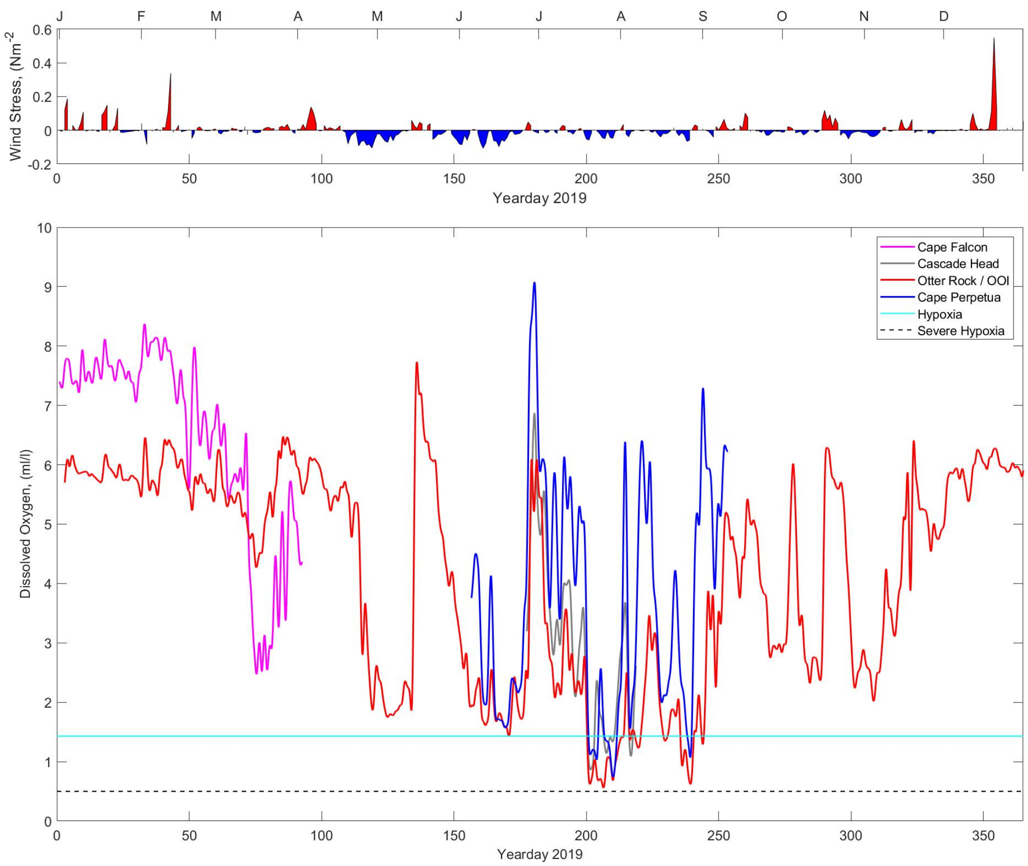
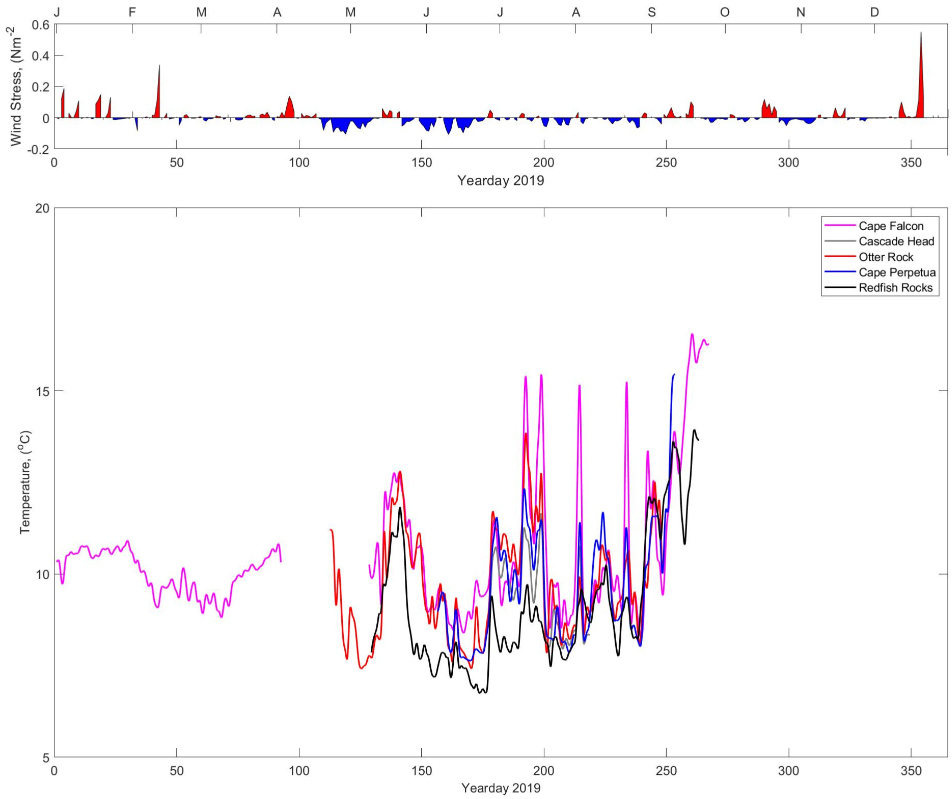
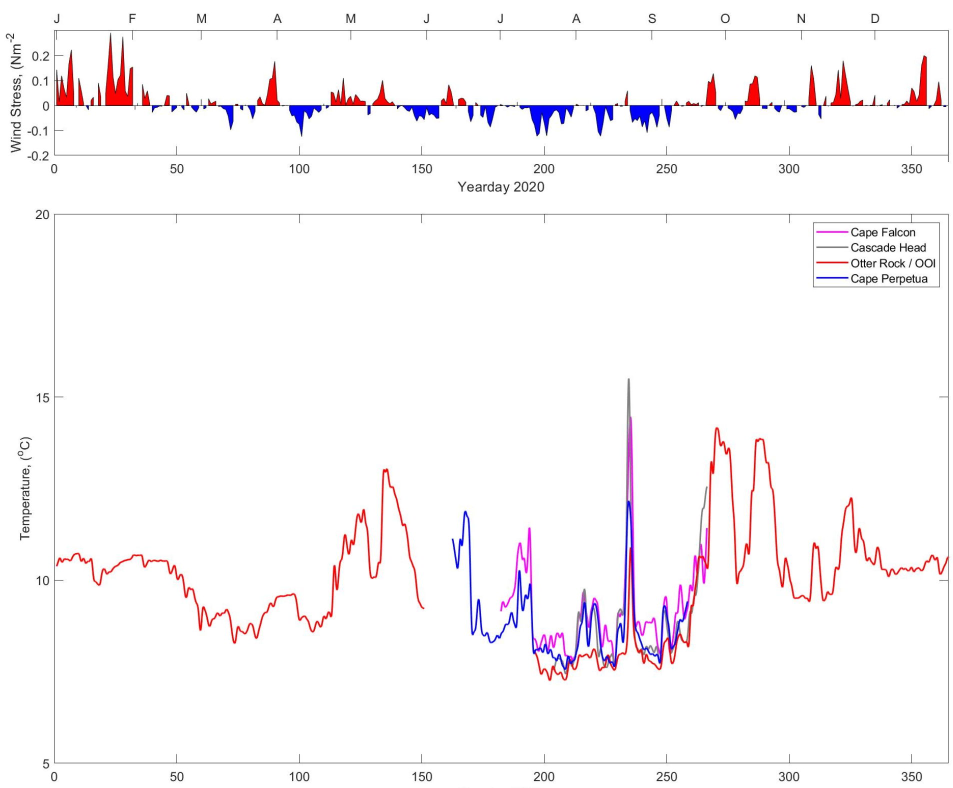
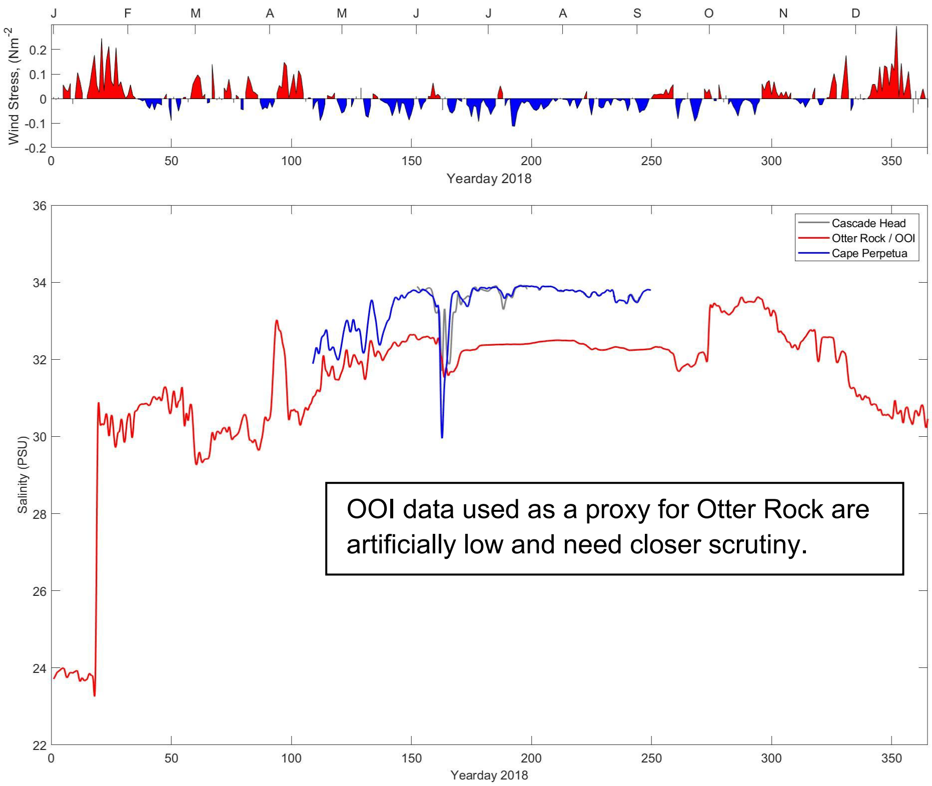


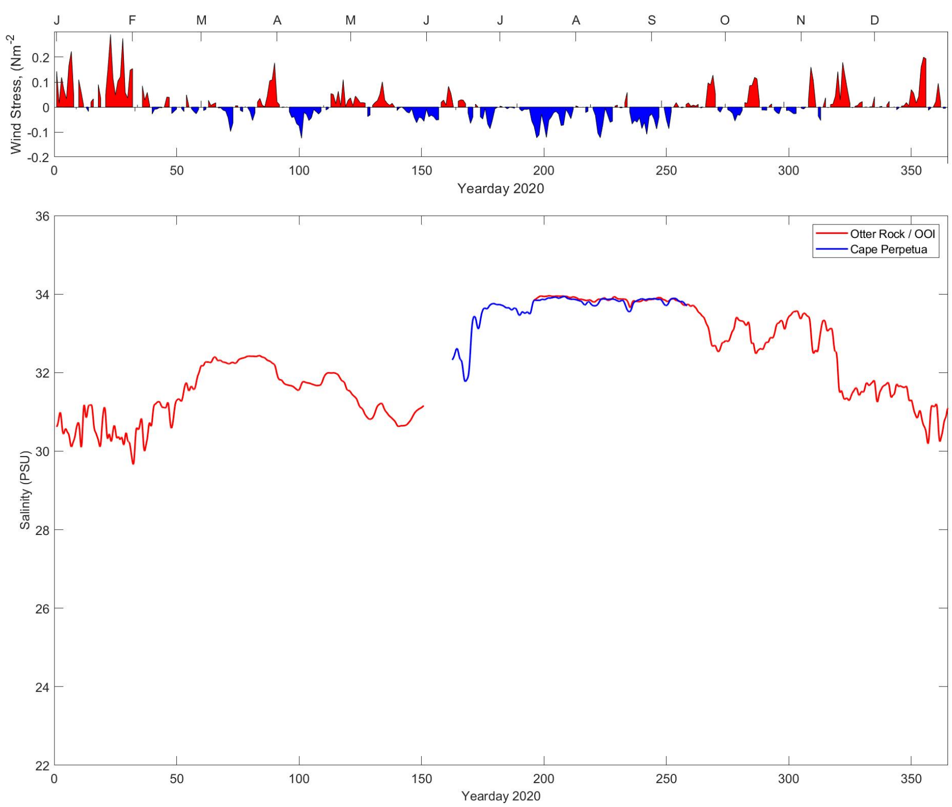
Figure B13. (top) North-south wind stress from Newport, Oregon, for 2019. (bottom) Near-bottom dissolved oxygen from 2019 from three of Oregon's marine reserves, CF, CH and CP, along with a proxy for Otter Rock Marine Reserve dissolved oxygen from the Ocean Observatories Initiative (OOI) Oregon Inshore Mooring located nearby off Yaquina Head. Note the initial drop in oxygen at the start of upwelling in mid-late April.

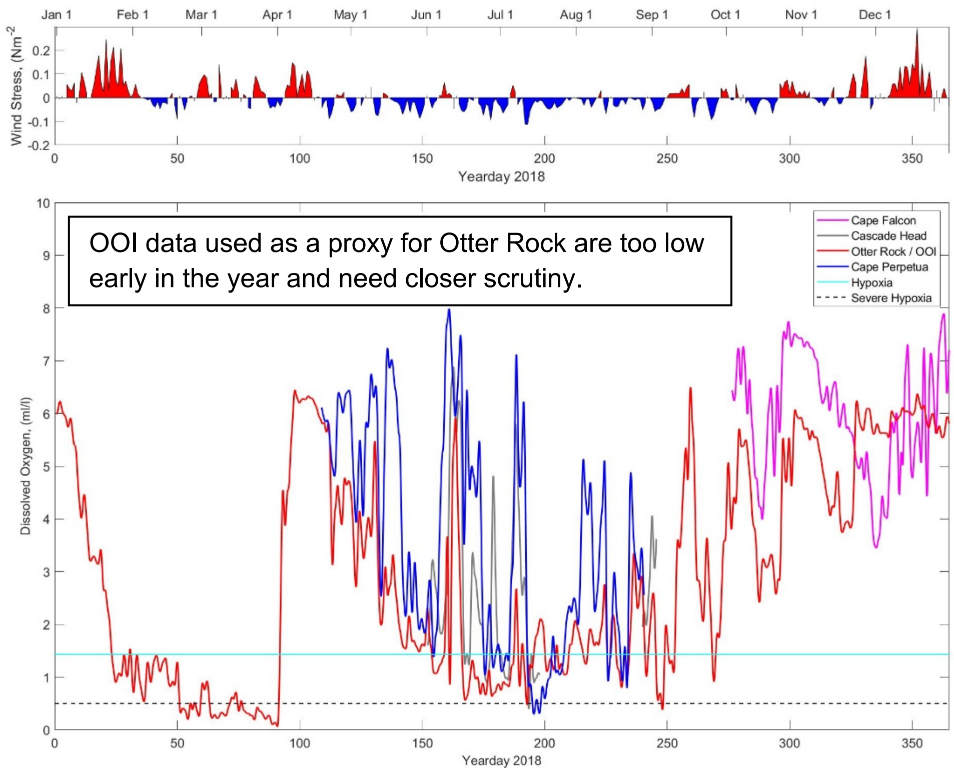
For completeness, here are the additional cross-reserve comparisons for 2018-2019.


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2019
Cape Falcon
Cascade Head
Otter Rock
Cape Perpetua
Redfish Rocks
Temperature, (^{o}C)
Yearday 2019

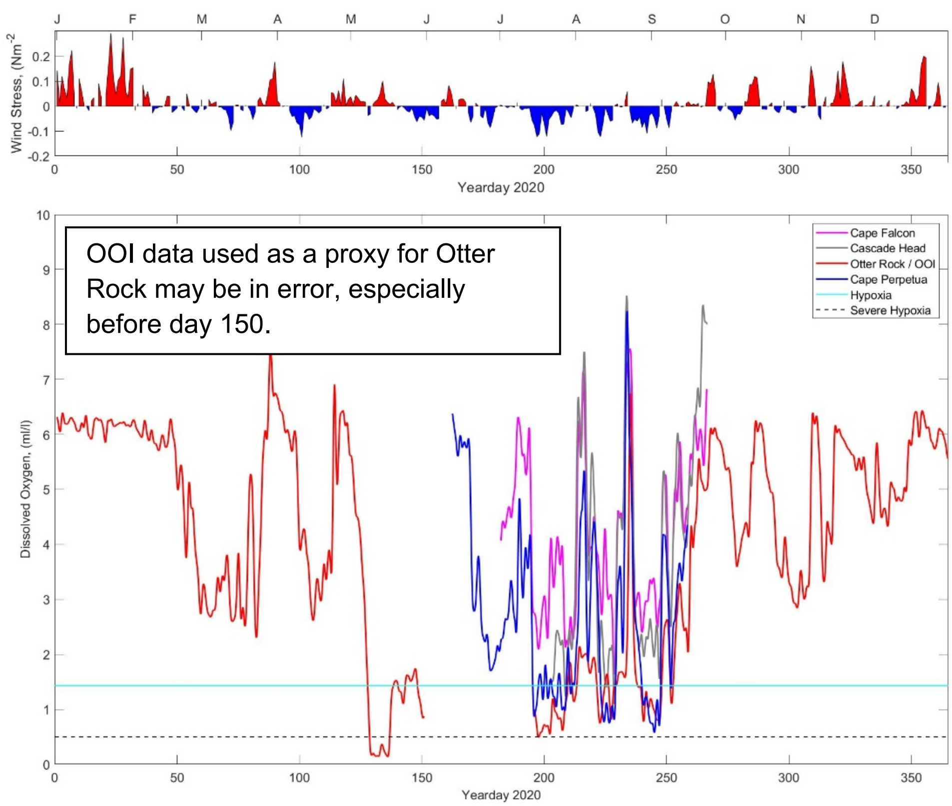

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2020
Cape Falcon
Cascade Head
Otter Rock / OOI
Cape Perpetua
Temperature, (^{o}C)
Yearday 2020


J F M A M J J A S O N D
Wind Stress, (Nm^-2)
Yearday 2018
Cascade Head
Otter Rock / OOI
Cape Perpetua
Salinity (PSU)
OOI data used as a proxy for Otter Rock are artificially low and need closer scrutiny.
Yearday 2018


J F M A M J J A S O N D
Wind Stress, (Nm^-2)
Yearday 2020
Otter Rock / OOI
Cape Perpetua
Salinity (PSU)
Yearday 2020



Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Dec 1
Wind Stress, (Nm^{-2}
Yearday 2018
OOI data used as a proxy for Otter Rock are too low early in the year and need closer scrutiny.
Cape Falcon
Cascade Head
Otter Rock / OOI
Cape Perpetua
Hypoxia
Severe Hypoxia
Dissolved Oxygen, (ml/l)
Yearday 2018



J
F
M
A
M
J
J
A
S
O
N
D
Wind Stress, (Nm^{-2}
Yearday 2020
OOI data used as a proxy for Otter Rock may be in error, especially before day 150.
Cape Falcon
Cascade Head
Otter Rock / OOI
Cape Perpetua
Hypoxia
Severe Hypoxia
Dissolved Oxygen, (ml/l)
Yearday 2020

Oregon Marine Reserve Data in Relation to Other Moorings off Oregon

Oceanographic moorings and coastal stations are maintained off Oregon by a variety of organizations including the National Oceanic and Atmospheric Administration (NOAA), the NOAA-sponsored Northwest Association for Networked Ocean Observing Systems (NANOOS), and the NSF-supported Ocean Observatories Initiative (OOI). These are labeled as “Active Oregon Ocean Sensors” in **Figure B14**. Note that the oceanographic moorings in and just offshore of the Cape Perpetua Marine Reserve, denoted in black, are maintained by the Oregon State University researchers as part of the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) Oregon’s marine reserves data, green in **Figure B14**, add to and extend these observing elements. In particular, the Oregon marine reserve data greatly expand the spatial coverage and number of moorings in Oregon state waters (within 3 nautical miles = 5 km of the coast) where the water depth is generally less than 50 m. In particular the Oregon marine reserves data provide the only oceanographic monitoring data in state waters south of Cape Blanco, a known oceanographic and biogeographic break along the Oregon coast.

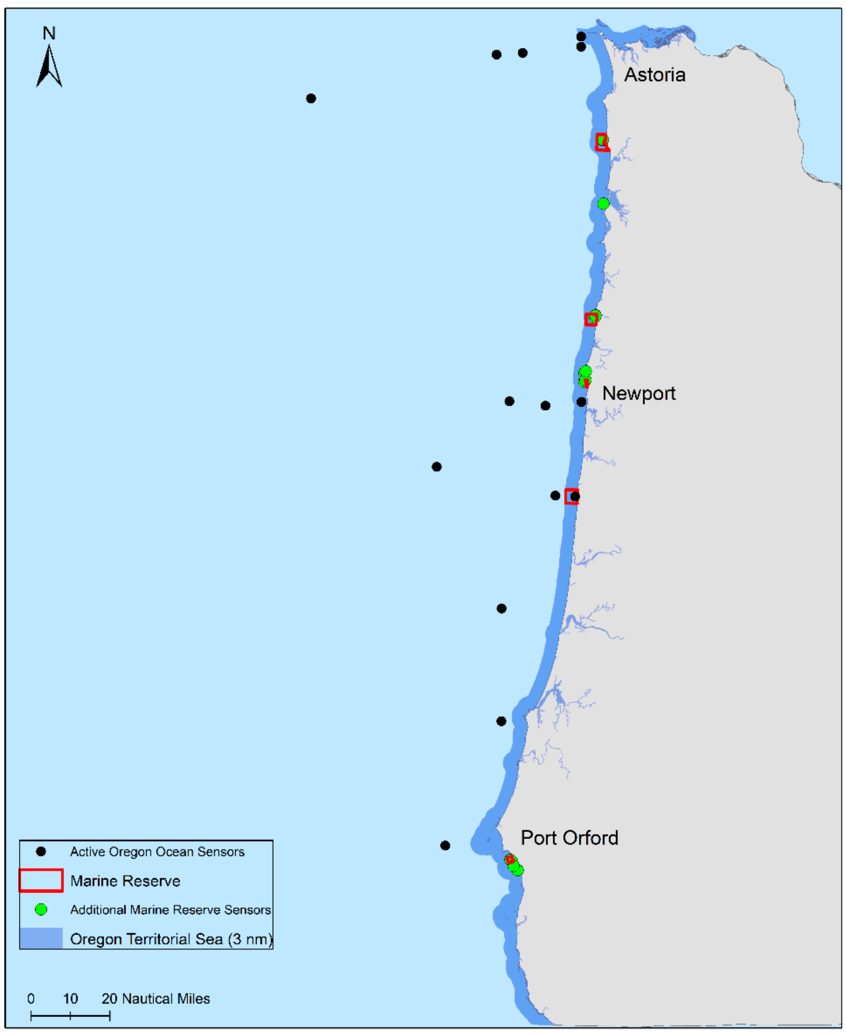


Figure B14. Map of oceanographic moorings in Oregon coastal waters (courtesy of Lindsay Aylesworth, ODFW).

For comparison to Oregon marine reserve data – note we use PISCO data collected in the Cape Perpetua Marine Reserve -- we use the only active oceanographic mooring within state waters, the Ocean Observatories Initiative's Inner Shelf mooring located just offshore of Yaquina Head, 5 km to the south of the Otter Rock Marine Reserve. As mentioned, above, we use the NOAA weather station from Newport, Oregon, as an indication of time-varying, coastal winds. In summary, the Oregon marine reserve oceanographic data greatly expands measurements along the Oregon coast over the inner shelf, water less than about 50 m depth. This is a key oceanographic region connecting the wind-driven offshore waters with the wave-driven surfzone and the rocky intertidal.

Intertidal pH (Francis Chan, Oregon State University)

Oregon's marine reserves have served as a model for community-supported ocean acidification (OA) monitoring. In 2016, with support from the Educational Foundation of America (EFA), OSU researchers implemented an intertidal pH monitoring program across the marine reserve system. This marine reserve OA monitoring networks is the first of its kind in the nation. It was made possible by the development of stable and precise solid state Durafet pH sensors that were custom designed by researchers at the Monterey Bay Aquarium Research Institute for deployment in challenging intertidal environments (NSF Award OCE-1220412). The initial award from EFA was to develop a coastal citizen scientist-supported OA monitoring network. Having engaged community teams in each of the reserves greatly facilitated the process of gathering partners. In addition, community team members had local knowledge that were crucial in identifying sites within each reserve that could be readily and safely accessed at low tide.

The intertidal monitoring network was first piloted at the Redfish Rocks reserve with the partnership from the Redfish Rocks Community Team. The effort grew to encompass Otter Rock with partnership from Charlie Plybon from the Surfrider Foundation, and Cascade Head with partnership from Dick Vander Schaaf from the The Nature Conservancy later that summer. Monitoring at the Cape Perpetua Marine Reserve continued through research activities of the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) program at OSU. The Cape Falcon Marine Reserve joined the network in 2017 with partnership from Dick Vander Schaaf and Chrissy Smith from the Friends of Cape Falcon Marine Reserve.

Initial data returned (**Figure B15**) highlighted 1) the propagation of low pH signals across the continental shelf and into the intertidal environment, 2) extremely high temporal variability in pH reflecting time variations in upwelling winds, and 3) spatial differences in the severity of exposure to low pH, corrosive waters. Subsequent deployments suggest the existence of 1) fine-scale differences in OA exposure (**Figure B16**), 2) in addition to regional differences are persistent across years and 3) regional OA differences reflect, in part, region-specific water mass properties that vary temperature vs. pH (**Figure B17**).

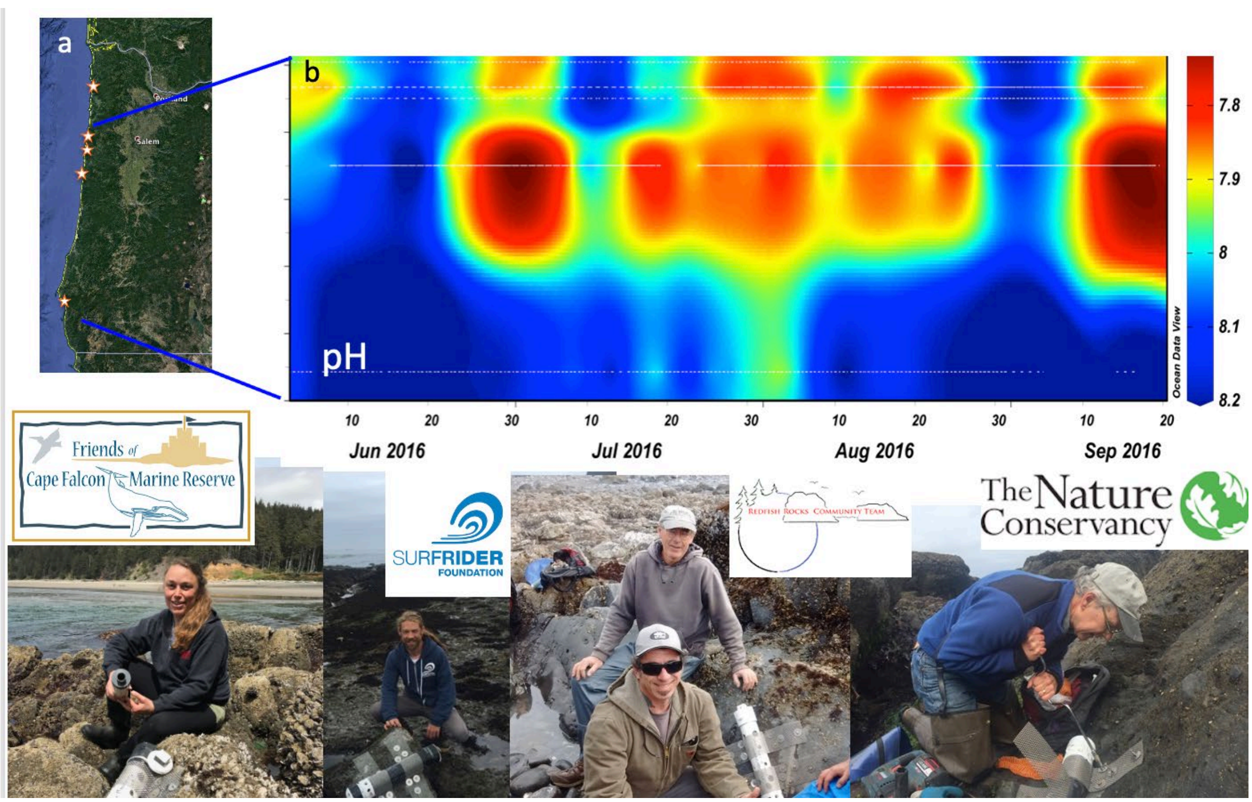


Figure B15. a. Location of marine reserves (star), and b. pH (total scale) observations from intertidal sensors in 2016 (Cape Falcon was added to the monitoring network in 2017). Bottom photos illustrate individual sites and partners.

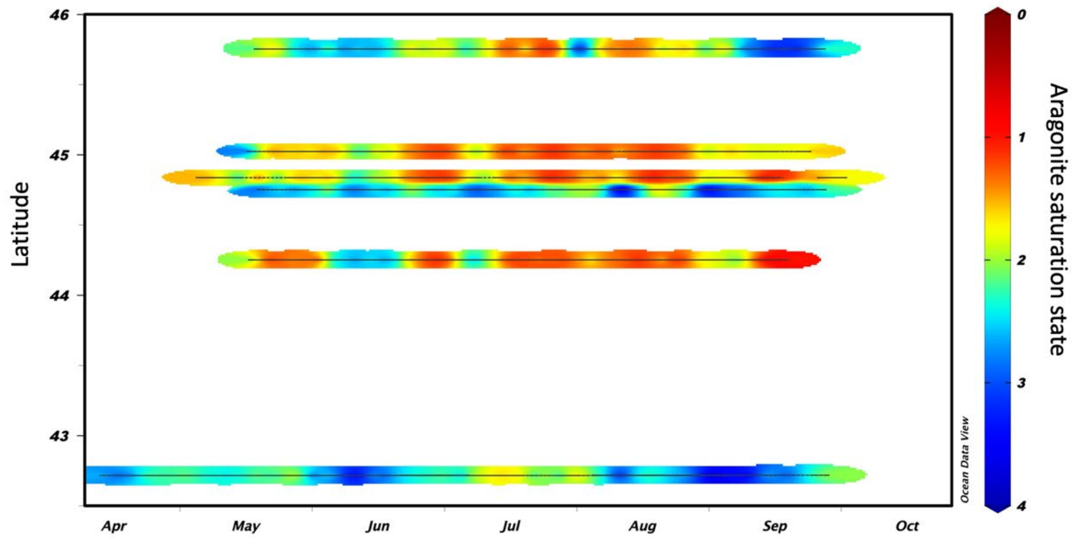


Figure B16. Climatological patterns (2016, 2017 to 2020) in aragonite saturation state from intertidal pH sensors. Aragonite saturation state was calculated from pH (total scale) and temperature and assumptions of conservative salinity and alkalinity ranges according to a method described in Chan et al. 2017. Note that an additional non-reserve site (Cape Foulweather) at 44.85 is included here.

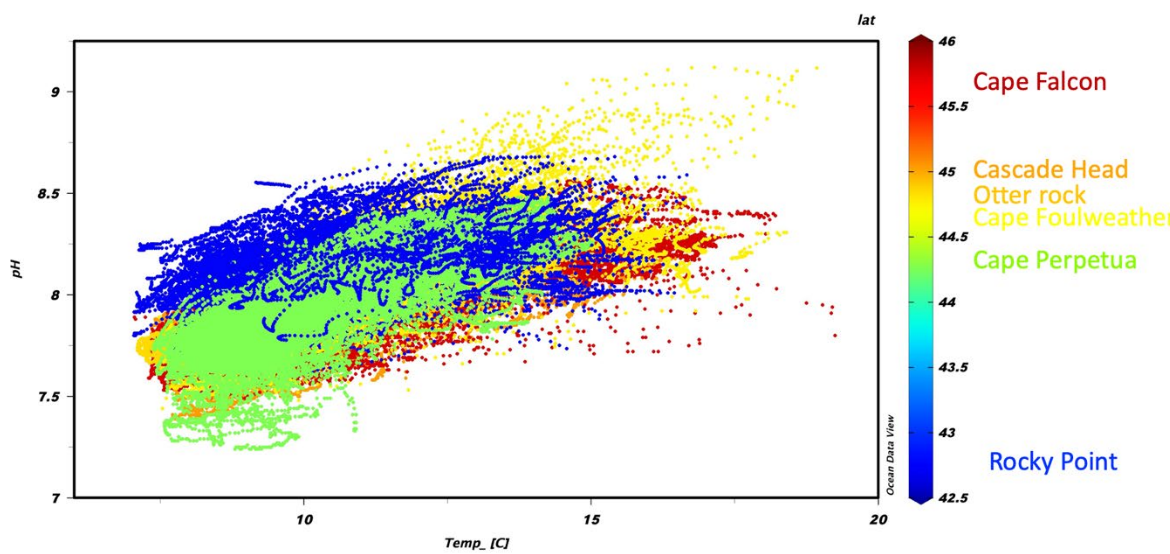


Figure B17. Compilation of T vs. pH (total scale) for intertidal measurements (2016 to 2020) illustrating the regional and site-dependent differences in water mass properties.

References:

Adams, K. A., J. A. Barth and F. Chan, 2013. Temporal variability of near-bottom dissolved oxygen during upwelling off central Oregon. *J. Geophys. Res.*, **118**, https://doi.org/10.1002/jgrc.20361 .

Barnes, C.A., Duxbury, A.C., Morse, B.-A., 1972. Circulation and selected properties of the Columbia River effluent at sea. In: Pruter, A.T., Alverson, D.L. (Eds.), The Columbia River Estuary and Adjacent Ocean Waters. University of Washington Press, Seattle, WA, pp. 41–80.

Barth, J. A., S. D. Pierce and R. L. Smith, 2000. A separating coastal upwelling jet at Cape Blanco, Oregon and its connection to the California Current System. *Deep-Sea Res. II*, **47**, 783-810, https://doi.org/10.1016/S0967-0645(99)00127-7 .

Barth, J. A., S. D. Pierce and R. M. Castelao, 2005. Time-dependent, wind-driven flow over a shallow mid-shelf submarine bank. *J. Geophys. Res.*, **110(C10)**, C10S05, https://doi.org/10.1029/2004JC002761 .

Castelao, R. M. and J. A. Barth, 2006. The relative importance of wind strength and along-shelf bathymetric variations on the separation of a coastal upwelling jet. *J. Phys. Oceanogr.*, **36**, 412-425, https://doi.org/10.1175/JPO2867.1 .

Chan, F., J. A. Barth, C. A. Blanchette, R. H. Byrne, F. Chavez, O. Cheriton, R. A. Feely, G. Friederich, B. Gaylord, T. Gouhier, S. Hacker, T. Hill, G. Hofmann, M. A. McManus, B. A. Menge, K. J. Nielsen, A. Russell, E. Sanford, J. Sevadjian, and L. Washburn, 2017. Persistent spatial structuring of coastal ocean acidification in the California Current System. *Nature Scientific Reports*, **7**, 2526, https://doi.org/10.1038/s41598-017-02777-y .

Chan, F., J. A. Barth, K. J. Kroeker, J. Lubchenco, and B.A. Menge, 2019. The dynamics and impact of ocean acidification and hypoxia: Insights from sustained investigations in the Northern California Current Large Marine Ecosystem. *Oceanography,* **32(3)**, 62-71, https://doi.org/10.5670/oceanog.2019.312 .

Heppell, S., J. Barth and H. Reiff, 2008. Size and spacing of marine reserves workshop report. Scientific and Technical Advisory Committee, Oregon Ocean Policy Advisory Council, 88 pp., https://www.oregonocean.info/index.php/opac-documents/workinggroups/stac/1482-oregon-size-and-spacing-workshop-report .

Huyer, A., 1983. Coastal upwelling in the California current system. *Progress in Oceanography*, **12**, 259–284.

Keller, A., V. Simon, F. Chan, W. W. Wakefield, M. E. Clarke, D. Kamikawa, E. L. Fruh and J. A. Barth, 2010. Demersal fish and invertebrate biomass in relation to an offshore hypoxic zone along the U.S. West Coast. *Fisheries Oceanography*, **19,** 76-87, https://doi.org/10.1111/j.1365-2419.2009.00529.x .

Kirincich, A. R. and J. A. Barth, 2009. Alongshelf variability of inner-shelf circulation along the central Oregon coast during summer. *J. Phys. Oceanogr.*, **39**, 1380-1398, https://doi.org/10.1175/2008JPO3760.1 .

Mazzini, P. L. F., J. A. Barth, R. K. Shearman and A. Erofeev, 2014. Buoyancy-driven coastal currents off the Oregon coast during fall and winter. *J. Phys. Oceanogr*, **44**, 2854-2876, https://doi.org/10.1175/JPO-D-14-0012.1 .

Menge, B. A., K. Milligan, J. E. Caselle, J. A. Barth, C. A. Blanchette, M. H. Carr, F. Chan, R. K. Cowen, M. Denny, S. D. Gaines, G. E. Hofmann, K. J. Kroeker, J. Lubchenco, M. A.

McManus, M. Novak, S. R. Palumbi, P. T. Raimondi, G. N. Somero, R. R. Warner, L. Washburn, and J. W. White, 2019. PISCO: Advances made through the formation of a large-scale, long-term consortium for integrated understanding of coastal ecosystem dynamics. *Oceanography*, **32(3)**, 16–25, https://doi.org/10.5670/oceanog.2019.307 .

Oregon Department of Fish and Wildlife, 2017. Marine Reserves: Ecological Monitoring Plan. https://oregonmarinereserves.com . 32 pp.

Samelson, R., Barbour, P., Barth, J., Bielli, S., Boyd, T., Chelton, D., Kosro, P., Levine, M., Skyllingstad, E. and J. Wilczak, 2002. Wind stress forcing of the Oregon coastal ocean during the 1999 upwelling season. J. Geophys. Res, 107(C5), 3034, https://doi.org/10.1029/2001JC000900 .

Appendix C: Oceanography Results by Reserve

Time series of available oceanographic data from each Oregon Marine Reserve are reported from north to south. To compare oceanographic parameters to the wind, we use north-south wind stress derived from winds measured at Newport, Oregon, available at http://damp.coas.oregonstate.edu/windstress/ .

For Cape Perpetua where data exist from 2003 to 2020, a seasonal climatology is computed for temperature, salinity and dissolved oxygen. This seasonal cycle is smoothed using cubic splines and anomalies are computed from the mean seasonal cycle and plotted for each year.

Cape Falcon

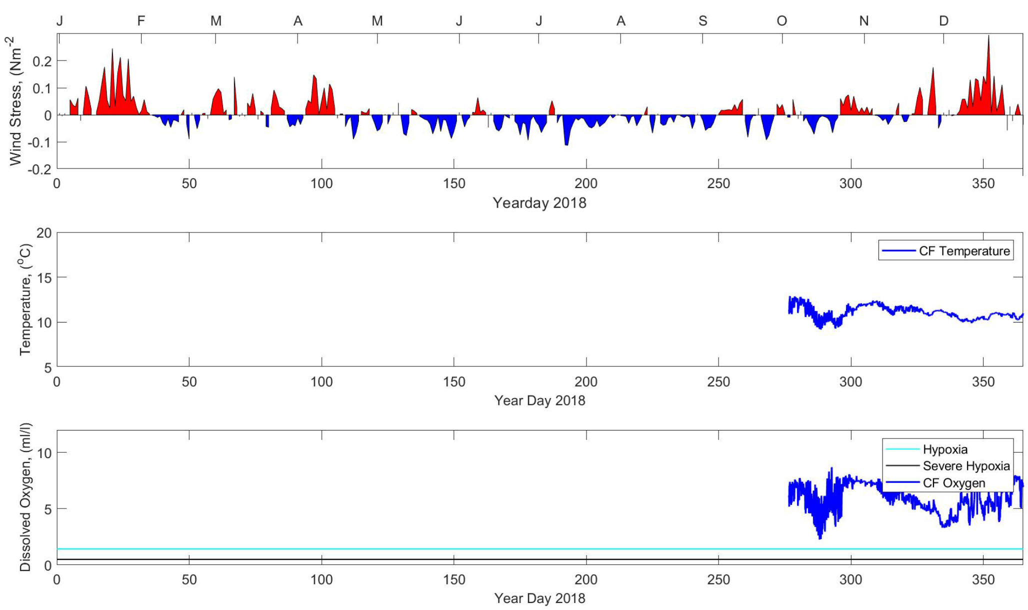
Temperature, salinity and dissolved oxygen were measured in the Cape Falcon Marine Reserve for 2018-2020 and from the nearby comparison area near Cape Meares (CFM; approximately 42.51N, 123.97W) in 2020. The temperatures at the two sites from the long-term deployments (> 1-2 days) in 2020 are similar, confirming that the thermal habitat in the marine reserve and comparison area are comparable.

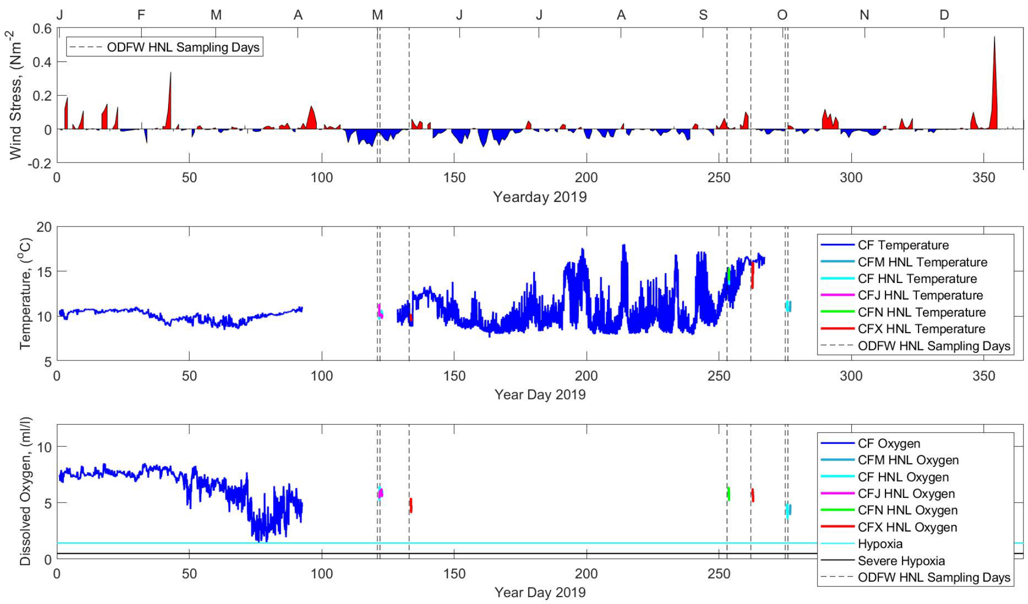
For 2019, daily-averaged oceanographic data from the day of and one day prior to ODFW MR hook and line (HNL), indicated by vertical dashed lines, are used by ODFW to investigate relationships among biological and oceanographic data. For 2019, data from short-term (1-2 days) instrumented crab pots (T and DO) deployed during the ODFW HNL sampling in the Cape Falcon Marine Reserve (CF HNL) and nearby comparison areas (see list below) were collected and included in the plot for that year. A stretched view of one deployment in September 2019 is also included.

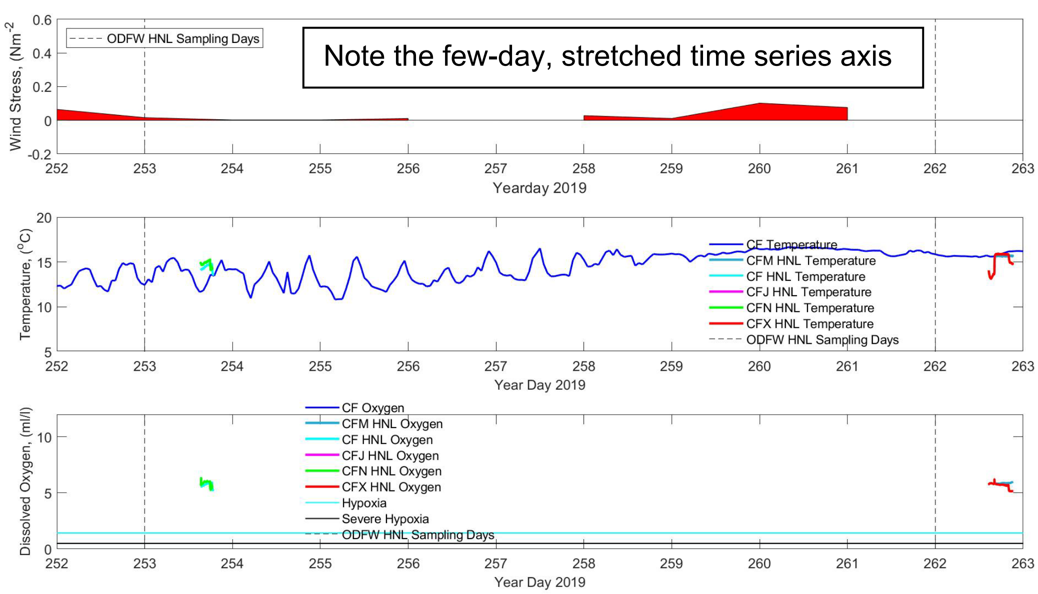
Cape Falcon comparison areas during ODFW hook and line (HNL) sampling and plot labels:

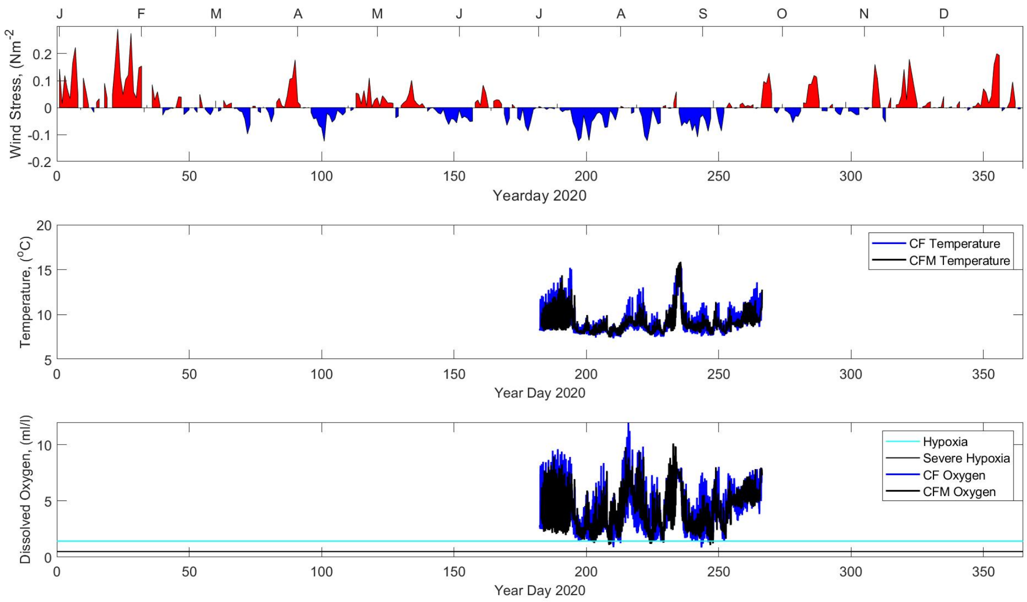
- Cape Meares (CFM HNL): 45.512N, 123.972W
- Cape Falcon North of Jetty (CFJ HNL): 45.757N, 123.974W
- Cape Falcon off Nehalem (CFN HNL): 45.714N, 123.956W
- Cape Falcon X (CFX HNL): 45.578N, 123.970W

Cape Falcon oceanographic mooring time series by year




J F M A M J J A S O N D
Wind Stress, (Nm⁻²)
ODFW HNL Sampling Days
Yearday 2019
Temperature, (°C)
CF Temperature
CFM HNL Temperature
CF HNL Temperature
CFJ HNL Temperature
CFN HNL Temperature
CFX HNL Temperature
ODFW HNL Sampling Days
Year Day 2019
Dissolved Oxygen, (ml/l)
CF Oxygen
CFM HNL Oxygen
CF HNL Oxygen
CFJ HNL Oxygen
CFN HNL Oxygen
CFX HNL Oxygen
Hypoxia
Severe Hypoxia
ODFW HNL Sampling Days
Year Day 2019

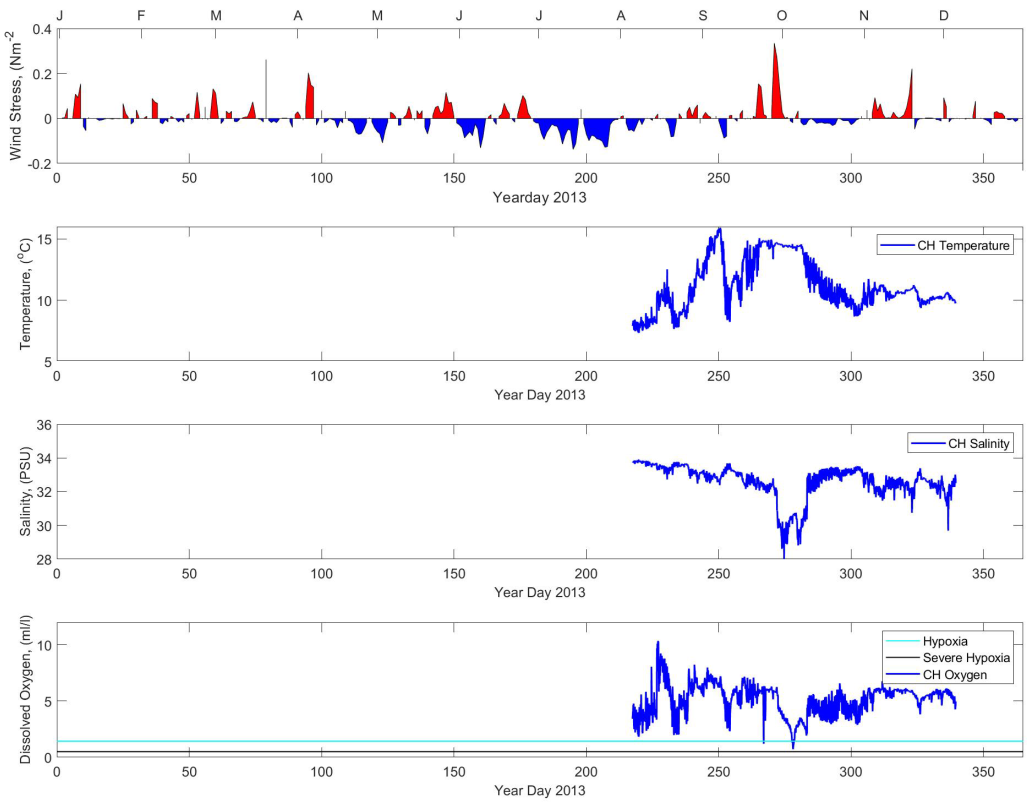

Wind Stress, (Nm⁻²)
ODFW HNL Sampling Days
Note the few-day, stretched time series axis
Yearday 2019
Temperature, (°C)
CF Temperature
CFM HNL Temperature
CF HNL Temperature
CFJ HNL Temperature
CFN HNL Temperature
CFX HNL Temperature
ODFW HNL Sampling Days
Year Day 2019
Dissolved Oxygen, (ml/l)
CF Oxygen
CFM HNL Oxygen
CF HNL Oxygen
CFJ HNL Oxygen
CFN HNL Oxygen
CFX HNL Oxygen
Hypoxia
Severe Hypoxia
ODFW HNL Sampling Days
Year Day 2019

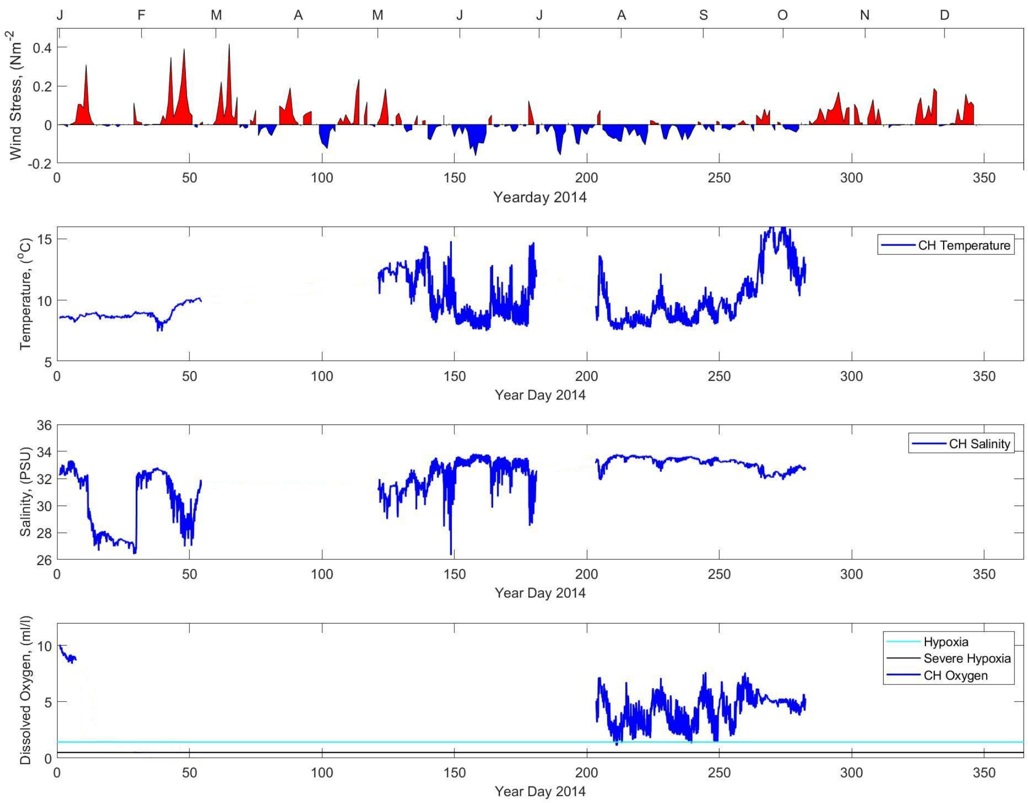

J
F
M
A
M
J
J
A
S
O
N
D
Wind Stress, (Nm^{-2}
Yearday 2020
Temperature, (^{o}C)
CF Temperature
CFM Temperature
Year Day 2020
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
CF Oxygen
CFM Oxygen
Year Day 2020

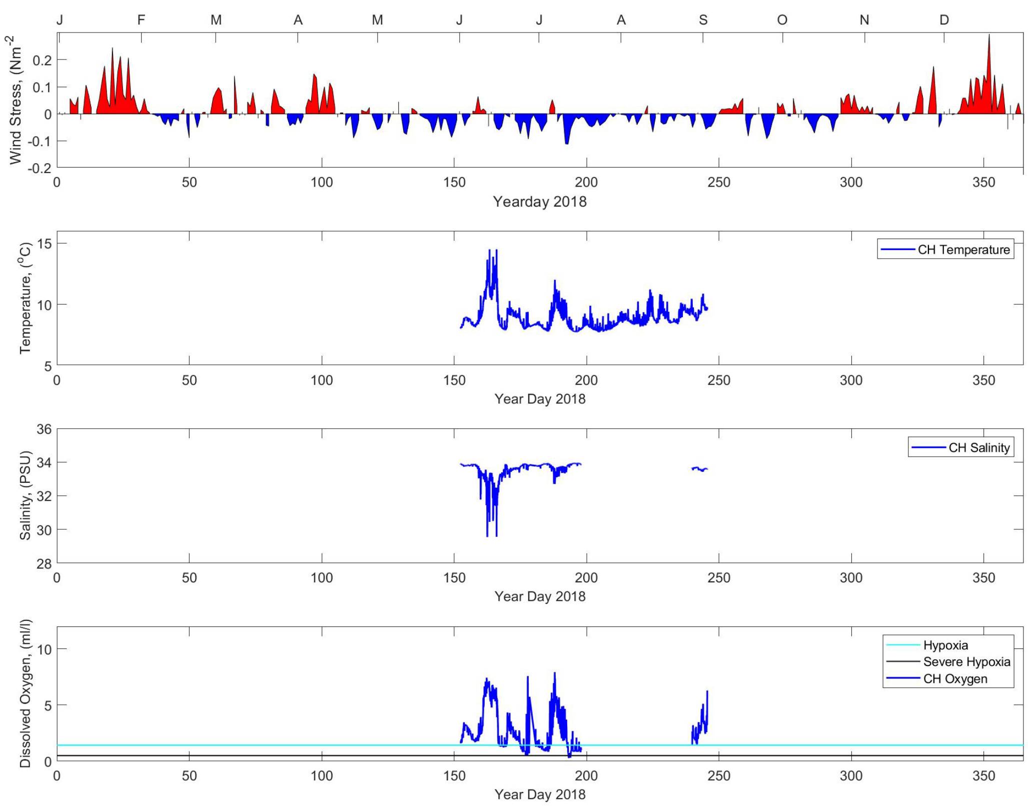
Cascade Head

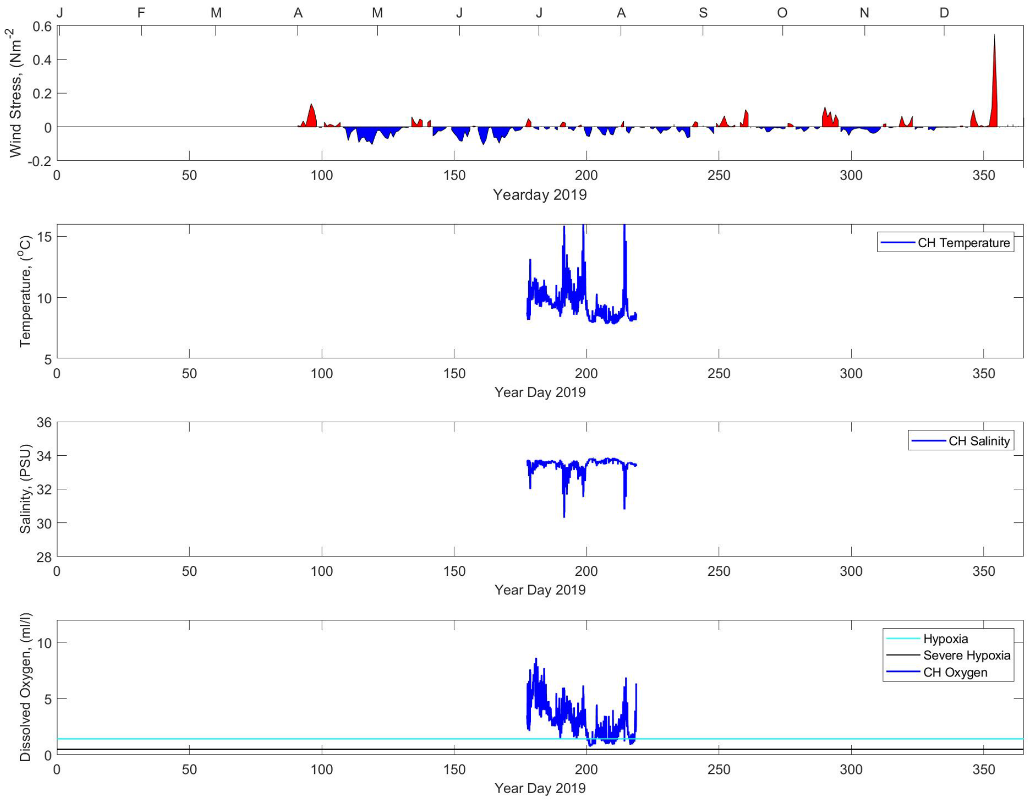
Temperature, salinity and dissolved oxygen were measured in the Cascade Head Marine Reserve for 2013-2015 and 2018-2020.

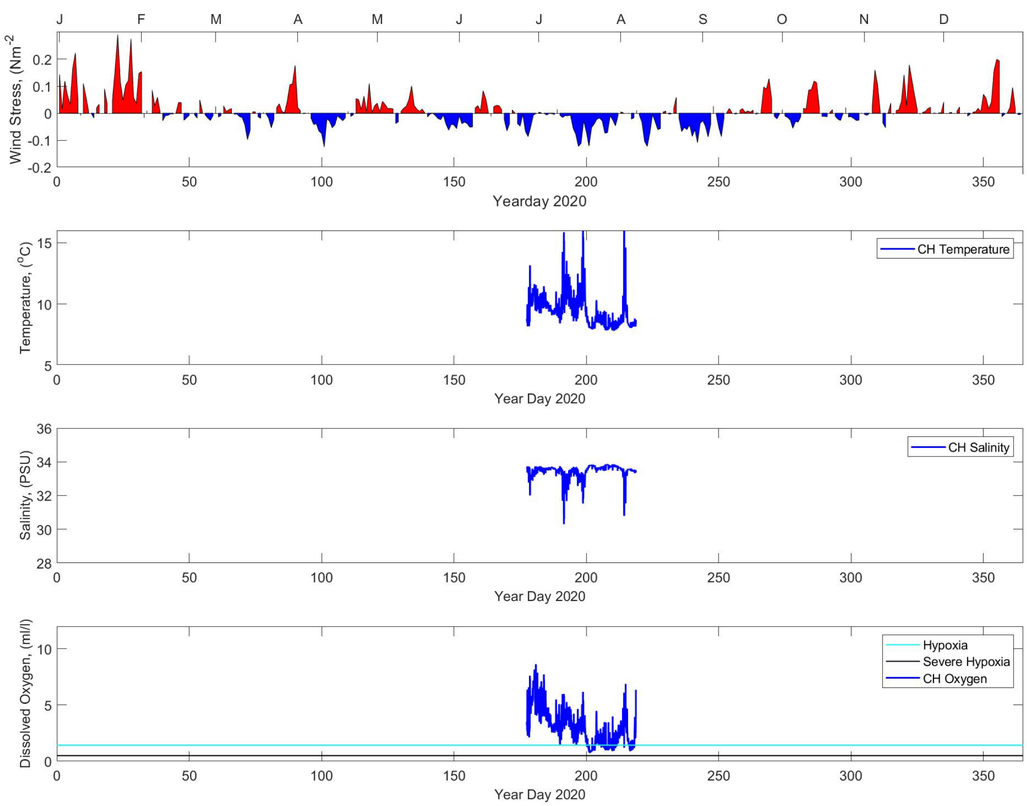
Cascade Head oceanographic mooring time series by year.




J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2014
Temperature, (^{o}C)
CH Temperature
Year Day 2014
Salinity, (PSU)
CH Salinity
Year Day 2014
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
CH Oxygen
Year Day 2014


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2018
Temperature, (^{o}C)
CH Temperature
Year Day 2018
Salinity, (PSU)
CH Salinity
Year Day 2018
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
CH Oxygen
Year Day 2018

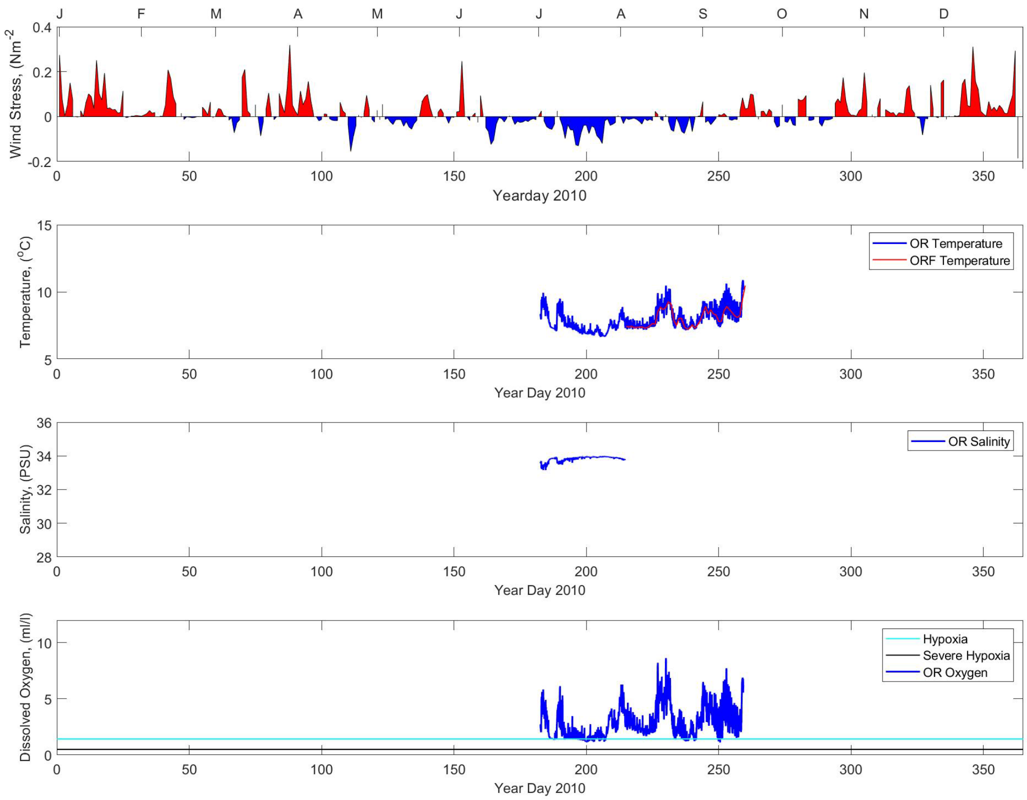

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2019
Temperature, (^{o}C)
CH Temperature
Year Day 2019
Salinity, (PSU)
CH Salinity
Year Day 2019
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
CH Oxygen
Year Day 2019

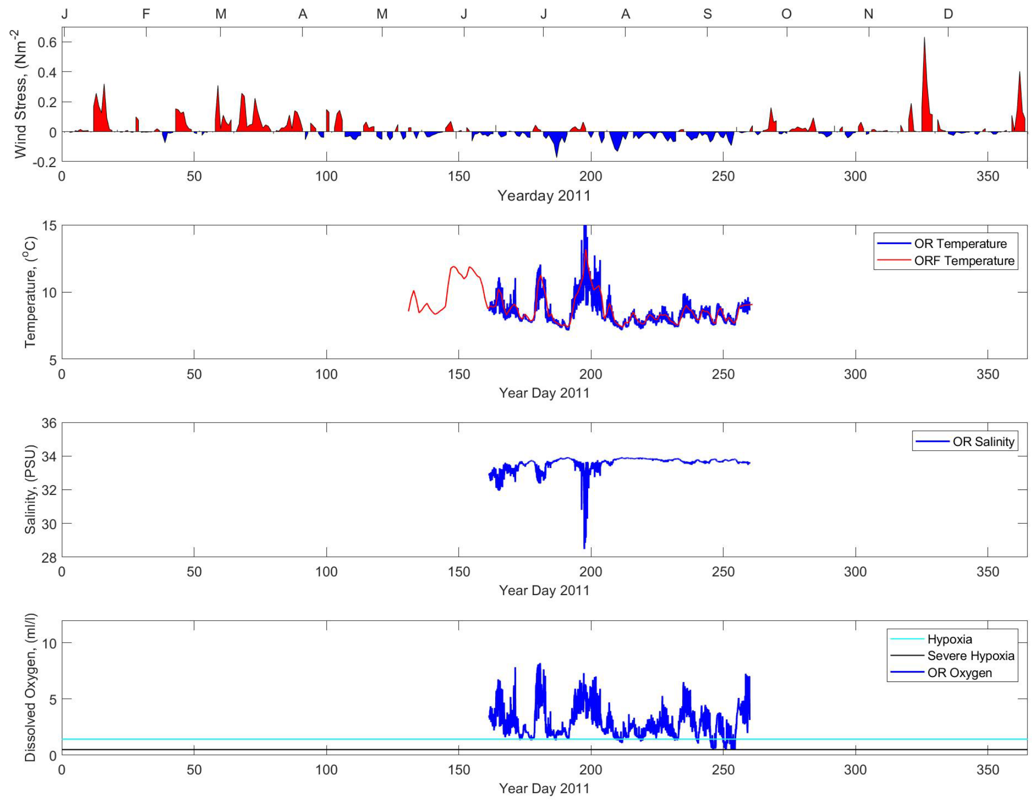

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2020
Temperature, (^{o}C)
CH Temperature
Year Day 2020
Salinity, (PSU)
CH Salinity
Year Day 2020
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
CH Oxygen
Year Day 2020

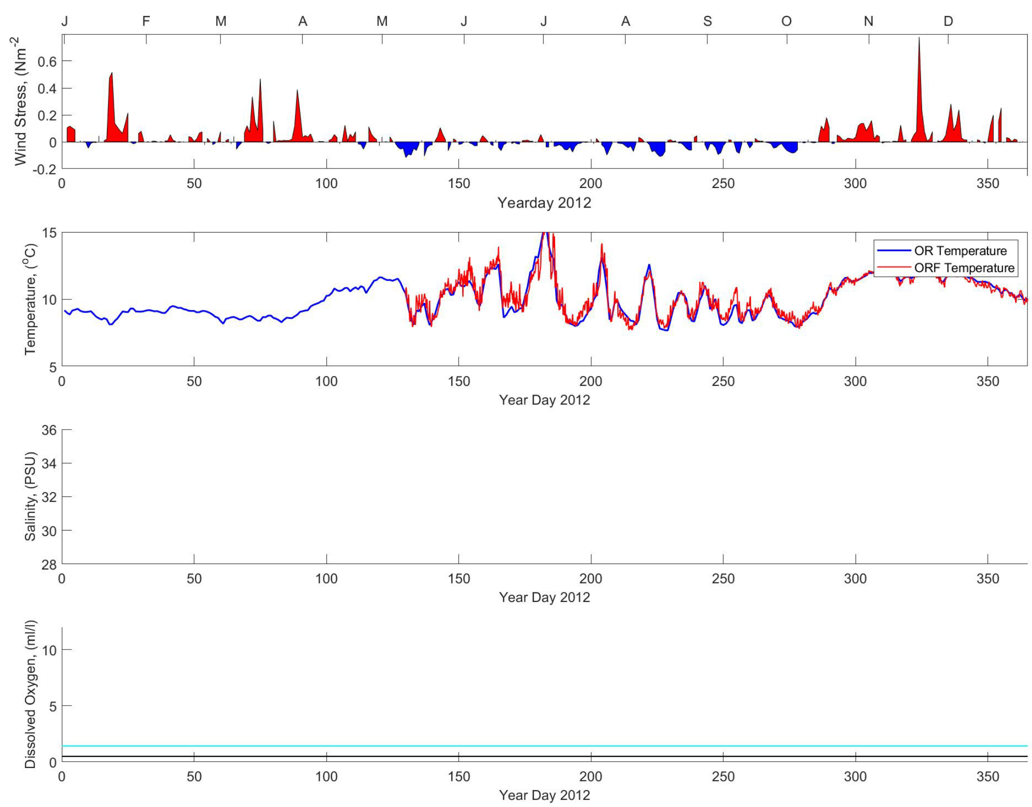
Otter Rock

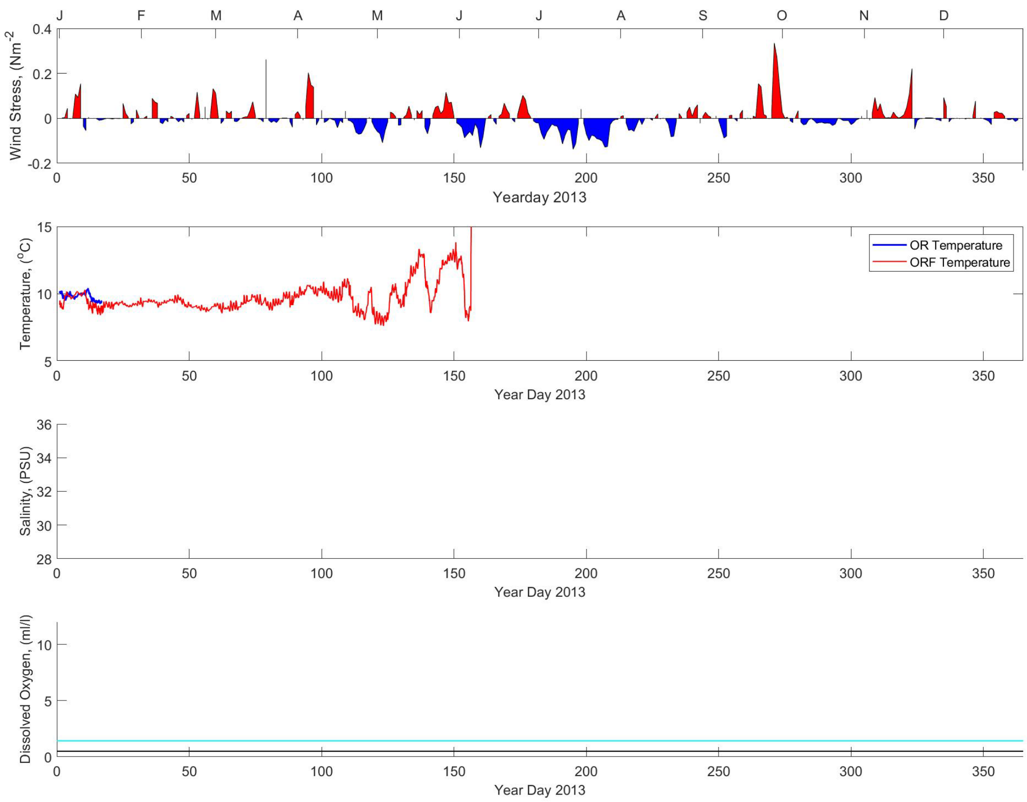
Temperature, salinity and dissolved oxygen were measured in the Otter Rock Marine Reserve and from the nearby comparison area near Cape Foulweather (ORF). The temperatures at the two sites are indistinguishable, confirming that the thermal habitat in the marine reserve and comparison area are comparable.

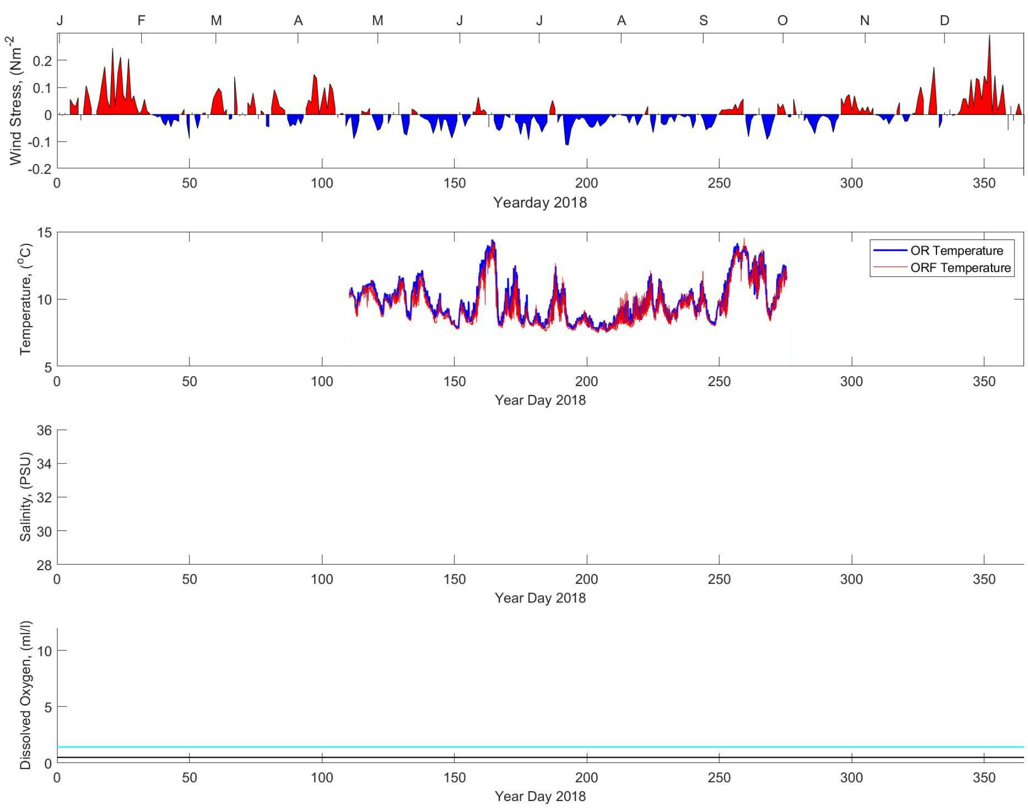
Otter Rock oceanographic mooring time series by year.

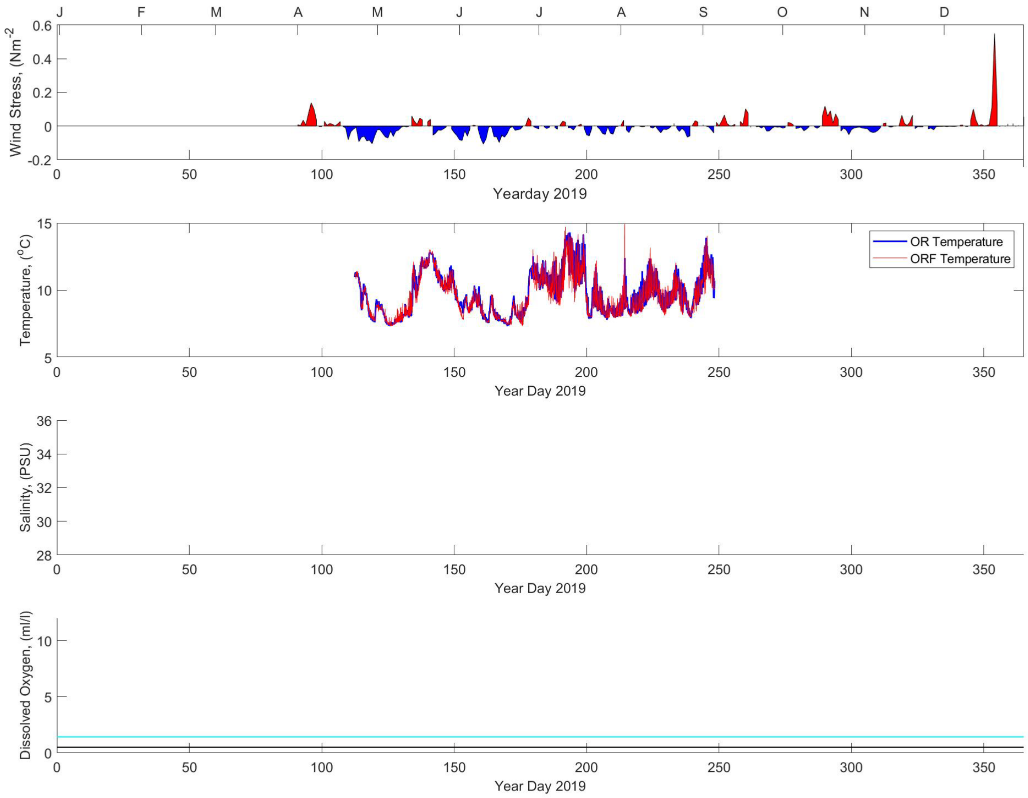



J F M A M J J A S O N D
Wind Stress, (Nm-2)
Yearday 2011
Temperature, (oC)
OR Temperature
ORF Temperature
Year Day 2011
Salinity, (PSU)
OR Salinity
Year Day 2011
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
OR Oxygen
Year Day 2011


J F M A M J J A S O N D
Wind Stress, (Nm-2)
Yearday 2012
Temperature, (oC)
OR Temperature
ORF Temperature
Year Day 2012
Salinity, (PSU)
Year Day 2012
Dissolved Oxygen, (ml/l)
Year Day 2012


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2013
Temperature, (°C)
OR Temperature
ORF Temperature
Year Day 2013
Salinity, (PSU)
Year Day 2013
Dissolved Oxygen, (ml/l)
Year Day 2013

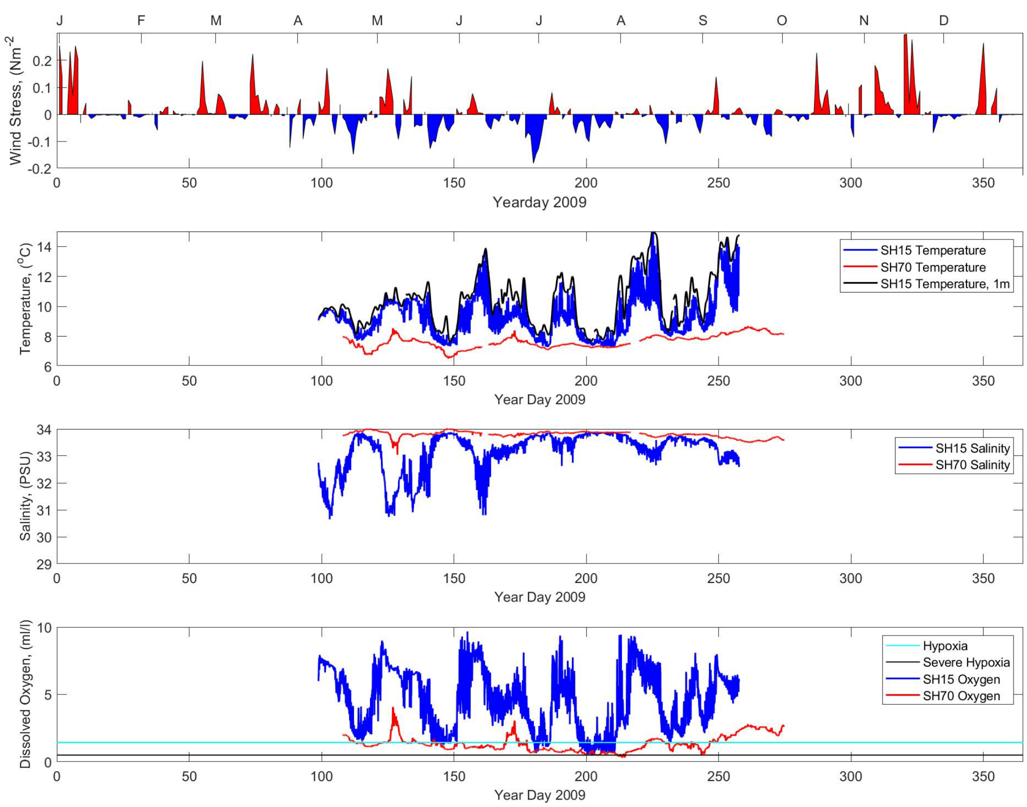

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2018
Temperature, (°C)
OR Temperature
ORF Temperature
Year Day 2018
Salinity, (PSU)
Year Day 2018
Dissolved Oxygen, (ml/l)
Year Day 2018

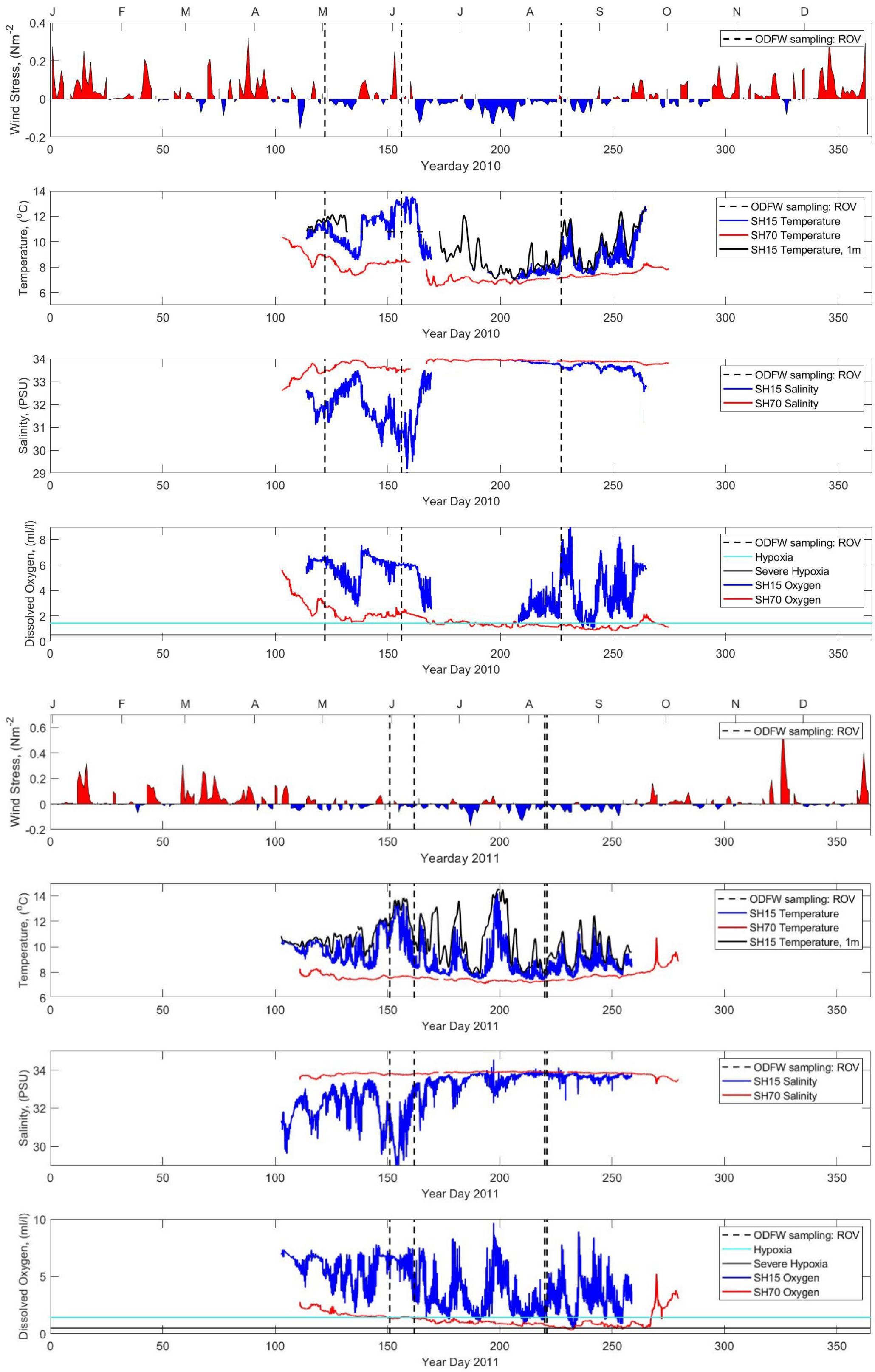

J
F
M
A
M
J
J
A
S
O
N
D
Wind Stress, (Nm-2)
Yearday 2019
Temperature, (°C)
Year Day 2019
OR Temperature
ORF Temperature
Salinity, (PSU)
Year Day 2019
Dissolved Oxygen, (ml/l)
Year Day 2019

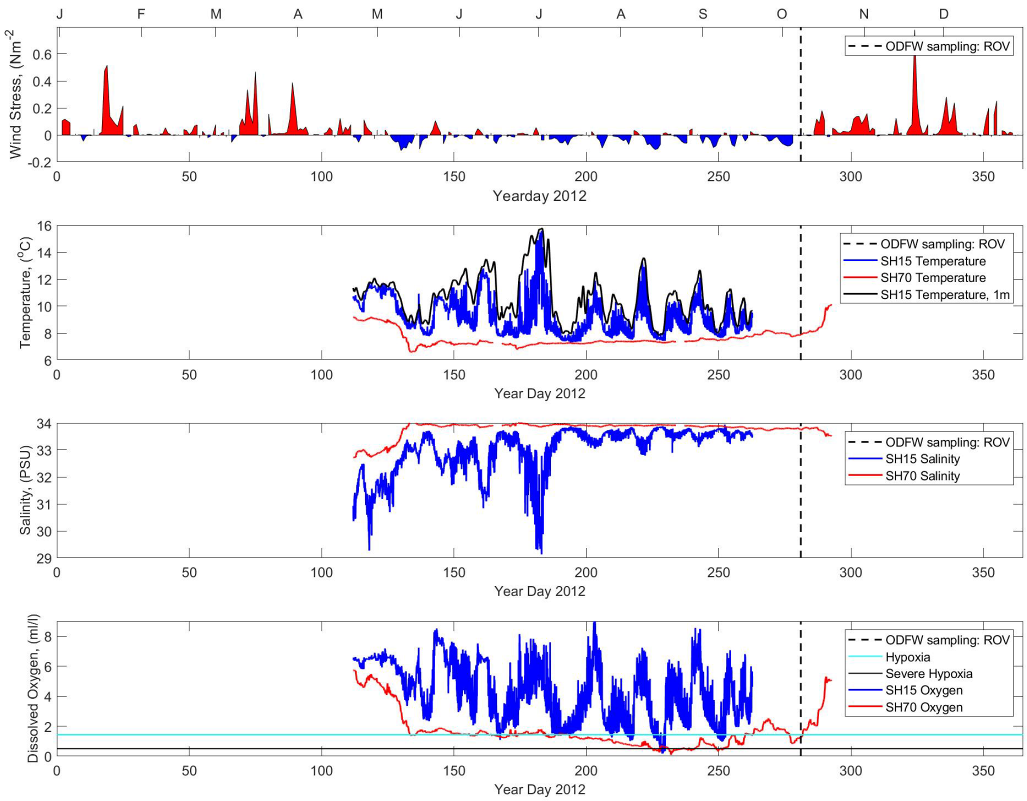
Cape Perpetua

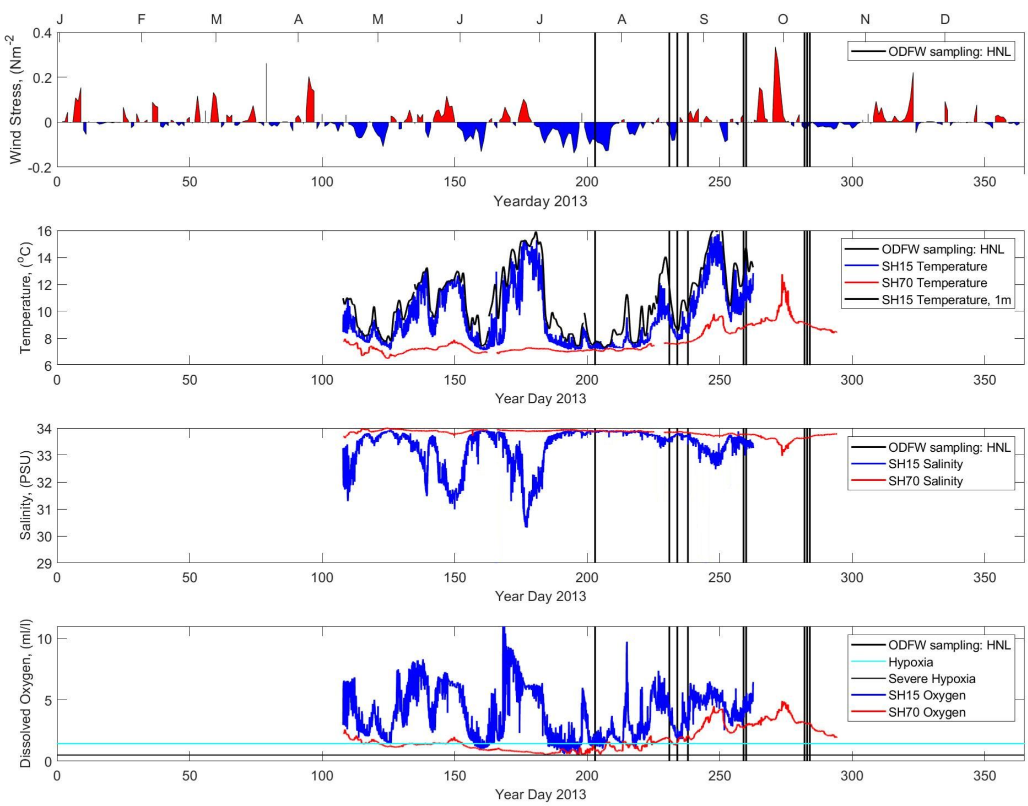
Cape Perpetua is one of the best monitored marine reserve areas in the country, having been a study sight for PISCO since 1999 (Menge et al., 2019). PISCO maintains spring-summer season oceanographic moorings to measure temperature, salinity and dissolved oxygen at several levels in the water column on the 15-m isobath, approximately 1.5 km offshore and within both state waters and the Cape Perpetua MR. In addition, through a combination of projects, an oceanographic bottom lander has been maintained on the 70-m isobath at the same latitude as the 15-m mooring (44 15'N), providing information about the source waters upwelled into shallower depths and the marine reserve (Adams et al., 2013). Lastly, pH has been monitored in the intertidal since 2016 (see Appendix B). At the CP MR, oceanographic data is only available in the MR itself, not in comparison areas. Times series of oceanographic data for 2009-2020 are presented in relation to the north-south component of wind stress in order to show the importance of wind driving at this location, similar to other locations along the Oregon coast. Daily-averaged oceanographic data from the day of and one day prior ODFW MR hook and line (HNL - solid) or remotely operated vehicle (ROV - dashed) sampling, indicated by vertical lines, are used by ODFW to investigate relationships among biological and oceanographic data.

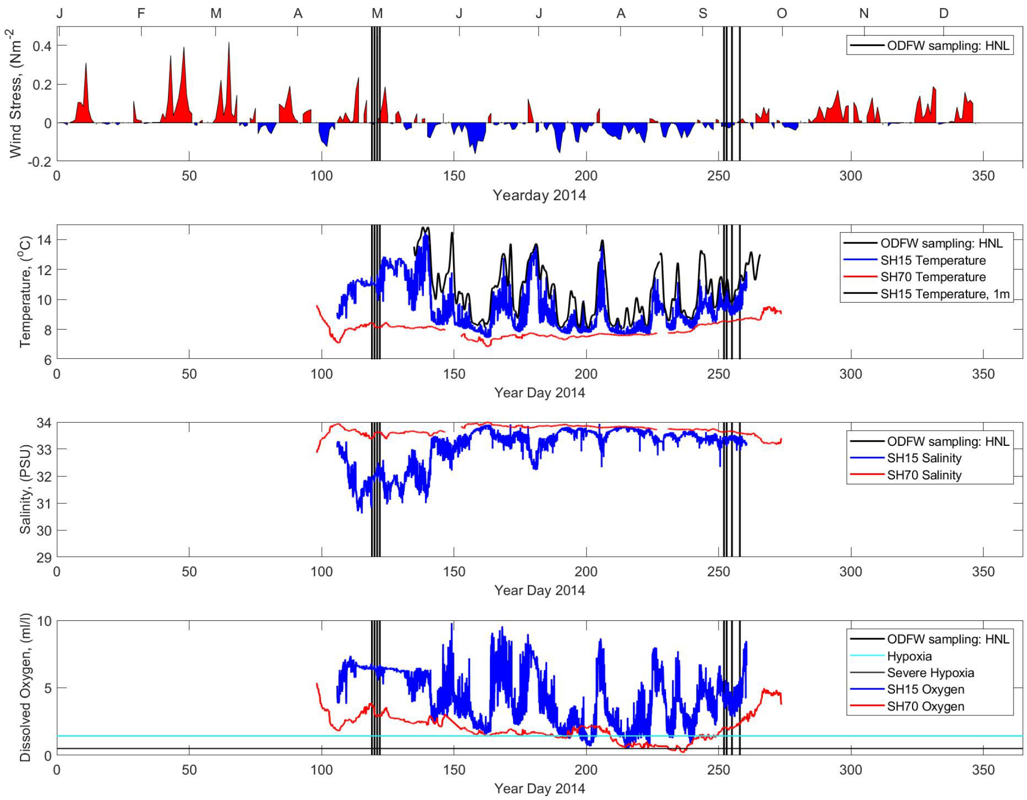
Cape Perpetua oceanographic mooring time series by year.

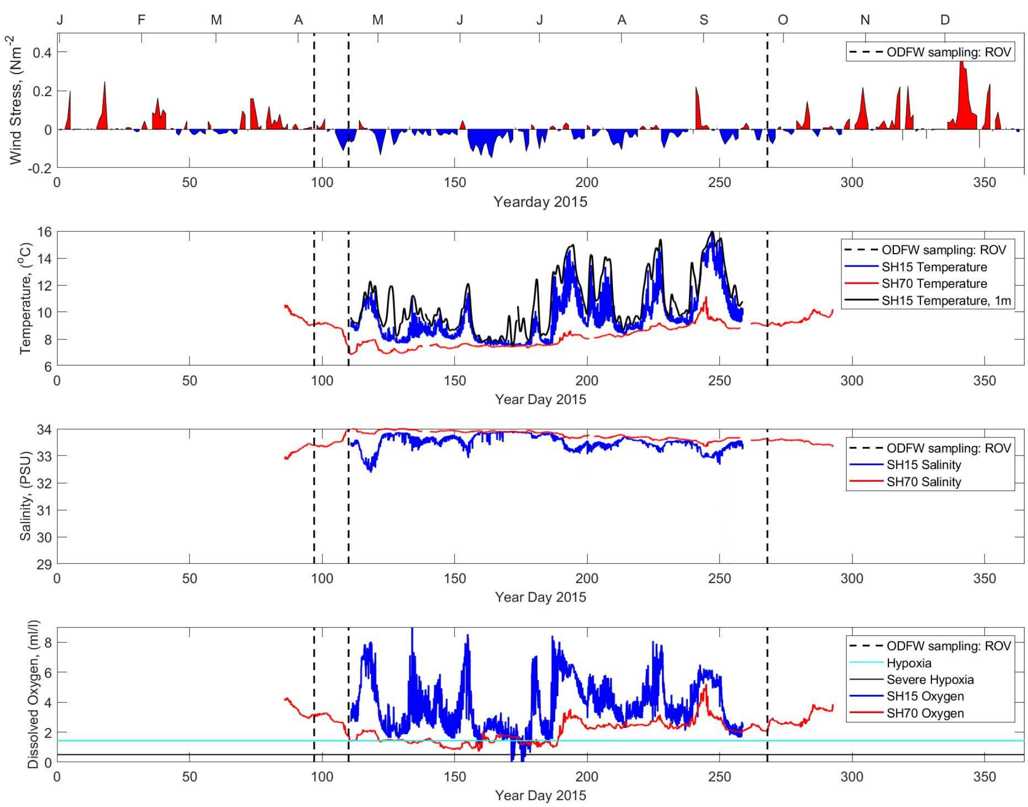


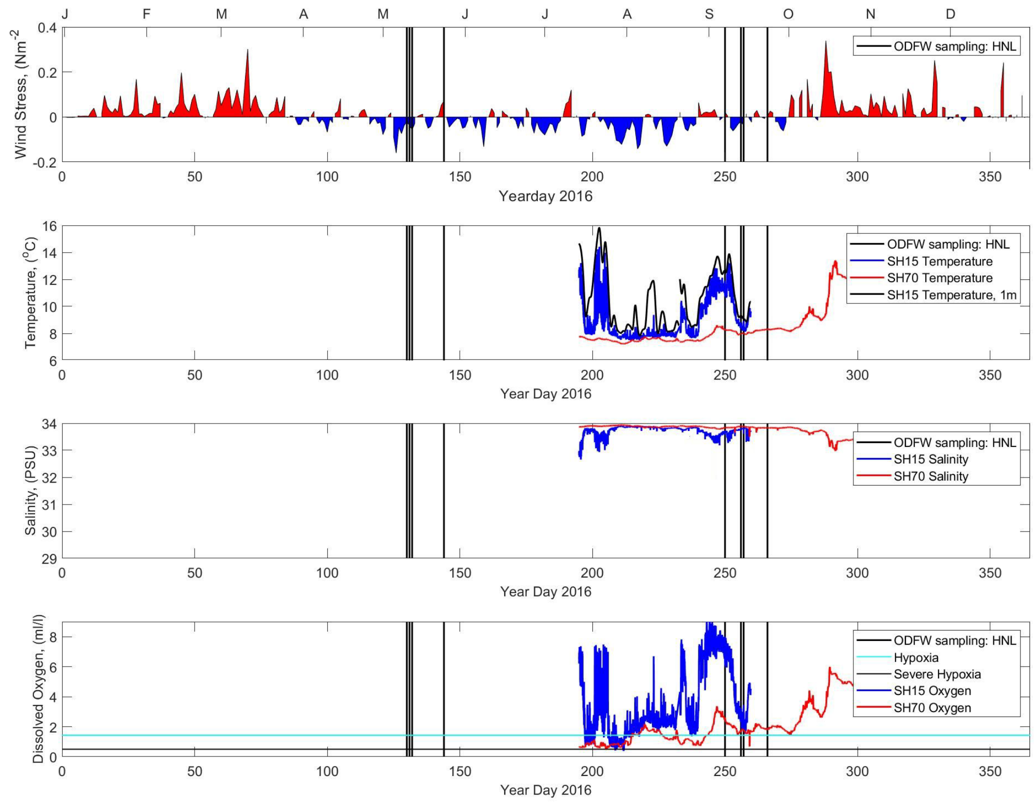

J F M A M J J A S O N D
Wind Stress, (Nm-2)
Yearday 2010
ODFW sampling: ROV
Temperature, (°C)
Year Day 2010
ODFW sampling: ROV
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Salinity, (PSU)
Year Day 2010
ODFW sampling: ROV
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Year Day 2010
ODFW sampling: ROV
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen
J F M A M J J A S O N D
Wind Stress, (Nm-2)
Yearday 2011
ODFW sampling: ROV
Temperature, (°C)
Year Day 2011
ODFW sampling: ROV
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Salinity, (PSU)
Year Day 2011
ODFW sampling: ROV
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Year Day 2011
ODFW sampling: ROV
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen

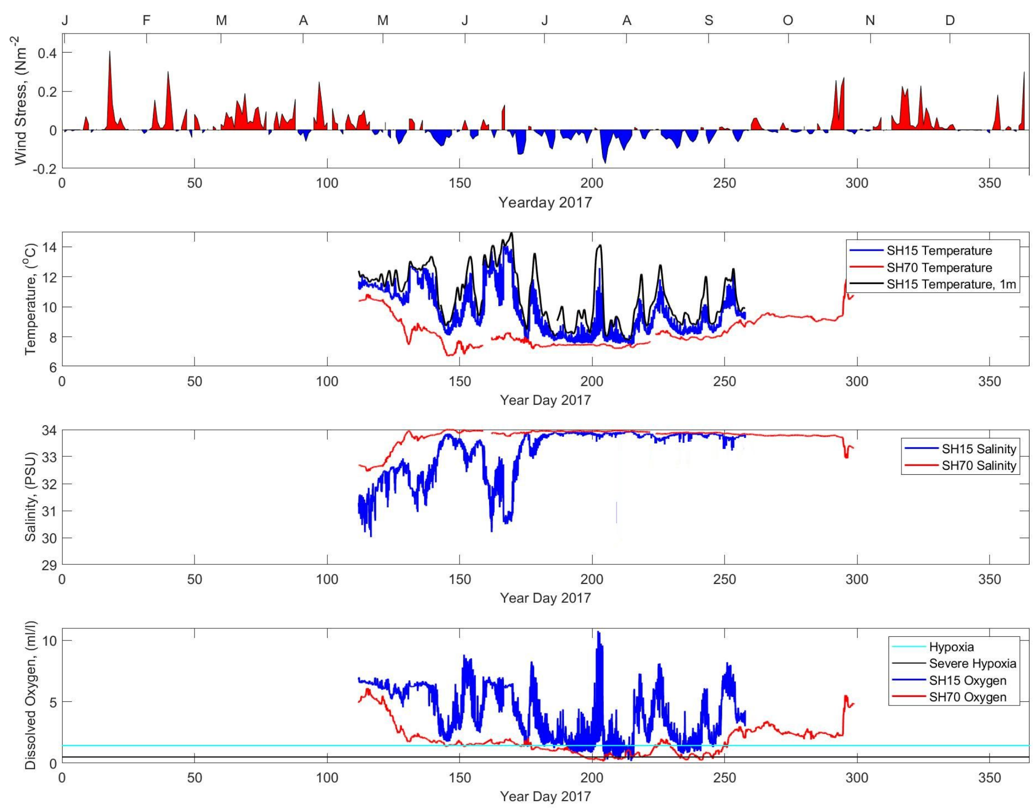

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2012
ODFW sampling: ROV
Temperature, (^{o}C)
Year Day 2012
ODFW sampling: ROV
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Salinity, (PSU)
Year Day 2012
ODFW sampling: ROV
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Year Day 2012
ODFW sampling: ROV
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen

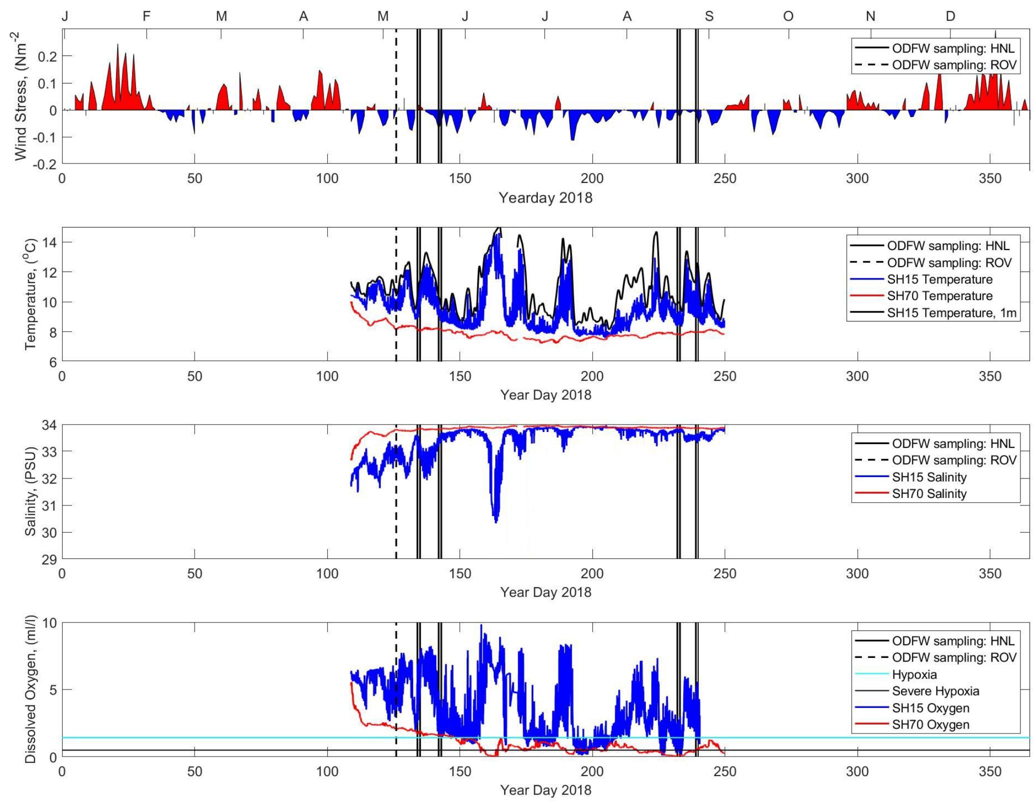

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2013
ODFW sampling: HNL
Temperature, (^{o}C)
Year Day 2013
ODFW sampling: HNL
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Salinity, (PSU)
Year Day 2013
ODFW sampling: HNL
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Year Day 2013
ODFW sampling: HNL
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen

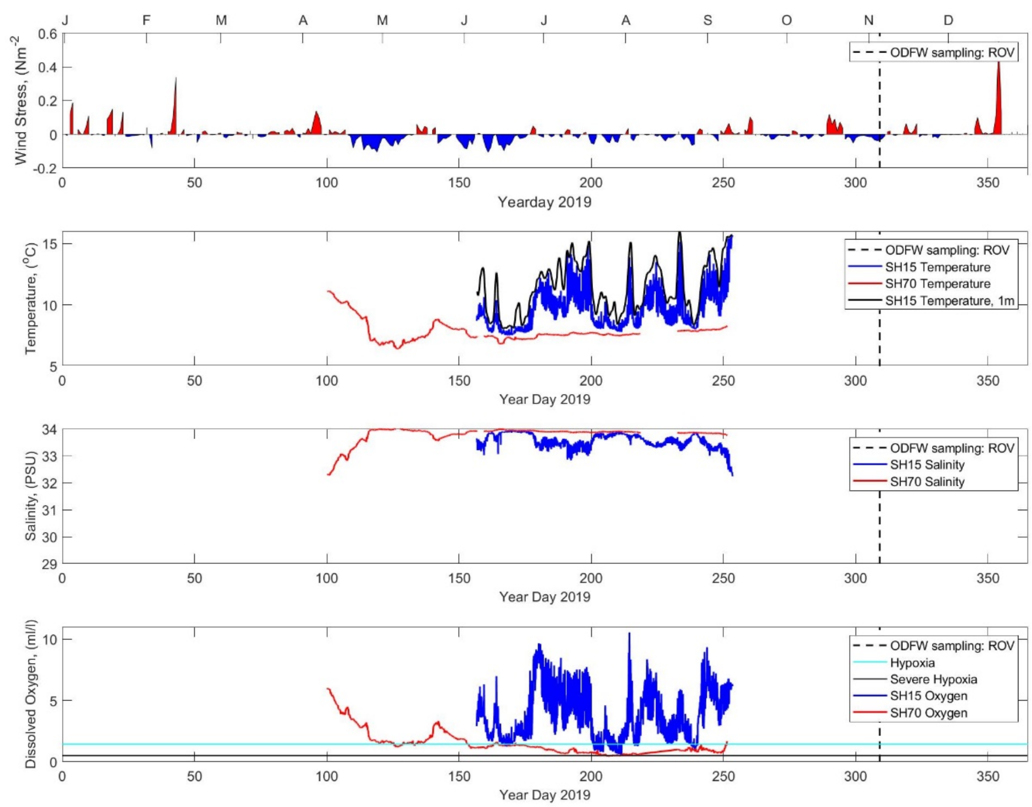

J F M A M J J A S O N D
Wind Stress, (Nm-2)
Yearday 2014
ODFW sampling: HNL
Temperature, (°C)
Year Day 2014
ODFW sampling: HNL
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Salinity, (PSU)
Year Day 2014
ODFW sampling: HNL
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Year Day 2014
ODFW sampling: HNL
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen

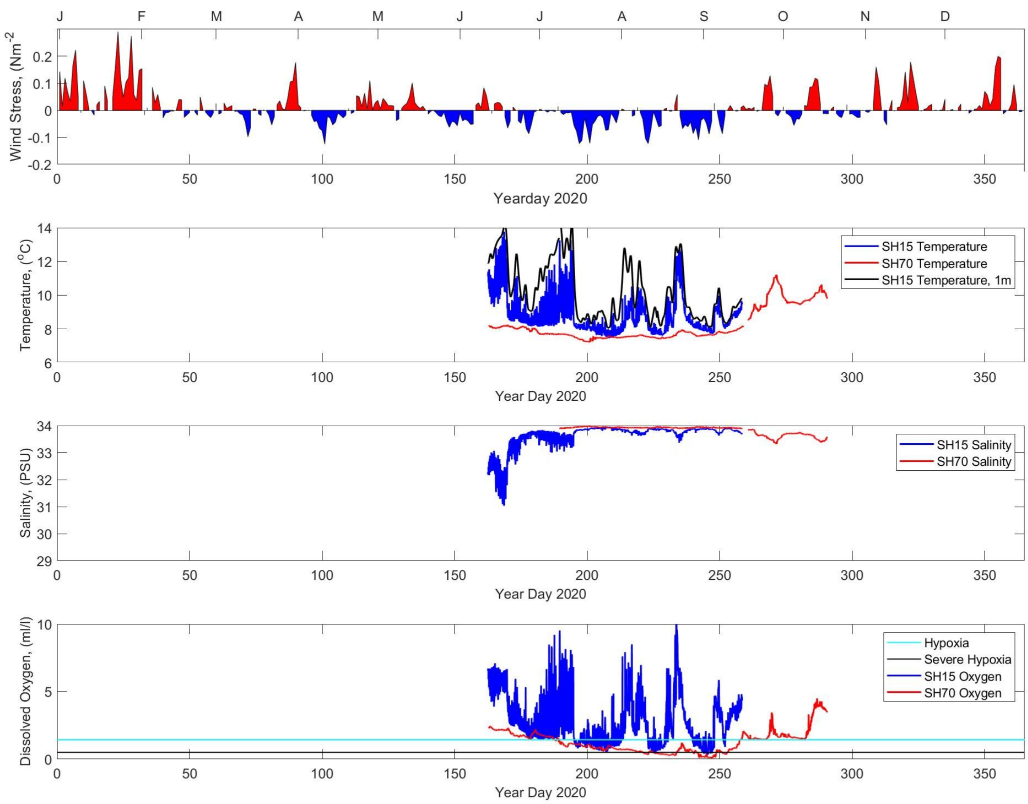

J F M A M J J A S O N D
Wind Stress, (Nm-2)
Yearday 2015
ODFW sampling: ROV
Temperature, (°C)
Year Day 2015
ODFW sampling: ROV
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Salinity, (PSU)
Year Day 2015
ODFW sampling: ROV
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Year Day 2015
ODFW sampling: ROV
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
ODFW sampling: HNL
Yearday 2016
Temperature, (^{o}C)
ODFW sampling: HNL
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Year Day 2016
Salinity, (PSU)
ODFW sampling: HNL
SH15 Salinity
SH70 Salinity
Year Day 2016
Dissolved Oxygen, (ml/l)
ODFW sampling: HNL
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen
Year Day 2016


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2017
Temperature, (^{o}C)
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Year Day 2017
Salinity, (PSU)
SH15 Salinity
SH70 Salinity
Year Day 2017
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen
Year Day 2017


J F M A M J J A S O N D
Wind Stress, (Nm^{-2}
ODFW sampling: HNL
ODFW sampling: ROV
Yearday 2018
Temperature, (^{o}C)
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Year Day 2018
Salinity, (PSU)
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen


J F M A M J J A S O N D
Wind Stress, (Nm^{-2}
ODFW sampling: ROV
Yearday 2019
Temperature, (^{o}C)
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Year Day 2019
Salinity, (PSU)
SH15 Salinity
SH70 Salinity
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen

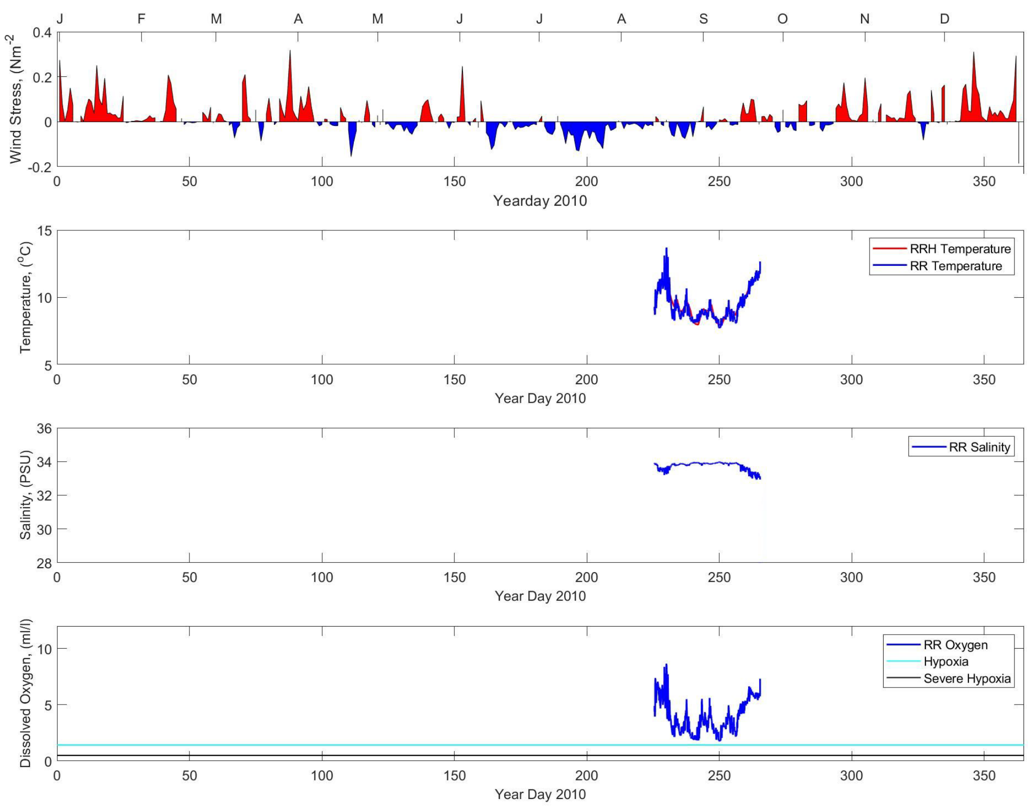

J F M A M J J A S O N D
Wind Stress, (Nm^{-2}
Yearday 2020
Temperature, (^{o}C)
SH15 Temperature
SH70 Temperature
SH15 Temperature, 1m
Year Day 2020
Salinity, (PSU)
SH15 Salinity
SH70 Salinity
Year Day 2020
Dissolved Oxygen, (ml/l)
Hypoxia
Severe Hypoxia
SH15 Oxygen
SH70 Oxygen
Year Day 2020

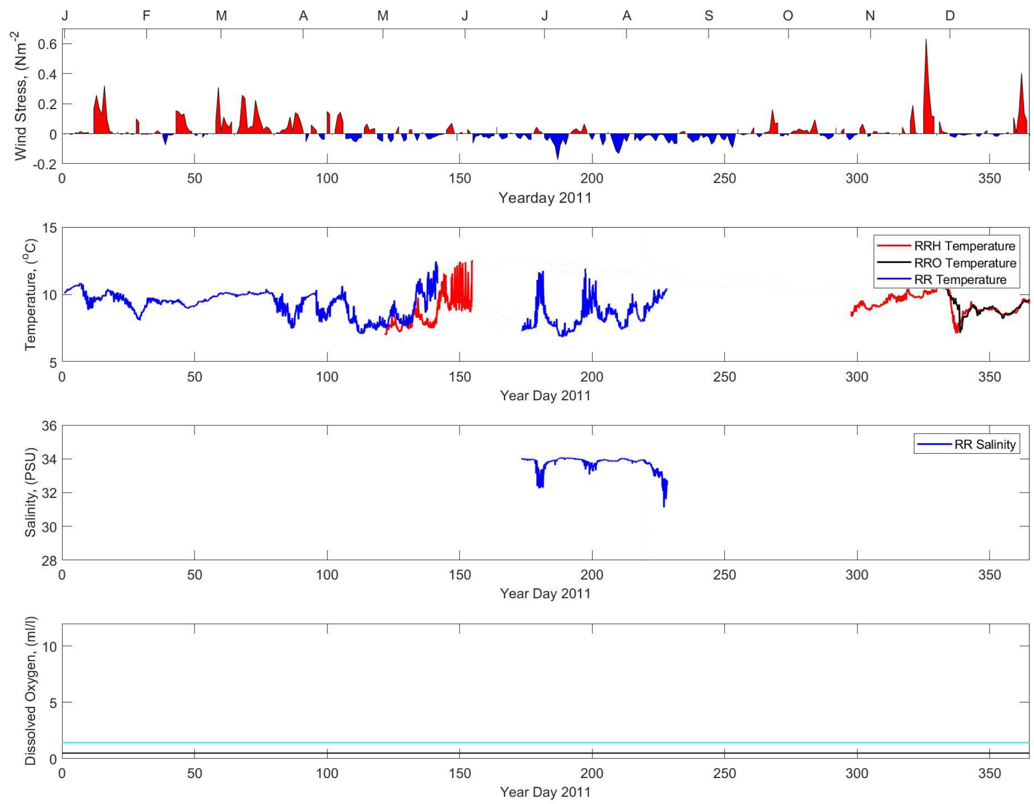
Redfish Rocks

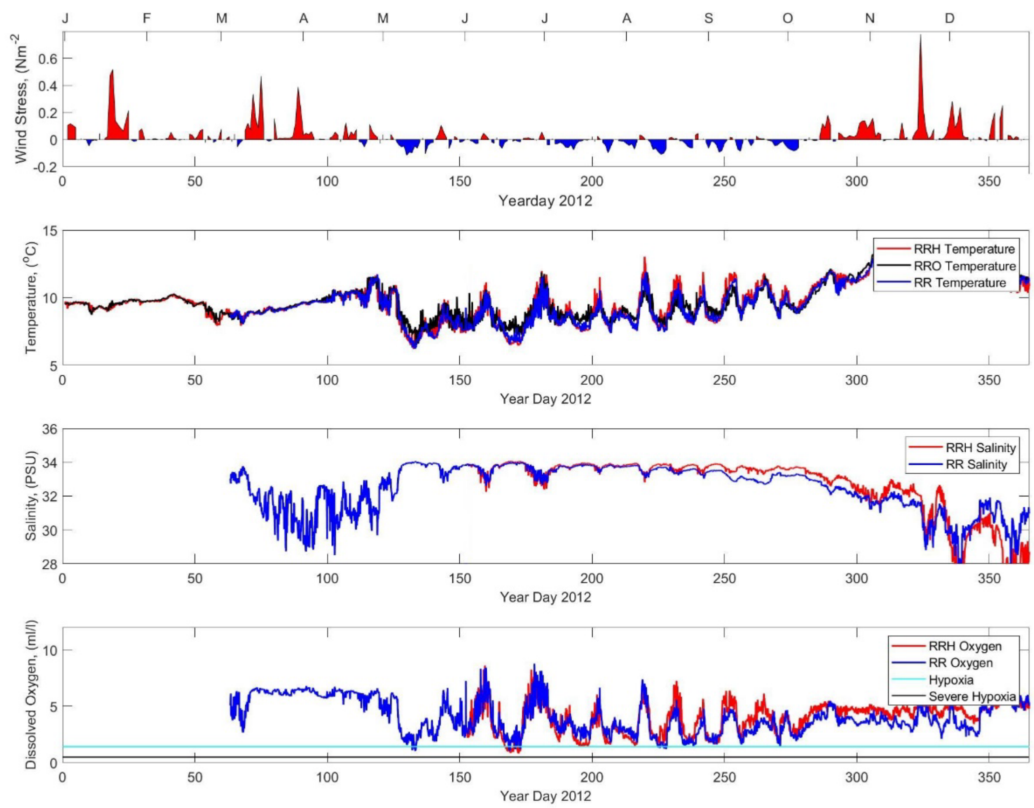
Temperature, salinity and dissolved oxygen were measured in the Redfish Rocks (RR) Marine Reserve and from two nearby comparison areas at Humbug (RRH; approximately 42.67N, 124.45W) and Orford Reef (RRO; approximately 42.78N, 124.60W). The temperatures at the three sites from the long-term deployments (> 1-2 days) are nearly indistinguishable, confirming that the thermal habitat in the marine reserve and comparison area are comparable.

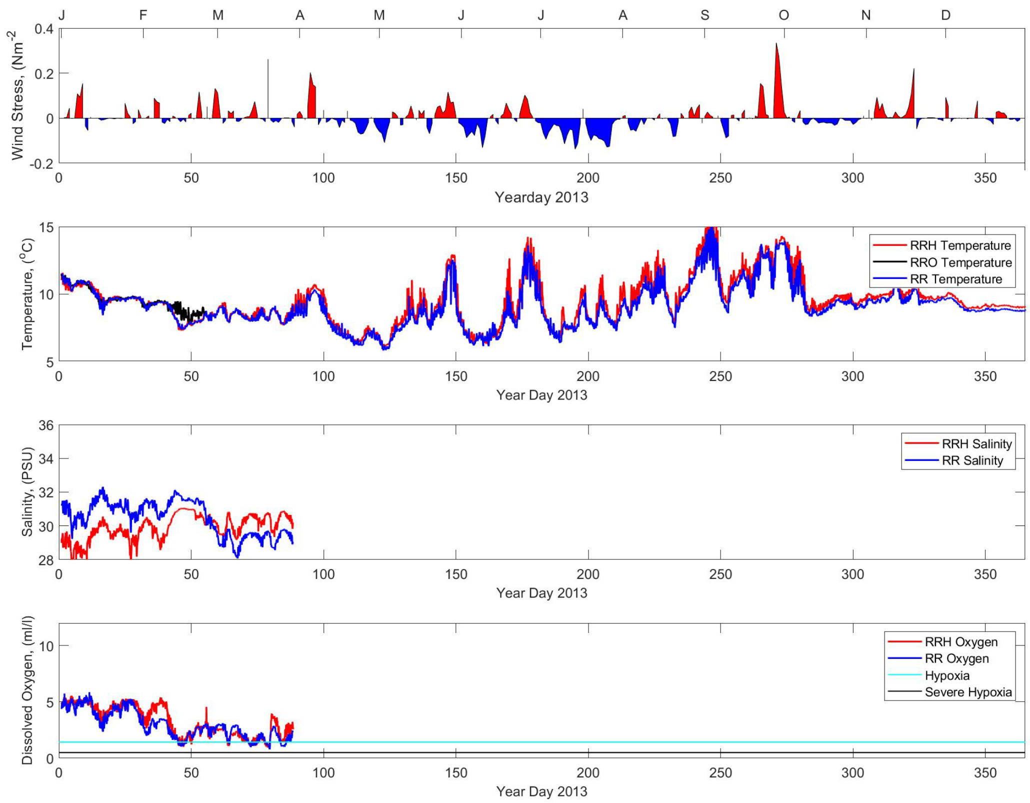
For 2019, data from short-term (1-2 days) instrumented crab pots (T and DO) deployed during the ODFW hook and line (HNL) sampling in the Redfish Rocks Marine Reserve (RR HNL) and Humbug Comparison Area (RRH HNL) were collected and included in the plot for that year. A stretched view of one deployment in August 2019 is also included. The instrumented crab pots (RR HNL and RRH HNL) were deployed in shallower water (~10-12 m) than the long-term RR and RRH platforms, hence the more tidal signal in the 1-2 day records.

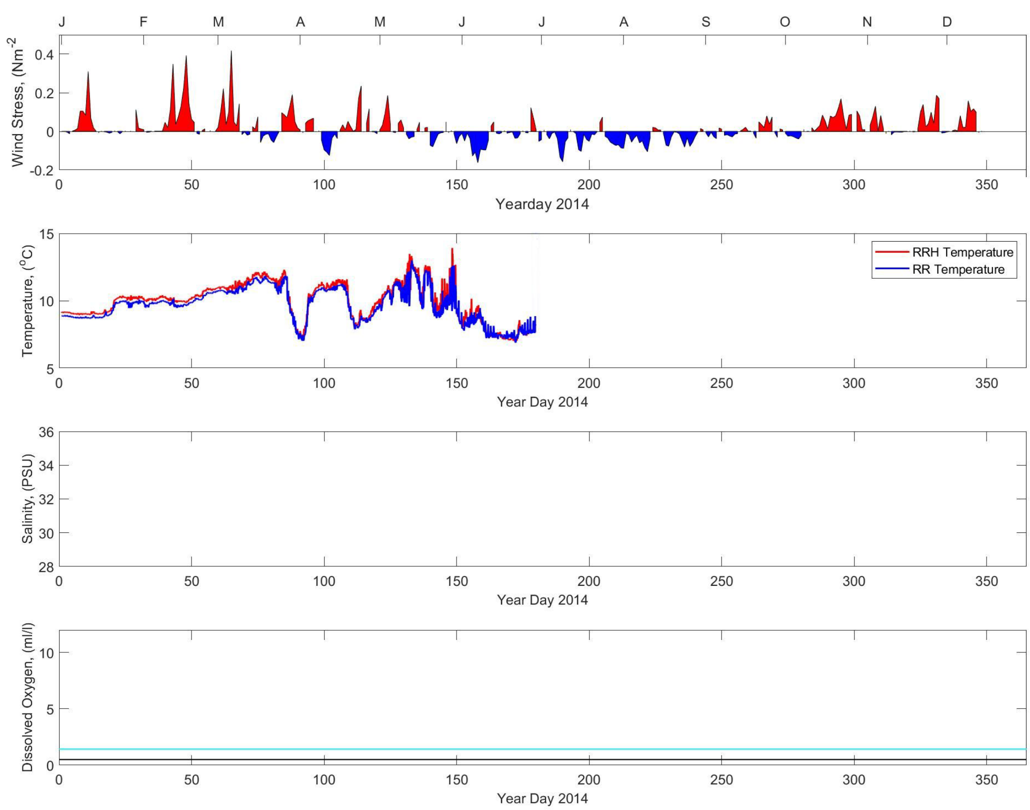
Redfish Rocks oceanographic mooring time series by year.

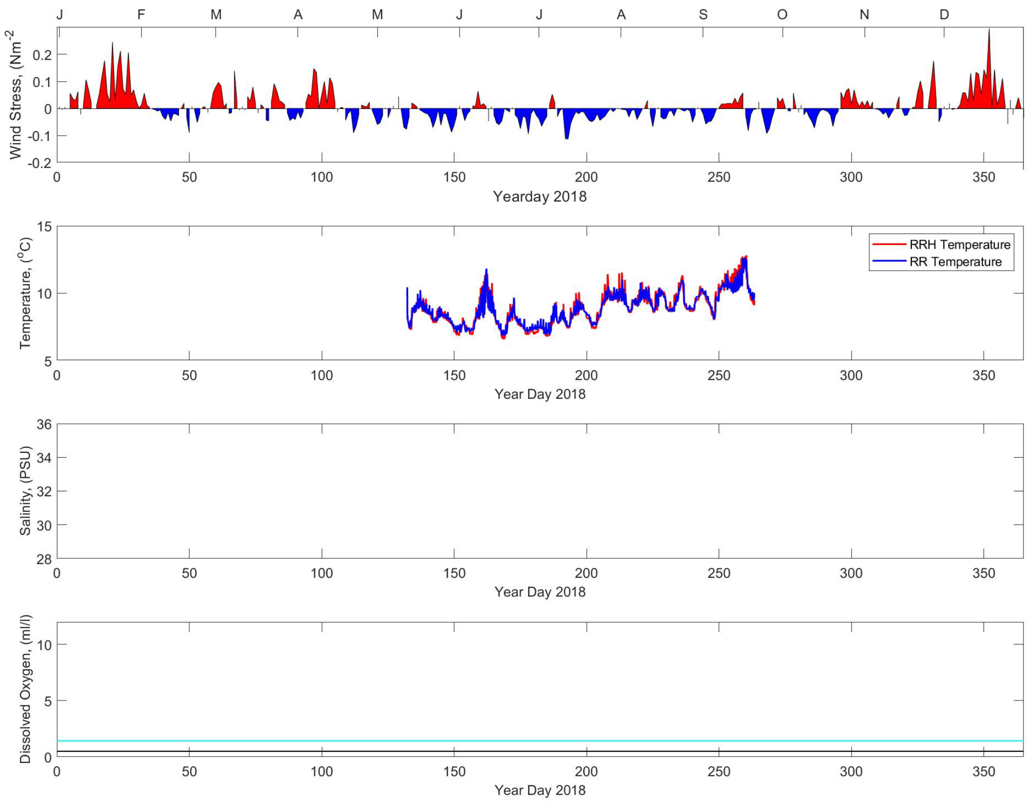


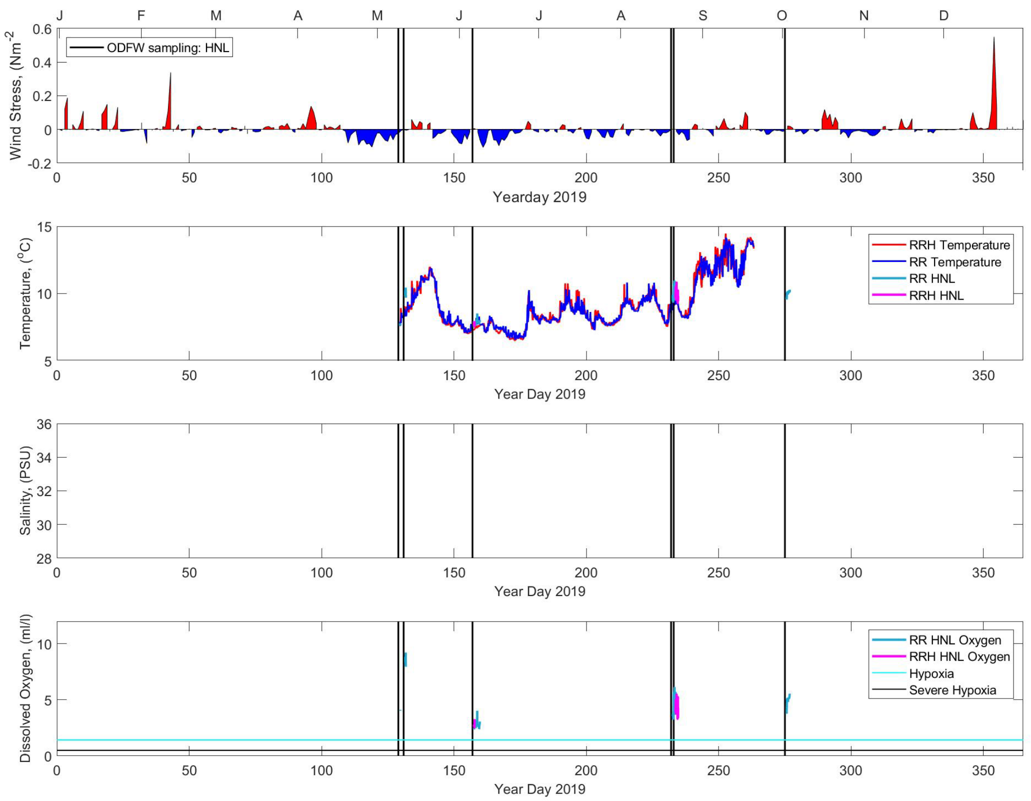

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2011
Temperature, (^{o}C)
RRH Temperature
RRO Temperature
RR Temperature
Year Day 2011
Salinity, (PSU)
RR Salinity
Year Day 2011
Dissolved Oxygen, (ml/l)
Year Day 2011

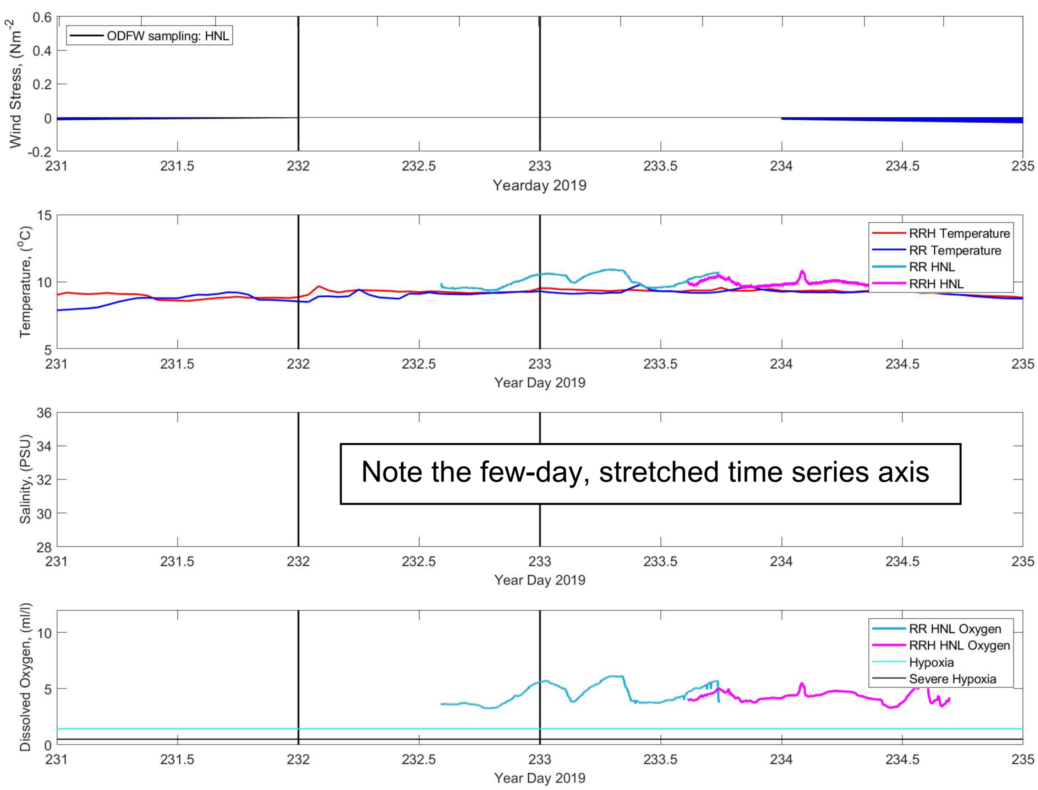

J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2012
Temperature, (^{o}C)
RRH Temperature
RRO Temperature
RR Temperature
Year Day 2012
Salinity, (PSU)
RRH Salinity
RR Salinity
Year Day 2012
Dissolved Oxygen, (ml/l)
RRH Oxygen
RR Oxygen
Hypoxia
Severe Hypoxia
Year Day 2012


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2013
Temperature, (^{o}C)
RRH Temperature
RRO Temperature
RR Temperature
Year Day 2013
Salinity, (PSU)
RRH Salinity
RR Salinity
Year Day 2013
Dissolved Oxygen, (ml/l)
RRH Oxygen
RR Oxygen
Hypoxia
Severe Hypoxia
Year Day 2013


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2014
Temperature, (^{o}C)
RRH Temperature
RR Temperature
Year Day 2014
Salinity, (PSU)
Year Day 2014
Dissolved Oxygen, (ml/l)
Year Day 2014


J F M A M J J A S O N D
Wind Stress, (Nm^{-2})
Yearday 2018
Temperature, (^{o}C)
RRH Temperature
RR Temperature
Year Day 2018
Salinity, (PSU)
Year Day 2018
Dissolved Oxygen, (ml/l)
Year Day 2018

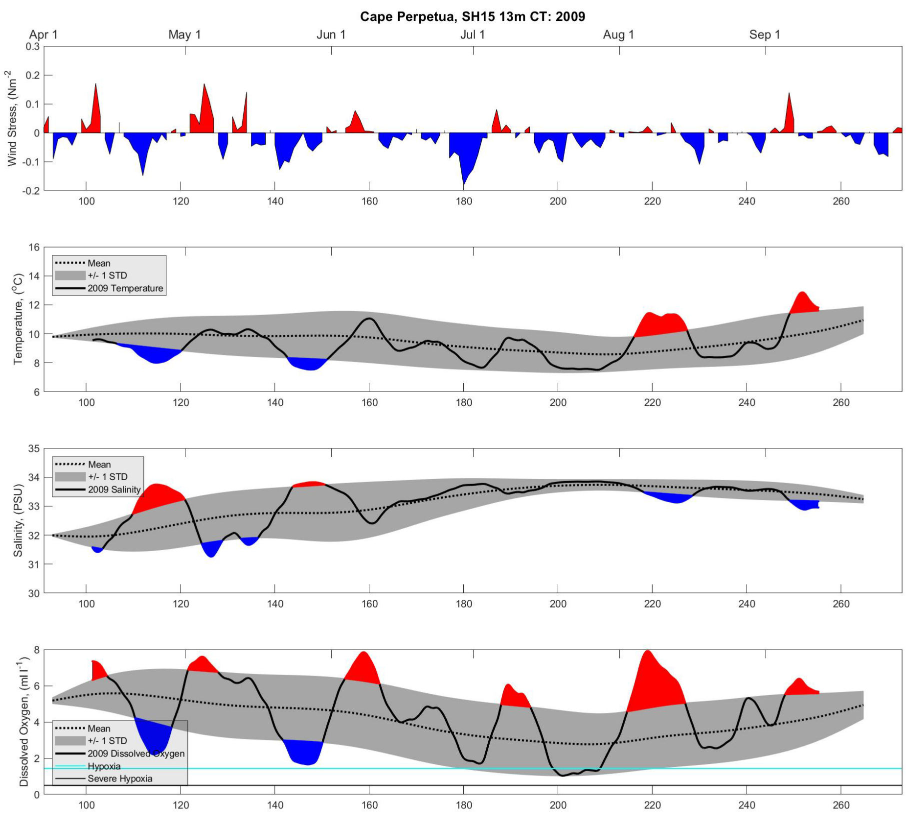

J F M A M J J A S O N D
ODFW sampling: HNL
Wind Stress, (Nm^{-2})
Yearday 2019
Temperature, (°C)
RRH Temperature
RR Temperature
RR HNL
RRH HNL
Year Day 2019
Salinity, (PSU)
Year Day 2019
Dissolved Oxygen, (ml/l)
RR HNL Oxygen
RRH HNL Oxygen
Hypoxia
Severe Hypoxia
Year Day 2019

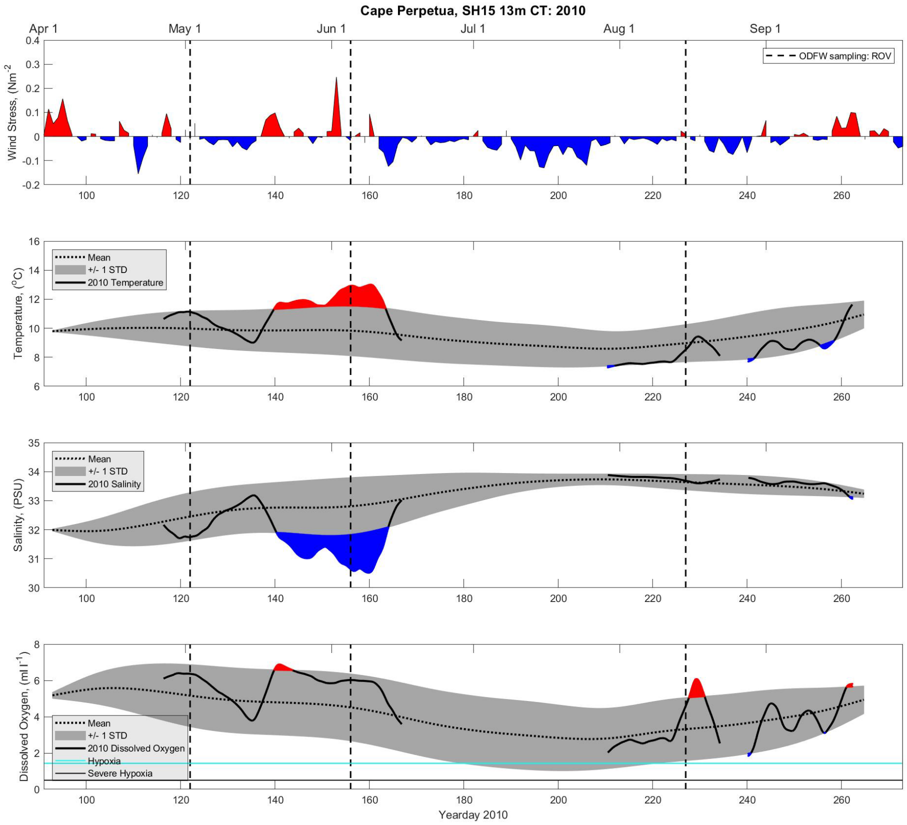

ODFW sampling: HNL
Wind Stress, (Nm^{-2})
Yearday 2019
Temperature, (°C)
RRH Temperature
RR Temperature
RR HNL
RRH HNL
Year Day 2019
Salinity, (PSU)
Note the few-day, stretched time series axis
Year Day 2019
Dissolved Oxygen, (ml/l)
RR HNL Oxygen
RRH HNL Oxygen
Hypoxia
Severe Hypoxia
Year Day 2019

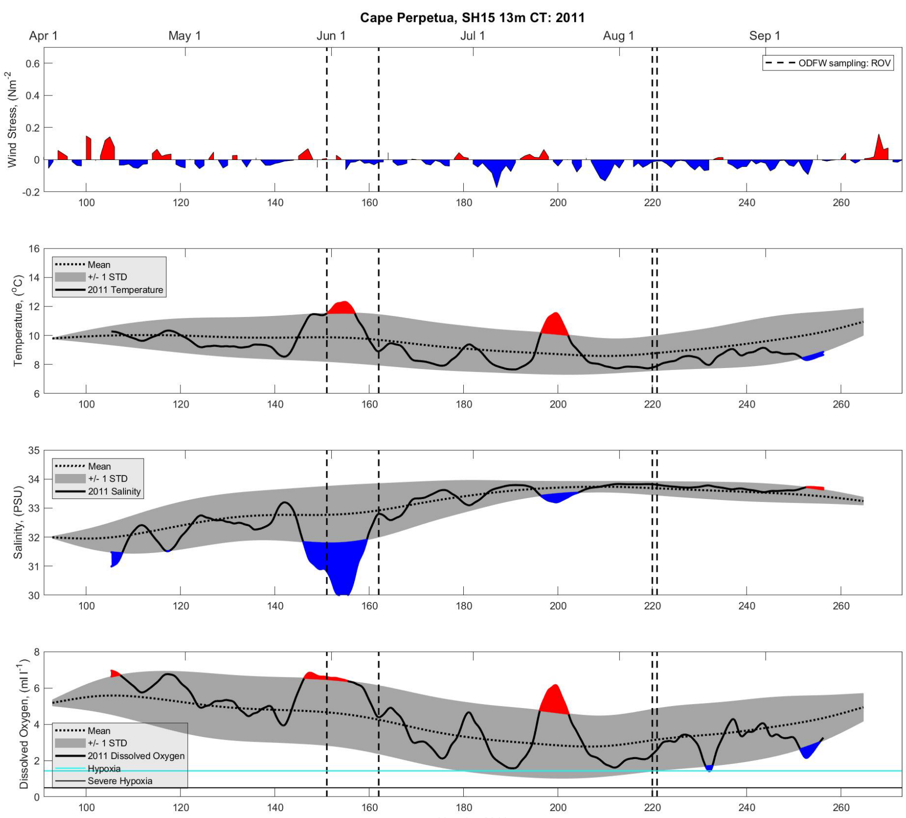
Cape Perpetua Anomaly Time Series

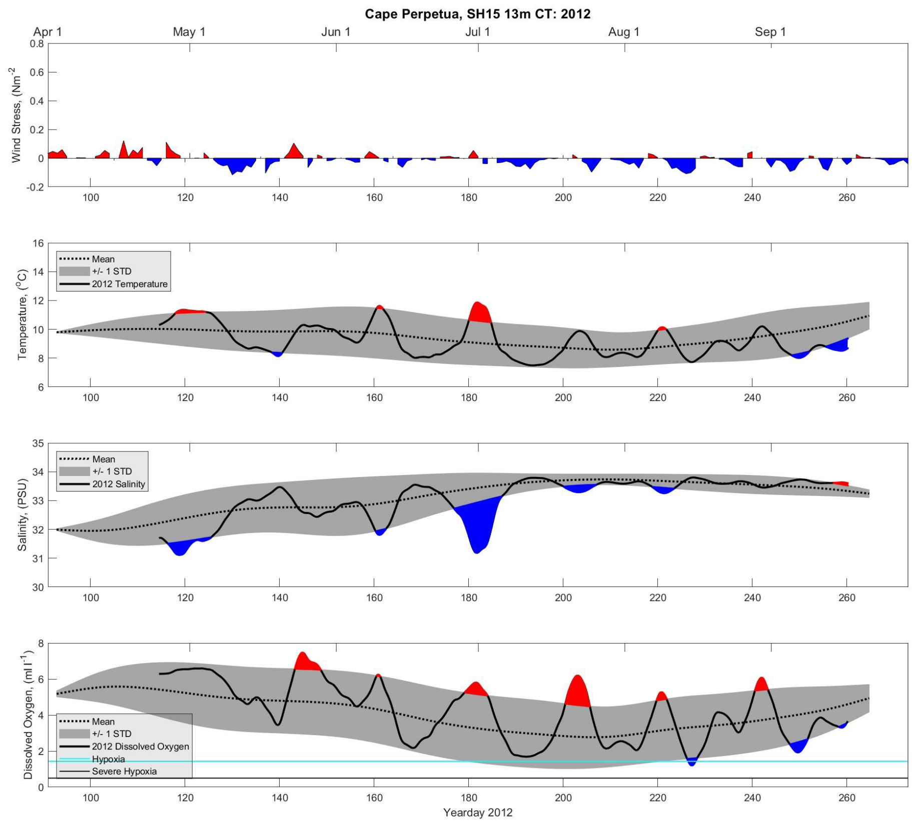
Since PISCO has been making long-term measurements at Cape Perpetua, a mean seasonal cycle can be calculated using data from 2003 to 2020. Since intraseasonal (20-40 day) oscillations are strong on the Oregon coast and occur with random phase (Bane et al. 2005), even this 18-year time series is not sufficient to create a smooth seasonal cycle by just averaging observations at each day. The mean seasonal cycle is found by fitting stiff splines to the 18-year time series. The smooth seasonal cycle is presented along with gray shading to indicate +/- one standard deviation (STD) about the mean. Time series of anomalies of oceanographic parameters from the smoothed, mean seasonal cycle are presented, and are shaded red when anomalies exceed the mean plus one STD and blue when anomalies are less than the mean minus one STD.

Cape Perpetua oceanographic mooring anomaly time series by year.

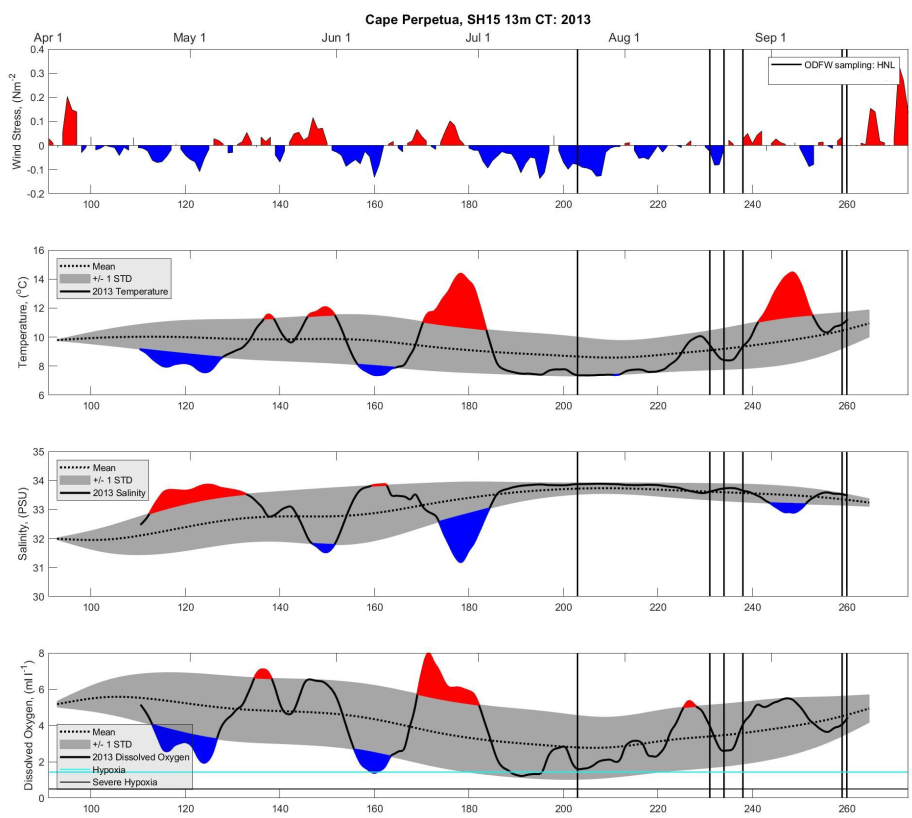



Cape Perpetua, SH15 13m CT: 2010
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Wind Stress, (Nm^{-2}
ODFW sampling: ROV
Temperature, (°C)
Mean
+/- 1 STD
2010 Temperature
Salinity, (PSU)
2010 Salinity
Dissolved Oxygen, (ml l^{-1})
2010 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2010

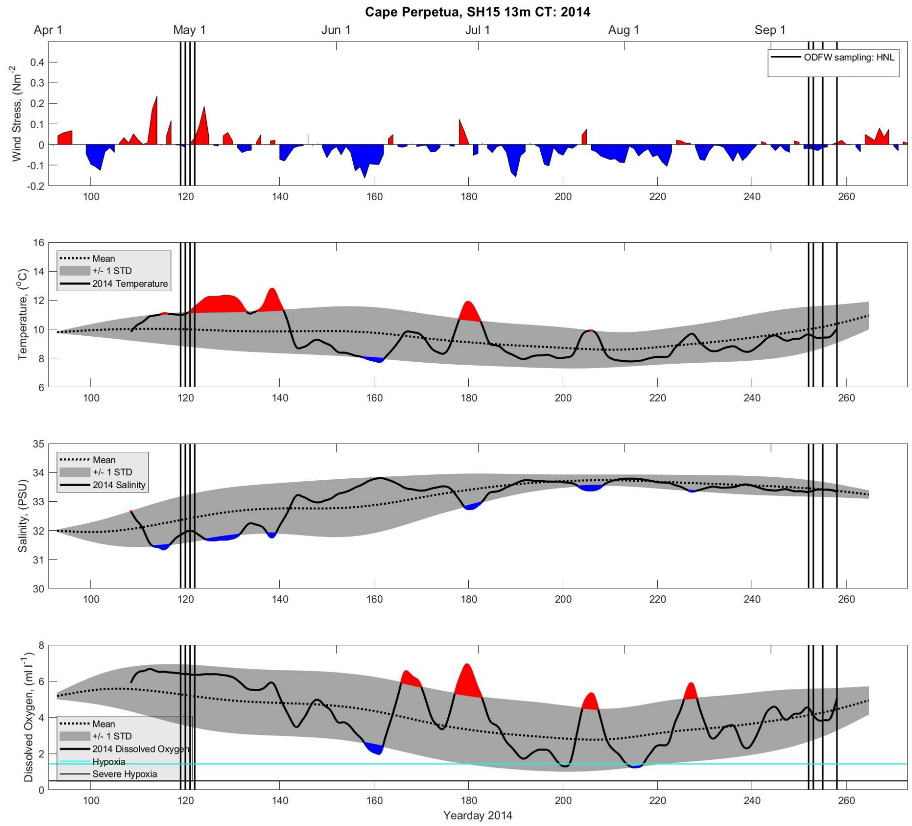

Cape Perpetua, SH15 13m CT: 2011
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Wind Stress, (Nm^{-2}
ODFW sampling: ROV
Temperature, (°C)
Mean
+/- 1 STD
2011 Temperature
Salinity, (PSU)
2011 Salinity
Dissolved Oxygen, (ml l^{-1})
2011 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2011

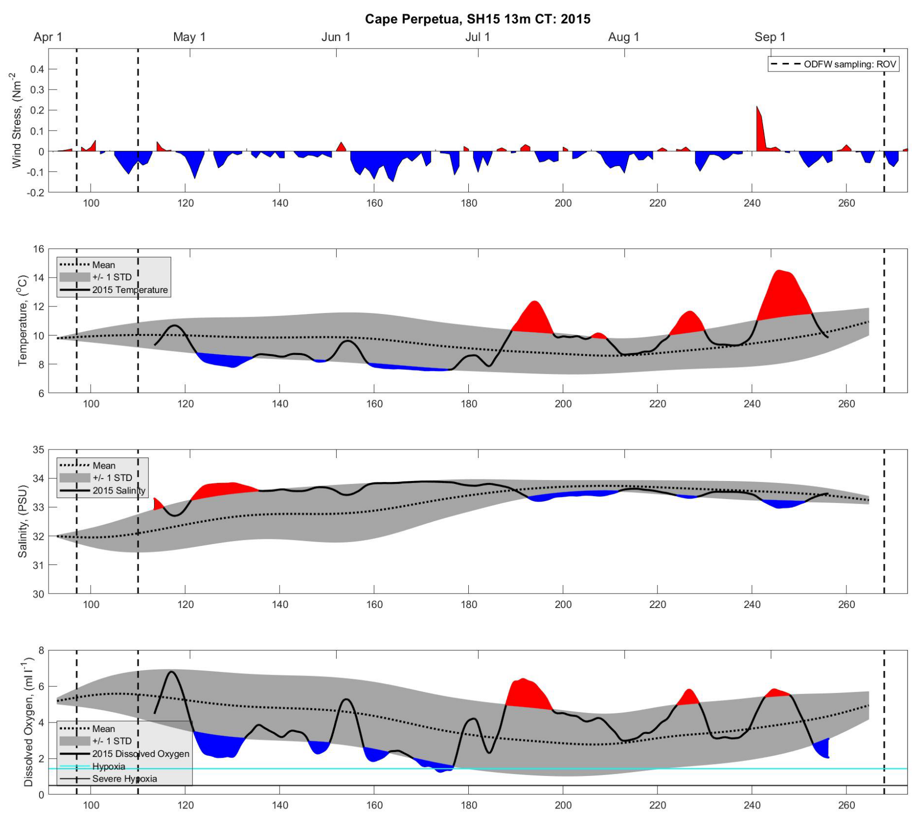


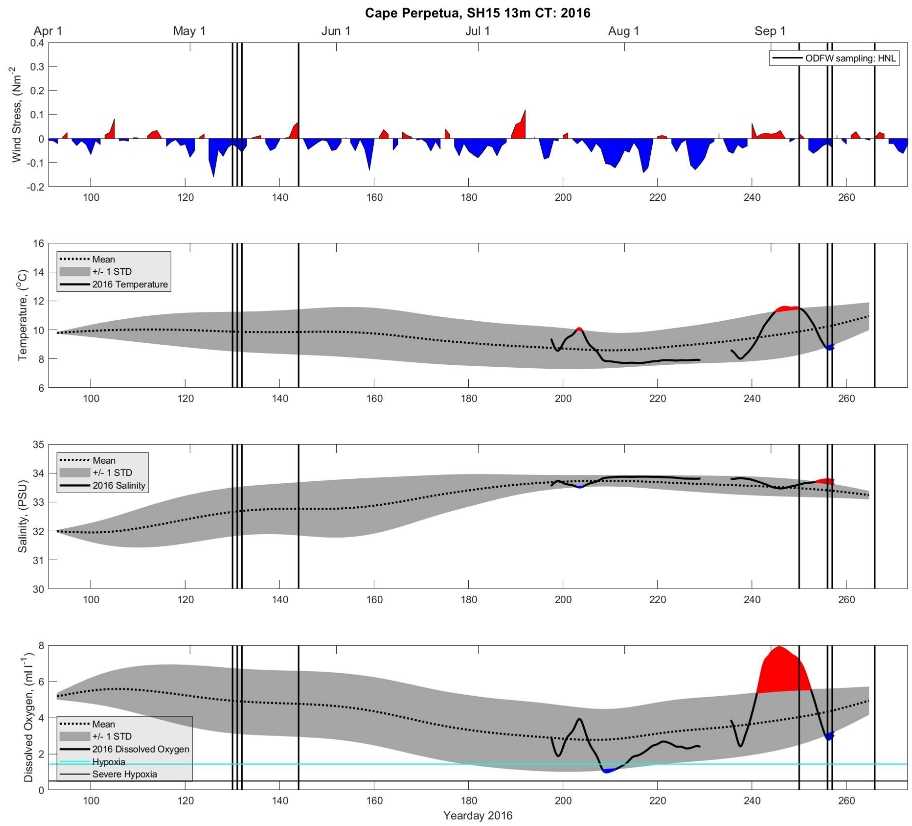
Cape Perpetua, SH15 13m CT: 2012
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Wind Stress, (Nm-2
Temperature, (°C)
Mean
+/- 1 STD
2012 Temperature
Salinity, (PSU)
2012 Salinity
Dissolved Oxygen, (ml l-1)
2012 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2012

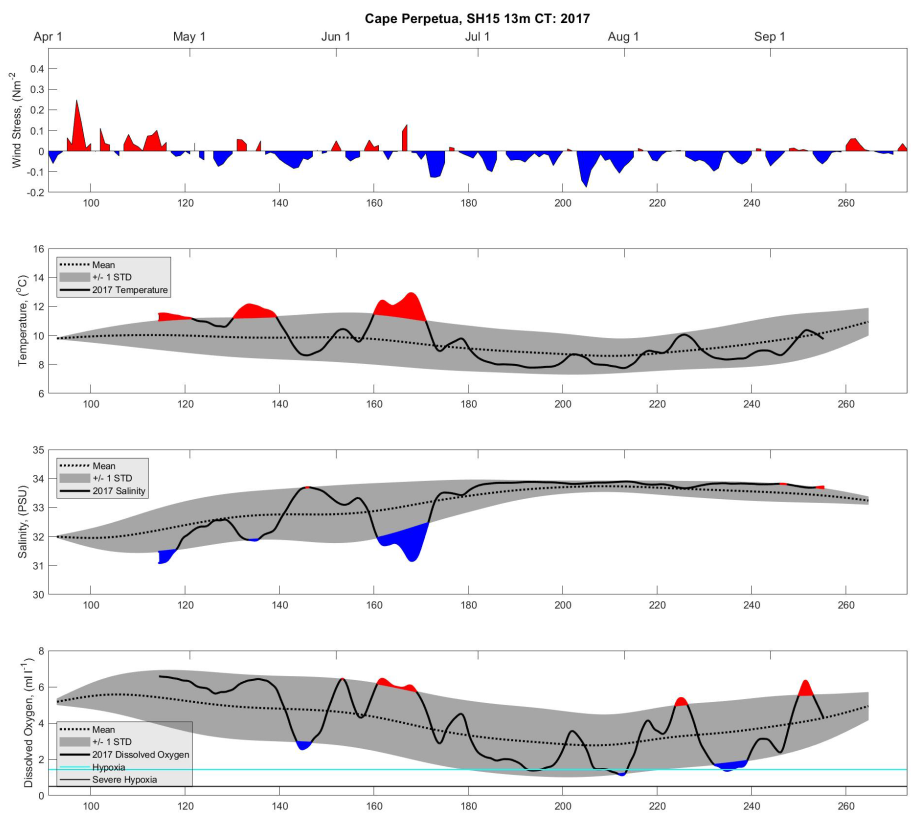


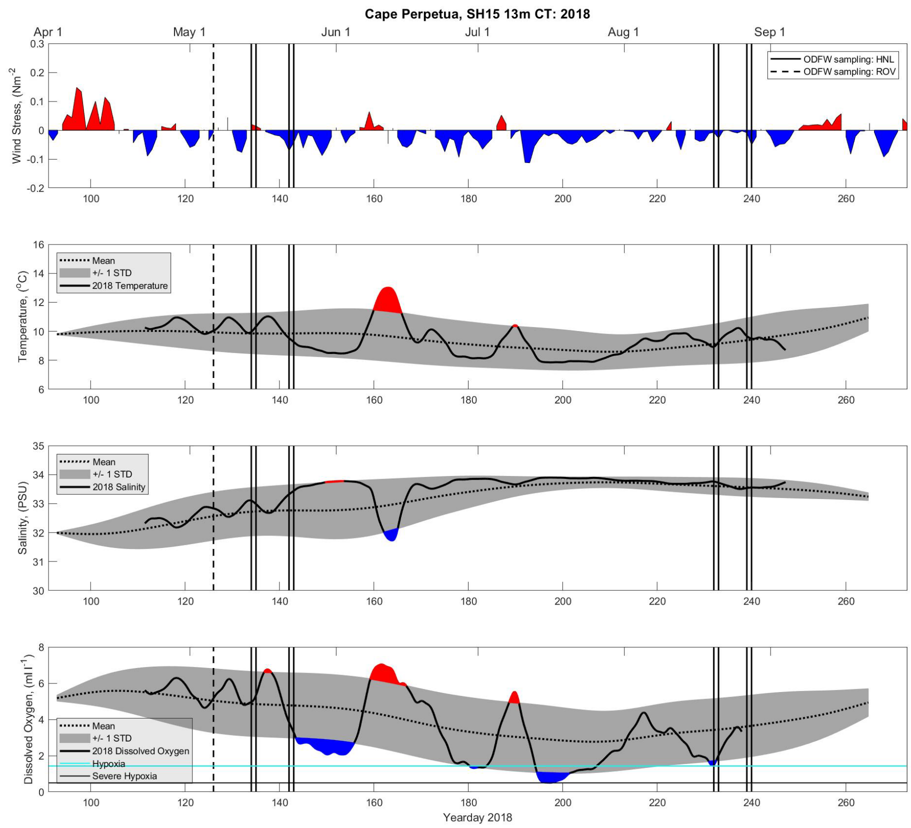
Cape Perpetua, SH15 13m CT: 2013
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
ODFW sampling: HNL
Wind Stress, (Nm-2
Temperature, (°C)
Mean
+/- 1 STD
2013 Temperature
Salinity, (PSU)
2013 Salinity
Dissolved Oxygen, (ml l-1)
2013 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2013

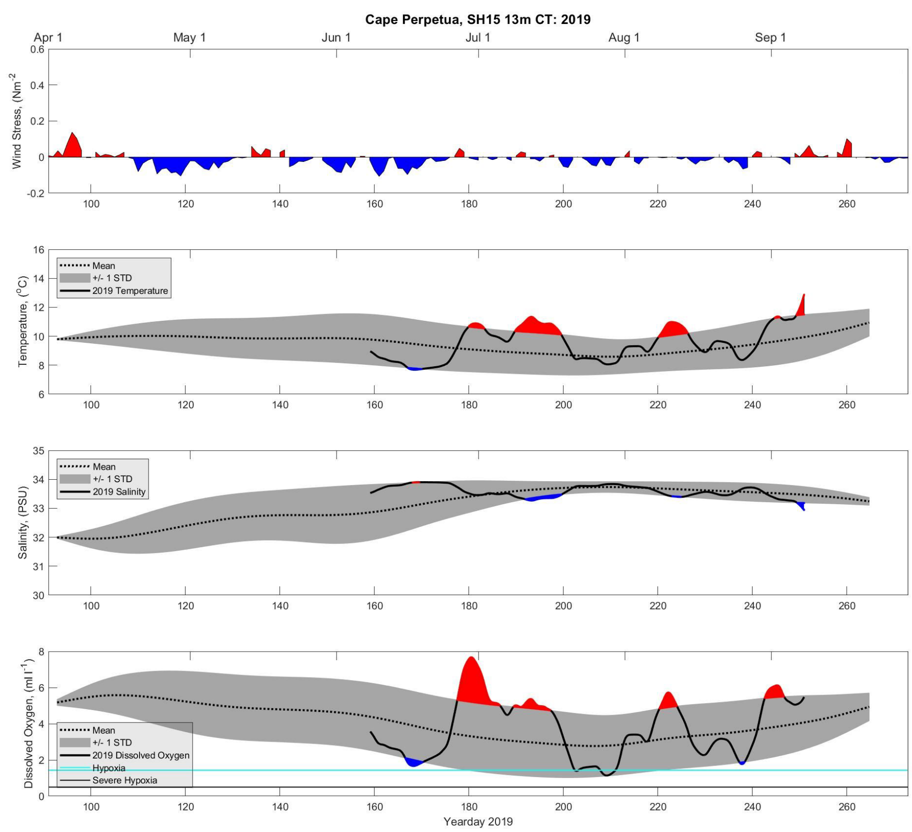

Cape Perpetua, SH15 13m CT: 2014
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
ODFW sampling: HNL
Wind Stress, (Nm-2
Temperature, (°C)
Salinity, (PSU)
Dissolved Oxygen, (ml l-1)
Mean
+/- 1 STD
2014 Temperature
2014 Salinity
2014 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2014

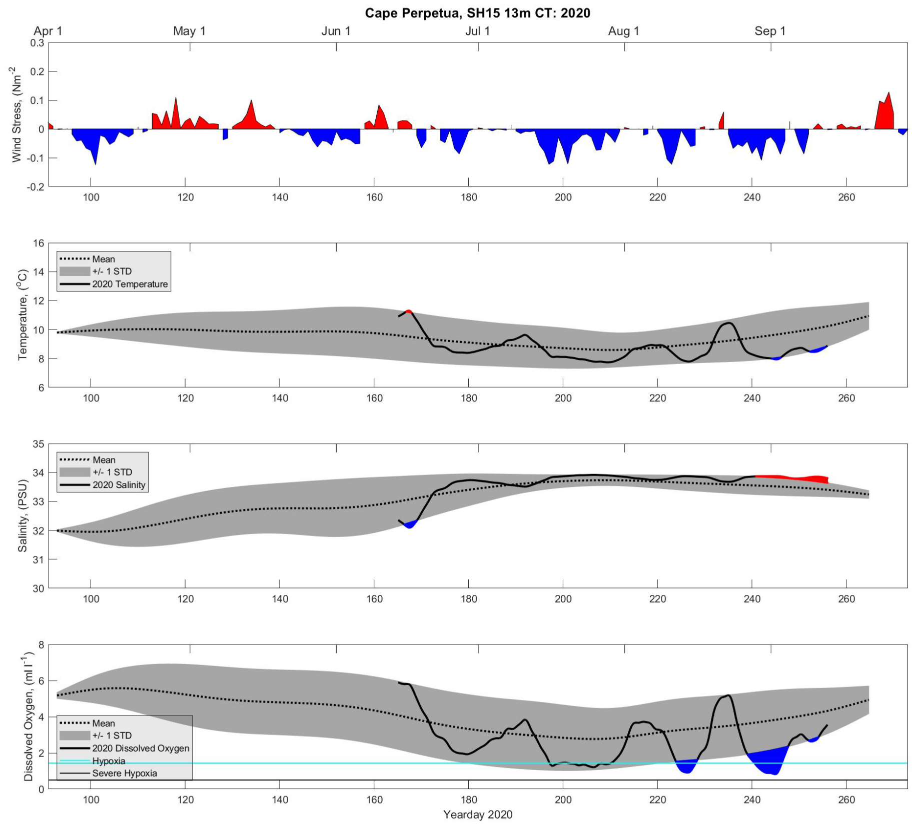

Cape Perpetua, SH15 13m CT: 2015
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
ODFW sampling: ROV
Wind Stress, (Nm-2
Temperature, (°C)
Salinity, (PSU)
Dissolved Oxygen, (ml l-1)
Mean
+/- 1 STD
2015 Temperature
2015 Salinity
2015 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2015


Cape Perpetua, SH15 13m CT: 2016
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
ODFW sampling: HNL
Wind Stress, (Nm^{-2})
Temperature, (°C)
Mean
+/- 1 STD
2016 Temperature
Salinity, (PSU)
2016 Salinity
Dissolved Oxygen, (ml l^{-1})
2016 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2016


Cape Perpetua, SH15 13m CT: 2017
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Wind Stress, (Nm^{-2})
Temperature, (°C)
Mean
+/- 1 STD
2017 Temperature
Salinity, (PSU)
2017 Salinity
Dissolved Oxygen, (ml l^{-1})
2017 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Yearday 2017


Cape Perpetua, SH15 13m CT: 2018
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Wind Stress, (Nm^{-2}
ODFW sampling: HNL
ODFW sampling: ROV
Mean
+/- 1 STD
2018 Temperature
Temperature, (°C)
2018 Salinity
Salinity, (PSU)
2018 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Dissolved Oxygen, (ml l^{-1})
Yearday 2018


Cape Perpetua, SH15 13m CT: 2019
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Wind Stress, (Nm^{-2}
Mean
+/- 1 STD
2019 Temperature
Temperature, (°C)
2019 Salinity
Salinity, (PSU)
2019 Dissolved Oxygen
Hypoxia
Severe Hypoxia
Dissolved Oxygen, (ml l^{-1})
Yearday 2019



References

Bane, J. M., M. D. Levine, R. M. Samelson, S. M. Haines, M. F. Meaux, N. Perlin, P. M. Kosro, and T. Boyd (2005), Atmospheric forcing of the Oregon coastal ocean during the 2001 upwelling season, J. Geophys. Res., 110, C10S02, https://doi.org/10.1029/2004JC002653 .