A high-resolution synthesis dataset for multistressor analyses along the U.S. West Coast

Esther G. Kennedy[1, 2], Meghan Zulian[1, 2], Sara L. Hamilton[2, 3], Tessa M. Hill[1, 2], Manuel Delgado[2], Carina R. Fish[1, 2], Brian Gaylord[2, 4], Kristy J. Kroeker[5], Hannah M. Palmer[1, 2], Aurora M. Ricart[6, 7], Eric Sanford[2, 4], Ana K. Spalding[8, 9], Melissa Ward[10], Guadalupe Carrasco[11], Meredith Elliott[12], Genece V. Grisby[1], Evan Harris[1], Jaime Jahncke[12], Catherine N. Rocheleau[1], Sebastian Westerink[13], Maddie I. Wilmot[1]

[1]Department of Earth and Planetary Sciences, University of California Davis, Davis, CA, USA
[2]Bodega Marine Laboratory, University of California Davis, Bodega Bay, CA, USA
[3]Oregon Kelp Alliance, Port Orford, OR, USA
[4]Department of Evolution and Ecology, University of California Davis, Davis, CA, USA
[5]Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA, USA
[6]Institut de Ciències del Mar, ICM-CSIC, Barcelona, Spain
[7]Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA
[8]Oregon State University, Corvallis, OR, USA
[9]Smithsonian Tropical Research Institute, Panama City, Panama
[10]Coastal and Marine Institute, San Diego State University, San Diego, CA, USA
[11]Department of Biology, Sonoma State University, Rohnert Park, CA, USA
[12]Point Blue Conservation Science, Petaluma, CA, USA
[13]Department of Land, Air and Water Resources, University of California Davis, Davis, CA, USA

Correspondence to: Esther G. Kennedy (egkennedy@ucdavis.edu)

Abstract. The global trends of ocean warming, deoxygenation, and acidification are not easily extrapolated to coastal environments. Local factors, including intricate hydrodynamics, high primary productivity, freshwater inputs, and pollution, can exacerbate or attenuate global trends and produce complex mosaics of physiologically stressful or favorable conditions for organisms. In the California Current System (CCS), coastal oceanographic monitoring programs document some of this complexity; however, data fragmentation and limited data availability constrain our understanding of when and where intersecting stressful temperatures, carbonate system conditions, and reduced oxygen availability ~~coastal conditions~~ manifest. Here, we undertake a large data synthesis to compile, format, and quality-control publicly available oceanographic data from the U.S. West Coast to create an accessible database for coastal CCS climate risk mapping, available at the National Centers for Environmental Information (Accession 0277984) under the DOI 10.25921/2vve-fh39 ~~10.25921/2vve-fh39~~ (Kennedy et al., 2023). With this synthesis, we combine publicly available observations and data contributed by the author team from synoptic oceanographic cruises, autonomous sensors, and shore samples with relevance to coastal ocean acidification and hypoxia (OAH) risk. This large-scale compilation includes 13.7 million observations from 6~~67~~ sources and spans from 1949 to 2020. Here, we discuss the quality and composition of the synthesized dataset, the spatial and temporal distribution of available data, and examples of potential analyses. This dataset will provide a valuable tool for scientists supporting policy- and management-relevant investigations including assessing regional and local climate risk, evaluating

the efficacy and completeness of CCS monitoring efforts, and elucidating ~~investigating~~ spatiotemporal scales of coastal oceanographic variability.

1 Introduction

Anthropogenic carbon dioxide (CO_2) emissions are causing dramatic ocean warming, acidification, and deoxygenation (Caldei~~ie~~ra and Wickett, 2003; Doney et al., 2009; Doney 2010; Levitus et al., 2012). Interactions among these stressors can compound the severity of each, often synergistically reducing growth, metabolism, and survival of marine organisms across diverse taxa (e.g., Byrne and Przeslawski, 2013; Gobler and Baumann, 2016). Multiparameter extreme events are increasingly common and destructive (Burger et al., 2013; Breitburg et al., 2015). However, global ocean trends may be masked, modified, or overshadowed in coastal ecosystems by combinations of complex local oceanographic processes, terrestrial runoff~~effluent from coastal settlements and agriculture~~, freshwater sources, and high local productivity ~~diverse and highly productive ecological communities~~ (Borges and Gypens, 2010; Cai et al., 2011; Fassbender et al., 2011; Frieder et al., 2012;~~Doney 2010;~~ Bauer et al., 2013~~; ~~; Takeshita et al., 2015~~Duarte et al., 2013); Woodson et al., 2019)~~. Despite thorough documentation of global ocean responses to anthropogenic forcing, understanding more localized conditions in coastal environments, such as the California Current System (CCS), remains an active area of research. Improved understanding of spatiotemporal patterns of warming, deoxygenation, and acidification is key to informing climate resilience and adaptation planning for and by the diverse peoples and ecological communities that depend on the coastal CCS (Field and Francis, 2006; Hodgson et al., 2018; IPCC 2019; Weisberg et al., 2020; Ward et al., 2022).

The CCS is an upwelling ~~eco~~system where seasonal winds transport cold, low-oxygen, high-CO_2 waters from depth up to nearshore surface environments (e.g,. Hickey, 1979; Huyer, 1983; Chavez and Messié, 2009). Upwelling intensity varies across small spatial and temporal scales and is typically concentrated in the spring and early summer (Hickey, 1979; Marchesiello et al., 2003; Garciá-Reyes and Largier, 2012; Jacox et al., 2018; Cheresh and Fiechter, 2020). During upwelling, extreme~~minimal~~ values of seasonal dissolved oxygen (DO) and carbonate chemistry parameters such as pH are naturally close to biologically significant thresholds, making organisms in the CCS particularly vulnerable to ocean acidification and hypoxia (OAH) events (e.g., Chan et al., 2008; Connolly et al., 2010; Feely et al., 2008; Gruber et al., 2012; Low et al., 2021; Kekuewa et al., 2022). Local adaptation to high environmental variability may provide some ecological resilience (e.g., Sanford and Kelly, 2011; Kelly and Hofmann., 2013; Donham et al., 2023), but widespread die-offs are already a feature of some OAH events (e.g., Grantham et al., 2004; Barton et al., 2015). The CCS is also vulnerable to warming and heatwaves (Cavole et al., 2016; Frölicher and Laufkötter, 2018; Rogers-Bennett and Catton, 2019; Sanford et al., 2019; Fumo et al., 2020; Cheung and Frölicher, 2020; Free et al., 2023). When extreme temperatures interact with low pH and low oxygen conditions, they can compound the vulnerability of organisms to environmental stressors (e.g., Kroeker et al., 2013; Swiney et al., 2017; Bednaršek et al., 2019; Howard et al., 2020b; Sunday et al., 2021). The balance between local upwelling intensity, warming-induced stratification, and both oceanic and terrestrial influences creates a spatiotemporal mosaic of coastal ocean conditions which, while previously acknowledged and documented (e.g., Feely et al., 2016a, Chan et al., 2017; Cheresh and Fiechter, 2020), remains incompletely described.

As a result of the connections between upwelling, low oxygen, and acidification events, models predict the CCS's vulnerability to extreme events will increase as climate change progresses (Gruber et al., 2012; Bakun et al., 2015). Relative to a preindustrial baseline, anthropogenic forcing has shallowed the depths of perenniallyoaled corrosive and hypoxic conditions by more than 50 m (Bograd et al., 2008; Feely et al., 2008; Chan et al., 2008; Gruber et al., 2012). Modeled projections of the CCS suggest that pH levels are declining sufficiently swiftly that by 2035, the range of annual variability may no longer overlap with conditions present in the 2010s, while the calcium carbonate mineral aragonite could be perennially undersaturated at 100 m depth by 2045 (Hauri et al., 2013; Marshall et al., 2017). Meanwhile, nearshore DO dissolved oxygen contentconcent isrations are expected to decline by 10-20 µmol kg^{-1} by the end of the century (Siedlecki et al., 2021). Upwelling-favorable winds may intensify under future warming (Sydeman et al., 2014; Bakun et al., 2015; Wang et al., 2015); although this effect may be counteracted in some locations by increased stratification of seawater layers (Howard et al., 2020a; Siedlecki et al., 2021) or in areas where wind-driven upwelling is not the dominant process (Garciá-Reyes and Largier, 2010). These competing forces might enhance the disparities between climate hot spots and refugia, underlining the importance of gathering and analyzing climate data with high spatiotemporal resolution.

Despite recognition of the complexity of CCS coastal climate stress, successfully capturing mesoscale, sub-seasonal, and very nearshore patterns of OAH and warming remains challenging. One impediment to unraveling this complexity is the decentralized and non-standardized nature of much OAH monitoring in the CCS, undertaken by governmental, non-profit, and academic centers with varying methodologies and approaches to data accessibility (Taylor-Burns et al., 2020). Further, existing synthesis datasets are not optimized for simultaneous analysis of nearshore warming, deoxygenation, and acidification risks (e.g., Hofmann et al., 2011; Sharp et al., 2022). For chemical oceanographers and modelers, the Surface Ocean CO_2 Atlas (SOCAT, Sabine et al., 2013; Bakker et al., 2016) and Coastal Ocean Data Analysis Product in North America (CODAP-NA, Jiang et al., 2021) are also valuable resources. However, the former includes only surface seawater observations of one principle parameter of the carbonate system, while the latter includes only discrete bottle observations from oceanographic cruises while excluding autonomous sensors observations and shore samples. SOCAT and CODAP-NA are high-quality and extremely well-curated, but the cost of their selectivity is that many available CCS OAH observations are not available through those compilations. In addition, there are a suite of nearshore ocean acidification, hypoxia, and temperature focused data collection efforts that use a variety of sensors and sampling techniques and have not yet been standardized or integrated. While several excellent databases compile place-specific biogeochemical data, such as CeNCOOS and SCCOOS (Terrill et al., 2006; Ruhl et al., 2021), they often are limited regionally, provide access to only a

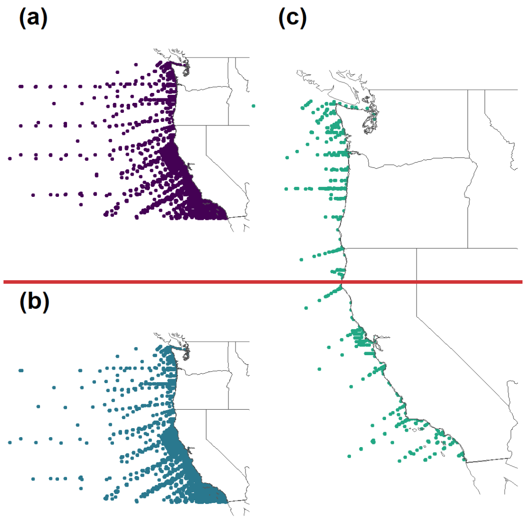
~~single parameter at a time, lack key datasets, or do not require standard data formats or quality assurance/quality control (QA/QC) methods (Weisberg et al., 2020).~~

A deliberate synthesis of OAH-relevant datasets ~~-~~with standardized formatting and quality control maximizes our ability to explore, map, and resolve coastal climate stress on sub-regional scales (Bushinsky et al., 2019; Chan et al., 2019). By including both discrete and autonomous sensor observations across depths and targeting all carbonate system and OAH-relevant parameters, this synthesis can complement the strengths of tightly focused compilations such as SOCAT (Bakker et al., 2016) and CODAP-NA (Jiang et al., 2021). Additionally, by applying uniform QC standards and formatting to data across the CCS, this compilation builds on the usability, reliability, and spatiotemporal scale of currently available public nearshore compilations (e.g., Ruhl et al., 2021).

Here, we present the Multistressor Observations of Coastal Hypoxia and Acidification (MOCHA) synthesis, the highest resolution OAH-relevant U.S. West Coast dataset to date. MOCHA is a compilation of ~~of~~ published nearshore temperature, dissolved oxygen, and carbonate chemistry-relevant datasets for the CCS and is newly ~~available~~ archived and available at the National Centers for Environmental Information (NCEI, https://doi.org/10.25921/2vve-fh39; Kennedy et al., 2023) along with associated metadata and quality assurance in adherence with the FAIR principles (Wilkinson et al., 2016~~; Kennedy et al., 2023~~). We source published data from within U.S. waters from oceanographic cruises, buoys, moorings, and shore samples as well as previously unpublished observations contributed by the author team, and present them in a formatted, quality-controlled, downloadable database for easy access and analysis by scientific teams across disciplines (Fig. 1). This data compilation includes 13.7 million observations from 66 data sources and spans from 1949-2020. To illustrate some of the synthesis product's potential uses, we further include and discuss several "case examples" focusing on very nearshore, shallow data, as these showcase the largest portion of the MOCHA dataset and its complementary strengths to SOCAT and CODAP-NA. However, we note that the compilation includes records at depth and those extending hundreds of kilometers offshore. It is our hope that this synthesis product supports scientific investigations at a wide range of spatial and temporal scales and allows investigators to link between shallow and nearshore or coastal and oceanic environments. While this dataset is not exhaustive, it ~~both~~ highlights real disparities in oceanographic monitoring intensity and provides future investigators the opportunity to compare and integrate their own datasets. We anticipate that this synthesis product will be broadly useful to OAH-focused investigative teams and particularly impactful for coastal scientists investigating policy- and management-relevant projects, such as investigating spatiotemporal variation in marine climate risk from OAH events and warming, evaluating the efficacy and completeness of CCS monitoring efforts, linking oceanographic conditions to coastal social or socio-economic considerations across large geographic ranges (e.g., Ward et al., 2022), evaluating spatial management zones such as aquaculture sites (Clements and Chopin, 2016) and marine protected areas (e.g., Hamilton et al., 2003), and pursuing other questions of interest to coastal communities ~~This synthesis provides an important tool for scientists across disciplines and coastal decision-makers to investigate spatiotemporal variation in marine climate risk from~~

Formatted: Default Paragraph Font

~~OAH events and warming, evaluate the efficacy and completeness of CCS monitoring efforts, link oceanographic conditions to coastal social or socio-economic considerations across large geographic ranges, evaluate spatial management zones such as aquaculture sites and Marine Protected Areas, and pursue other questions of interest to coastal communities~~.



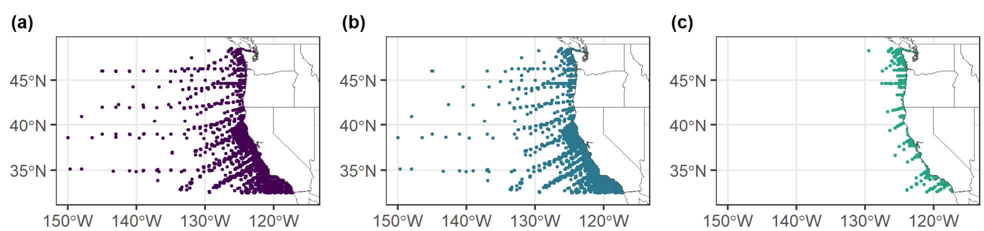


Figure 1: All individual locations for temperature (a), dissolved oxygen (b), and pH~~carbonate system~~ (c) observations included in this synthesis along the U.S. West Coast. The pH extent fully captures the extent of all other carbonate system parameters. These figures overstate the useful spatial density of the data, as many individual locations have only been sampled once, but highlight the limited scale of available carbonate‑system observations relative to more commonly assessed parameters like temperature and dissolved oxygen.

2. Methods

2.1 Data Sources and Types

This project compiled published and publicly available data, as well as data contributed by the author team, including multiparameter OAH-relevant observations from shipboard discrete water samples, *in-situ* autonomous sensors, and shore-collected samplesdatasets from along the U.S. West Coast. We primarily sourced multiparameter data through existing public data portals, such as NCEI and the Ocean Observing Systems portals, but additionally contacted colleagues to request their assistance in locating datasets, presented the project at conferences and management meetings to collect community feedback on included datasets, and scanned published literature that likely included relevant datasets. We and literature searches, prioritizeding datasets that included carbonate -system or dissolved oxygen observations in addition to temperature. When available alongside our target parameters, we also incorporated published chlorophyll and nutrient contentsoncentrations. In all cases, we took the published or publicly hosted data as our starting point, rather than asking for the unprocessed data from the original investigators, then applied additional quality-control measures described in Sect. 2.4. We have limited this publication to data collected before 2020 and data collected within U.S. waters, but we will continue to incorporate new observations according to the methods outlined below, where possible, and will periodically make updated versions of this synthesis dataset publicly available at NCEI (https://doi.org/10.25921/2vve-fh39; Kennedy et al., 2023).

The data in this synthesis comes from a wide array of observational methods and instruments. We screened carbonate -system datasets before incorporating them following the discussions of method reliability summarized in Martz et al., (2015). The carbonate -system observational methods included in this synthesis dataset are: (1) discrete seawater samples, preserved at the time of collection and analyzed in a lab with established standards and techniques (e.g., Dickson and Sabine, 2010), of pH, total alkalinity (TA), and dissolved inorganic carbon (DIC); (all preserved at the time of collection and analyzed in a lab with established techniques; e.g., Dickson et al., 2007); (2) pH measurementsobservations from ion-sensitive field-effect transistor-based autonomous sensors (e.g., Honeywell Durafet; Martz et al., 2010) or spectrophotometric sensors (e.g., SAMI-pH; Lai et al., 2018); and (3) pCO_2 measurementobservations from autonomous equilibrium-based infrared gas analyzers (e.g., MAPCO2; Sutton et al., 2014) or spectrophotometric methodsspectrophotometric sensors (e.g., SAMI-CO2; Schar et al., 2009). We did not include pH measured on glass electrode sensors, due to known issues with precision and calibration (Martz et al., 2010). We discarded any dissolved oxygen and carbonate -system datasets that lacked accompanying temperature data. , as accurate observations of both parameters require simultaneous temperature readings (Dickson et al., 2007). While we preferred carbonate system observations that also included salinity measurements, we retained pH and pCO_2 data without concurrent salinity measurements if they passed all other QC checks (e.g., Chan et al., 2017; Donham et al., 2023). Data collection methods are available for all parameters except temperature and salinity and have been simplified into four groups: 1) "discrete", for bottle-collected samples analyzed in a laboratory, 2) "CTD" for observations from ship-side profiles with autonomous sensor

Formatted: Subscript

arrays~~ing devices~~, 3) “autonomous sensors”, for stationary instruments collecting data at pre-programmed intervals, and 4) “handheld sensors” for observations collected in the field via a glass-electrode probe. The specific instruments associated with each data source are available in the dataset ~~M~~metadata t~~T~~able in the Supplemental Information and archived at NCEI, Accession 0277984 (MOCHA_metadata_table_v2.csv; Kennedy et al., 2023).

2.2 Formatting

After identifying a dataset of interest, we downloaded all available processed data and metadata, including descriptive papers, primary investigator information, project and instrument descriptions, and the original source of the data. Each dataset was assigned a unique identifying number to ensure that every data point could be quickly associated with its parent data source and metadata (Table 1). For all datasets, we retained a copy of the original published data. We manipulated each~~all~~ original dataset into a comma-separated file with minimal alterations - typically limited to eliminating extra header rows and streamlining column names - before transferring datasets into R or Python for further formatting to ensure that all manipulations were trackable.

This synthesis dataset is structured such that each row represents an ~~a set of~~ oceanographic observation~~s~~ from a shared time, depth, location, and data source, which may include one or more individual parameter measurements. Parameter measurements are linked with the parameter collection method, such as “discrete” or “autonomous sensor”, and the data quality flag in adjacent columns. Additionally, all observations are also accompanied by “sample scheme” and “habitat” columns to facilitate easy data filtering. The sample scheme column~~For easy filtering,~~ classifies~~ we included a “collection method” column that classified~~ each dataset as one of four types: “cruise” for ship-collected samples, “mooring” for autonomous instruments attached to buoys, “intertidal/subtidal autonomous sensor” for shore- or diver-accessed autonomous sensors, and “intertidal/subtidal discrete collection~~hand collected~~” for water samples collected by hand from a dock or the shore. The habitat column identifies observations ~~We also assigned each observation a habitat type, labeling observations as~~ “estuarine” if they were collected within semi-restricted lagoons and bays (e.g., Humboldt Bay), or “oceanic” otherwise.~~ We recorded measured variables, data types, and data quality in adjacent columns.~~

~~-~~For a full description of included parameters, refer to the submission metadata ~~detailed metadata table~~ archived at NCEI (SubmissionForm_carbon_v1_428.csv; Kennedy et al., 2023~~ (Kennedy et al., 2023~~) and the dataset metadata table in the Supplemental Information.

We retained all directly measured chemical oceanographic observations as we incorporated each dataset, converted observations to standard units if necessary, and mapped them directly to our corresponding synthesis dataset columns. Fortuitously, all pH observations ingested into this compilation were already reported on the total pH scale, but we converted discrete pH observations reported at 25^{o}C to *in-situ* conditions using accompanying temperature, salinity, pressure, carbonate-system, and nutrient conditions using the R package seacarb and recommended constants for the temperature and salinity and nutrient data as available (Gattuso et al., 2023). We did not retain published data calculated from algorithms or empirical relationships, such as TA calculated extrapolated from a TA-salinity relationship salinity measurementsor pH derived from temperature, salinity, and DO measurements (e.g., Alin et al., 2012), nor any calculated carbonate system variables, regardless of whether the source publication included such data. While we note that published data may have been summarized or filtered by the initial investigators, we did not further summarize or filter data before including it in this compilation except for the Ocean Observatories Initiative (OOI) moorings dataset (dataset 66)s, discussed below.

ID	**Dataset**	**Primary location**	**Sampling scheme**	**Habitat**	**Citation**
1	Sea-surface water temperature, Santa Barbara Harbor	Santa Barbara LTER, CA	Intertidal/Subtidal discrete collection	Oceanic	Carter et al., 2021
2	National Data Buoy Center Station BDXC1	Bodega Head, CA	Mooring	Oceanic	National Data Buoy Center, 2023
3	Mid-water SeaFET and CO_2 system chemistry at Alegria (ALE)	Santa Barbara LTER, CA	Mooring	Oceanic	Santa Barbara Coastal LTER et al., 2018
5	West Coast Ocean Acidification Cruise 2016	West Coast of the U.S.	Cruise	Oceanic	Alin et al., 2017
6	National Data Buoy Center Station 46025	Channel Islands, CA	Mooring	Oceanic	National Data Buoy Center, 2023
7	National Data Buoy Center Station 46217	Channel Islands, CA	Mooring	Oceanic	National Data Buoy Center, 2023
8	National Data Buoy Center Station 46053	Channel Islands, CA	Mooring	Oceanic	National Data Buoy Center, 2023
9	National Data Buoy Center Station TDPC1	Eureka, CA	Mooring	Oceanic	National Data Buoy Center, 2023
10	National Data Buoy Center Station FPXC1	Fort Point, San Francisco Bay, CA	Mooring	Estuarine	National Data Buoy Center, 2023
11	National Data Buoy Center Station 46221	Santa Monica Bay, CA	Mooring	Oceanic	National Data Buoy Center, 2023
12	National Data Buoy Center Station 46235	Imperial Beach, CA	Mooring	Oceanic	National Data Buoy Center, 2023

Formatted: Font: Bold

Formatted Table

14	National Data Buoy Center Station 46251	Santa Cruz Basin, CA	Mooring	Oceanic	National Data Buoy Center, 2023
15	National Data Buoy Center Station ICAC1	Santa Monica, CA	Mooring	Oceanic	National Data Buoy Center, 2023
16	National Data Buoy Center Station PRYC1	Point Reyes, CA	Mooring	Oceanic	National Data Buoy Center, 2023
17	National Data Buoy Center Station HBXC1	Humboldt Bay, CA	Intertidal/Subtidal sensor deployment	Estuarine	National Data Buoy Center, 2023
18	National Data Buoy Center Station MBXC1	Morro Bay, CA	Mooring	Estuarine	National Data Buoy Center, 2023
19	National Data Buoy Center Station MLSC1	Moss Landing, CA	Mooring	Oceanic	National Data Buoy Center, 2023
20	National Data Buoy Center Station MTYC1	Monterey, CA	Mooring	Oceanic	National Data Buoy Center, 2023
21	West Coast Ocean Acidification Cruise 2013	West Coast of the U.S.	Cruise	Oceanic	Feely et al., 2015a
22	West Coast Ocean Acidification Cruise 2012	West Coast of the U.S.	Cruise	Oceanic	Feely et al., 2016b
23	West Coast Ocean Acidification Cruise 2011	West Coast of the U.S.	Cruise	Oceanic	Feely et al., 2015b
24	West Coast Ocean Acidification Cruise 2007	West Coast of the U.S.	Cruise	Oceanic	Feely et al., 2013
25	California Cooperative Oceanic Fisheries Investigations (CalCOFI) bottle database (1949 - 2019)	California	Cruise	Oceanic	California Cooperative Oceanic Fisheries Investigations (CalCOFI), 2020
26	Applied California Current Ecosystem Studies Partnership cruise observations (2013-2019)	Central California	Cruise	Oceanic	Davis et al., 2018 *Previously unpublished data contributed by the authors.

27	UC Davis Coastal discrete ocean acidification dataset	West Coast	Intertidal/Subtidal discrete collection	Oceanic	Feely et al., 2016a *Previously unpublished data contributed by the authors.
28	Bodega Marine Laboratory weekly Horseshoe Cove discrete shore samples	Bodega Marine Laboratory, CA	Intertidal/Subtidal discrete collection	Oceanic	*Previously unpublished data contributed by the authors.
30	Mid-water SeaFET pH and CO_2 system chemistry at Arroyo Quemado Reef (ARQ)	Santa Barbara LTER, CA	Mooring	Oceanic	Santa Barbara Coastal LTER et al., 2020a
31	Mid-water SeaFET pH and CO2 system chemistry with surface at Mohawk Reef (MKO)	Santa Barbara LTER, CA	Mooring	Oceanic	Santa Barbara Coastal LTER et al., 2020b
32	Mid-water SeaFET pH and CO2 system chemistry at Santa Barbara Harbor/Stearns Wharf	Santa Barbara LTER, CA	Mooring	Oceanic	Santa Barbara Coastal LTER et al., 2020c
33	Ocean Margin Ecosystems Group for Acidification Studies (OMEGAS)	West Coast	Intertidal/Subtidal sensor deployment	Oceanic	Menge et al., 2015
34	EAGER Project: pH/pCO2-sensing mooring platform on the Oregon coast	Oregon	Mooring	Oceanic	Chan et al., 2012
35	NH10 mooring SAMI-CO_2 time-series	Oregon	Mooring	Oceanic	DeGrandpre, 2016
36	SB LTER calibration water-sample pH and CO2 system chemistry	Santa Barbara LTER, CA	Cruise	Oceanic	Santa Barbara Coastal LTER et al., 2022

37	Bodega Marine Reserve monthly shore samples	Bodega Marine Reserve, CA	Intertidal/Subtidal discrete collection	Oceanic	*Previously unpublished data contributed by the authors.
39	California Coastal seagrass project	California	Intertidal/Subtidal sensor deployment	Varies by site	Ricart et al., 2021
40	California kelp forest tidal FET sites	California	Intertidal/Subtidal sensor deployment	Oceanic	Kroeker et al., 2023
41	NOAA Northwest Pacific harmful algal bloom program cruise SH1709	Washington and Oregon	Cruise	Oceanic	Alin et al., 2019
42	Oceanographic cruise calibration and validation samples of California Current Ecosystem	Southern California Bight	Cruise	Oceanic	Send et al., 2016
43	CCE1 mooring pCO_2 time-series	Point Conception, CA	Mooring	Oceanic	Sutton et al., 2016b
44	CCE2 mooring pCO_2 time series	Point Conception, CA	Mooring	Oceanic	Sutton et al., 2012
45	CeNCOOS in situ water monitoring data at Trinidad Head, California	Trinidad, CA	Intertidal/Subtidal sensor deployment	Oceanic	Shaughnessy, 2023
46	SFSU Estuary and Ocean Science Department YSI	Tiburon Peninsula, CA	Intertidal/Subtidal sensor	Estuarine	Dewitt, 2022
47	CeNCOOS water monitoring data at the Santa Cruz municipal wharf	Santa Cruz, CA	Intertidal/Subtidal sensor deployment	Oceanic	Kudela, 2020

49	San Francisco Estuary Institute and the Aquatic Science Center Regional Monitoring Program	San Francisco Bay, CA	Cruise	Estuarine	Bezalel et al., 2021
50	West Coast Estuary Data: Santa Monica Bay	Santa Monica	Mooring	Oceanic	Rosenau et al., 2021a
51	West Coast Estuary Data: San Francisco Bay	SF Bay	Mooring	Estuarine	Rosenau et al., 2021a
52	Validation discrete observations for the Cha Ba mooring	La Push, WA	Cruise	Oceanic	Alin et al., 2016
53	Morro Bay BM1 T-Pier (NOAA Station MBXC1)	Morro Bay, CA	Mooring	Estuarine	Walter, 2023
54	Morro Bay BS1 Station	Morro Bay, CA	Mooring	Estuarine	California Polytechnic State University, 2023
55	Cape Elizabeth mooring MAPCO2 time-series	Cape Elizabeth, WA	Mooring	Oceanic	Sutton et al., 2013
56	Stillwater Cove TidalFET	Carmel, CA	Intertidal/Subtidal sensor deployment	Oceanic	Donham, 2022a
57	National Data Buoy Center Station 46211	Grays Harbor, WA	Mooring	Oceanic	National Data Buoy Center, 2023
58	National Data Buoy Center Station NEAW1	Neah Bay, WA	Mooring	Estuarine	National Data Buoy Center, 2023
59	National Data Buoy Center Station CECC1 – 9419750	Crescent City, CA	Intertidal/Subtidal sensor deployment	Oceanic	National Data Buoy Center, 2023
60	National Data Buoy Center Station 46237	San Francisco, CA	Mooring	Oceanic	National Data Buoy Center, 2023

61	National Data Buoy Center Station 46240	Monterey Bay, CA	Mooring	Oceanic	National Data Buoy Center, 2023
62	National Data Buoy Center Station PORO3	Port Orford, OR	Mooring	Oceanic	National Data Buoy Center, 2023
63	National Data Buoy Center Station CHAO3	Charleston, OR	Mooring	Estuarine	National Data Buoy Center, 2023
64	CB-06 mooring MAPCO2 time-series	Coos Bay, OR	Mooring	Oceanic	Sutton et al., 2019
65	NH10 mooring MAPCO2 time-series	Newport, OR	Mooring	Oceanic	Sutton et al., 2016a
66	Ocean Observatories Initiative (OOI) Washington and Oregon inshore and shelf moorings	Washington and Oregon	Mooring	Oceanic	NSF Ocean Observatories Initiative, 2022
67	Trinidad Head Line CTD Hydrography	Northern California	Cruise	Oceanic	Bjorkstedt, 2023
68	Newport Hydrographic Line CTD casts 1997–2021	Central Oregon	Cruise	Oceanic	Risien et al., 2022b
69	Oregon's Marine Reserve mooring	Oregon	Mooring	Oceanic	Aylesworth et al., 2022
70	CMOP Saturn-02 mooring	Columbia River Estuary, OR	Mooring	Estuarine	Columbia River Intertribal Fish Commission Center for Coastal Margin Observation and Prediction, 2023
71	Monthly cross-shore transects of biogeochemical properties in La Jolla, CA	Southern CA	Cruise	Oceanic	Kekuewa and Andersson, 2022

Table 1: Overview of the included data sources in the MOCHA compilation. The origins of all the included datasets in this compilation are f~~ully described and cited in~~urther described in the dataset metadata table~~Metadata Table~~ available in the paper Supplement and archived at~~at~~ NCEI (https://doi.org/10.25921/2vve-fh39, dataset_metadata_table_v2.csv, Kennedy et al., 2023). Additional, detailed ~~Detailed~~ discussions of the following datasets have been previously published: 5 (Feely et al., 2008); 21-24, 26 (Feely et al., 2016a); 25 (Bograd et al., 2003); 26 (Davis et al., 2018); 33 (Chan et al., 2017); ~~38 (Hollarsmith et al., 2020); 39 (Ricart et al., 2021); 40 (Kroeker et al., 2023);~~ 49 (Salop and Herrmann, 2019); 50 and 51 (Rosenau et al., 2021b); 56 (Donham et al., 2022b); 66 (Trowbridge et al., 2019); 67 (Bjorkstedt and Peterson, 2015); 68 (Risien et al., 2022a); 69 (Barth et al., 2021); 70 (Baptista et al., 2015); and 71 (Kekuewa et al., 2022).

2.3 Dataset 66: Ocean Observatories Initiative (OOI) Moorings ~~Datasets~~

The Washington and Oregon OOI~~-~~ mooring data (dataset 66) included millions of observations of temperature, salinity, dissolved oxygen, pH, and pCO_2 at sub-minute resolutions. The size of these datasets required us to aggregate the data to daily mean values before incorporation into the larger synthesis dataset. ~~We filtered raw OOI with input from the OOI staff to remove outlying and unreliable data, grouped the remaining data by day, aggregated to daily mean values, then quality-controlled the aggregated data a second time according to the methods described in Sect. 2.4.~~

Because much of this~~the publicly available~~ OOI data had not been previously quality controlled, we contacted OOI staff for their guidance on initially filtering the raw data before aggregation. They provided extensive code developed by the sensor manufacturers and OOI staff to identify erroneous pH and DO data from the raw publicly available streams, available at https://github.com/oceanobservatories/ooi-data-explorations/tree/master/python, as well as significant protocol guidance that has since been made public (Palevsky et al., 2022). OOI staff also provided access to discrete sample analyses taken at the sensor moorings to further ground-truth measurements~~sensor readings~~. We only retained data for aggregation if it 1) passed through the provided OOI ~~manufacturer's~~ code's automated checks, 2) had discrete samples associated with the beginning and end of that sensor's deployment, 3) the daily mean sensor values for DO ~~dissolved oxygen~~ and pH on the day of discrete sampling were within 20 µ~~µ~~mol ~~/~~kg~~-1~~ of the discrete sample dissolved oxygen and/or 0.05 pH units, and 4) displayed reasonable DO content and ~~/~~pH values~~concentrations~~ and variance ~~in those concentrations~~ over time, following OOI's suggested protocols for both automated and "human in the loop" quality control practices (Palevsky et al., 2022). We eliminated all DO data prior to 2018 based on advice of OOI staff because the DO sensors prior did not have adequate biofouling control. We then aggregated these data into daily mean values before formatting and quality controlling them further following the practices described for all other incorporated datasets and described in Sect 2.4~~as normal~~.

2.4 Quality Control

After formatting individual datasets, we checked all observations to standardize quality across data sets and to avoid using questionable data points in future analyses.~~-~~ Our quality assurance/quality control (QA/QC)~~QA/QC~~ methods drew from a combination of the publishing authors' notes, plots of the data, and expert knowledge of the CCS. The majority of our incorporated datasets had been previously published and subjected to at least automated QA/QC processes, but additional "human in the loop" secondary QC was necessary for almost all datasets, particularly those from autonomous sensors

Formatted: Default Paragraph Font

Formatted: Default Paragraph Font, English (United Kingdom)

(Pavlevsky et al., 2022). Incoming quality-control notes associated with each data source ranged widely, though most datasets that did include quality information followed the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) system, which assigns flags based on internal instrument checks, data reasonableness, and collection method (Bushnell 2018). Given the variability in flagging schemes that incorporated datasets used and the impossibility of accurately assigning detailed QARTOD-style flags to datasets that did not include similarly detailed notes, we opted to create a simpler, three-level quality scheme that all datasets could be easily mapped to. Using available existing QA/QC information and our further quality control investigations, we categorized each data point as one of three confidence levels: 1 for "plausible and reasonableliable" data, 2 for data that we had not assessed yet, and 3 for "low quality or unreliable" data. We flagged all data the publishing authors had listed as unreliable or suspect with a 3. Regardless of published notes, we assigned all other observations a flag of 2 before furtheradditional evaluation by our project team.

Given the diversity of the datasets and projects this synthesis draws from, we examined each dataset individually using a combination of plots tailored to maximize our ability to identify and evaluate anomalies in that dataset's specific oceanographic and spatiotemporal context. Given that this synthesis primarily sourceds mostly published data, we erred towards retaining data as "plausible", rather than following a more stringent flagging philosophy. We recommend that investigators perform additional QC with the MOCHA dataset targeted towards their project requirements. Common quality control plotting techniques included property-property plots of temperature, salinity, DOdissolved oxygen, pH, TAtotal alkalinity, and DICdissolved inorganic carbon against one another; single-parameter time series from sensor and long-running datasets; and map views and oceanographic cross sections of synoptic cruise data. We examined questionable data through as many different views as possible, such as examining apparent outliers in a temperature-salinity property-property plot individually in their respective time series, to ensure that we were not flaggingtrimming real or plausible observations. When possible, we further evaluated suspicious observations against other datasets collected nearby. We discussed all data flagging decisions with at least three project members. After this focused quality control, all observations not flagged as "low quality or unreliable" (3) were upgraded to our "plausible and reliable" flag (1) with the exception of 300 surf zone DO measurements taken from shore, which were left as "unevaluated" since they do not reflect oceanic conditions (2). All subsequent mapping and analysis with the observed oceanographic values used only "plausible and reliable" data. For a full example of our formatting and flagging practices, please refer to the Supplemental Information.

2.5 Example Subset: Daily Data

High-resolution (sub-daily observations) autonomous sensors are an important component of this synthesis dataset, but the data they produce comes with significant computational costs. Furthermore, variability on the scales of hours or minutes captured by such high-resolution records is less comparable to lower-resolution datasets such as those collected over quarterly or annual synoptic oceanographic cruises. To evaluate the spatiotemporal extent of our data coverage, seasonal patterns, and relationships between observed parameters, we created an aggregated summary dataset of we aggregated the dataset to dailydaily mean values for each location, depth, and data source. We dropped all questionable individual parameter measurementsdata (i.e.,. data flagged with a "3" QA/QC code) before creating this summary dataset to ensure that unreliable data did not influence averages. The daily averaging reduced the number of observations (rows) from 13.7 million to 1.2 million as high-resolution sensor datasets, some with observations every 20 minutes, were collapsed into a single row per dayis reduced the total number of observations from 13.7 million to 1.2 million. We used this summary dataset in all following example cases analyses that do not explicitly cite "original data." This aggregated summary dataset is available alongside the full MOCHA compilation at NCEI (aggregated_daily_dataset.csv, Kennedy et al., 2023) and we We have included the code necessary to recreateproducee it this summary dataset from the published data compilation in our public code repository (https://github.com/egkennedy/DSP_public_codehttps://github.com/egkennedy/DSP_public_code)).

Formatted: Default Paragraph Font

2.6 Additional Carbonate System Calculations

To maximize the OAH information available in our daily summarized dataset, we calculated the full carbonate system parameters for all discrete samples that included at least two high-quality observations of primary variables of the carbonate system (pH, TA, DIC, or pCO_2) in addition to high-quality, co-occurring temperature and salinity measurements. These calculated parameters can be reproduced using the code in our public code repository (https://github.com/egkennedy/DSP_public_code). We used the R package "seacarb" (Gattuso et al., 2018) for all carbonate system calculations and used constants appropriate for the temperature and salinity as recommended by Dickson et al. (2007). In cases where more than two carbonate system parameters were available, we prioritized TA-DIC pairs following Dickson (2010), then TA-pH pairs, then DIC-pH pairs. When applicable for mapping and time series analyses, measured and calculated carbonate system observations were concatenated, with measured data prioritized in all overdetermined systems. All references to an analysis of "original" data and all discussions of the distribution of observations only include directly measured variables; however, the oceanographic relationships discussed in Sect 3.5 and shown in Figs. 3, 5, and 6 include these additional calculated observations.

3 Results and Discussion

3.1 Overall Data Totals

This synthesis dataset includes observations from 667 individual data sources organized across 13.7 million rows ("observations") and 41 columns and spans from 1949-2020. This includes 24.1 million individualunique parameter measurements, with 13.2 million temperature, 3.6 million salinity, 3.3 million DO, 2.1 million pH, 1.2 million chlorophyll, 561,000 nutrient, 113,000 pCO_2, 9,30010,400 TA, and 8,300500 DIC measurements. While we prioritized multiparameter datasets for this effort, our synthesis also includes several temperature-only, high-resolution records to fill specific project needs. The full suite of carbonate system parameters can be directly calculated from 48,000 observations with two reliable carbonate system parameter observations and co-occurring reliable temperature and salinity measurements.

Across sampling schemes, moorings contribute the bulk of the MOCHA observations with 8.9 million rows, followed by intertidal or subtidal autonomous sensors with 3.8 million, oceanographic cruise observations (which include CTD profiles) with 98,000, and finally intertidal and subtidal discrete collections with 24,000. By measurement method, autonomous sensors are the most common, contributing 5 million individual measurements, versus 224,000 individual discrete measurements, 193,000 CTD measurements, and 828 handheld field sensor measurements. Summarizing the data by day for each dataset, location, and depth provides a clearer picture of the availability of multiparameter data by muting the outsized influence of high-resolution sensors. Of the 1.2 million daily averaged observations, just 104,000 are temperature-only.

3.2 Aggregated Daily Data Totals

Summarizing the data by day for each dataset, location, and depth provides a clearer picture of the availability of multiparameter data by diminishing muting the outsized influence of high-resolution temperature sensors. Of the 1.2 million daily averaged observations, just 104,000 are temperature-only. Individual parameter totals are shown in Table 2.. Full carbonate system calculations could be performed on 12,000 of the daily observations with measurements of temperature, salinity, and two of the principle carbonate system parameters.

Data totals across dissolved oxygen and carbonate-system observations varied substantially by observational method. Autonomous sensors are the most common observational method in the original dataset with 5 million individual measurements, versus 226,000 individual discrete measurements, 193,000 CTD measurements, and 828 handheld field measurements. As with the disaggregated, full dataset, data totals varied substantially by measurement method and autonomous Across data aggregated by day, autonomous sensors are still the most common, contributingwith 643,000 individual daily averaged parameter measurements, versus 223,000 discrete, 192,000 CTD, and 816 handheld sensor measurementsobservations. For evaluating the spatiotemporal coverage of carbonate-system observations, we calculated an additional 4,599 daily pH observations from paired discrete samples of two other primary carbonate system parameters, equal to 3.1% of the total directly measured daily pH observations (Table 2). The calculated pH observations were included in our analysis of the spatiotemporal extent of available OAH data discussed in Sect 3.3 and the oceanographic relationships discussed in Sect. 3.5.

Parameter	Collection Method	Daily Total Observations	Overall Reliability Rate
DO	discrete	199,8168363	99.70%
	autonomous sensor	563,8854020	92.40%
	CTD	128,562961	99.90%

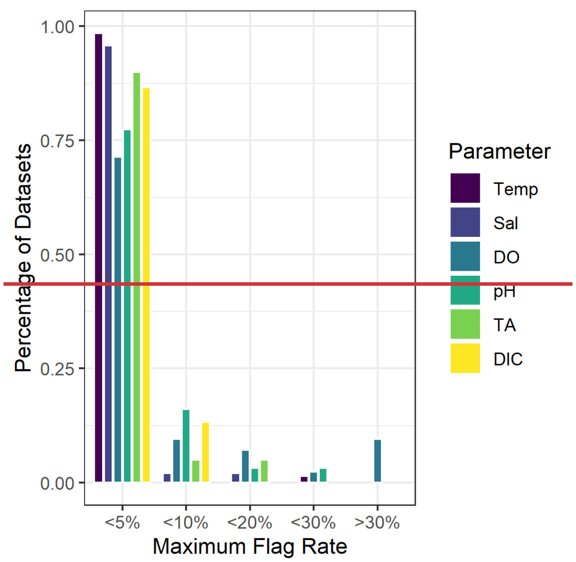
Formatted Table

	handheld sensor	382816	93.28.70%
pH	discrete	4,068912	99.68.70%
	autonomous sensor	78,8945	88.70%
	CTD	63,404	100%
DIC	discrete	8,211363	99.10%
TA	discrete	8,8589908	98.270%

Table 2: Overview of dissolved oxygen (DO), pH, dissolved inorganic carbon (DIC), and total alkalinity (TA)parameter observation methods, total number of daily observations (grouped by data source, location, and depth), and the overall reliability rates. -Autonomous sensors are associated with slightly lower reliability rates due to periods of sensor bio-fouling or malfunction.

3.32 Flagging and Reliability

The amount of original data flagged as unreliable varied substantially by dataset, parameter, and observation method, but was typically low (Fig. 2). As the bulk of the data in this synthesis product was previously published and had undergone some preliminary QA/QC prior to our incorporation, high reliability rates were expected. Of the dozens of datasets contributing temperature and salinity observations, only one dataset each had a parameter flag rate above 5%. Flag rates above 10% were uncommon for all parameters across all datasets, and completely absent for TA and DIC observations. For pH and DO, flag rates within datasets were above 10% for 3 and 8 datasets, respectively. In each case,These high rates of "unreliable" data were caused by either (1) clear periods of autonomous sensor malfunction, (2) observational methods described by the publishing authors as unreliable, or (3) more rarely, 3) more rarely, intentionallyslightly higher QA/QC standards applied to data that had not been previously screened and published. The vulnerability of autonomous sensors to periods of biofouling or sensor malfunction contributed to higher flag rates relative to other methods, but all four methods were largely reliable (Table 2). Across the entire MOCHA compilationall datasets, 99.8% of temperature, 96.8% of salinity, 93.1% of DO, 89.1% of pH, 99.1% of DIC, and 98.27% of TA measurementsobservations were considered "reliable or plausible". Across all individual observationsmeasurements, 97.3% are classified as reliable.



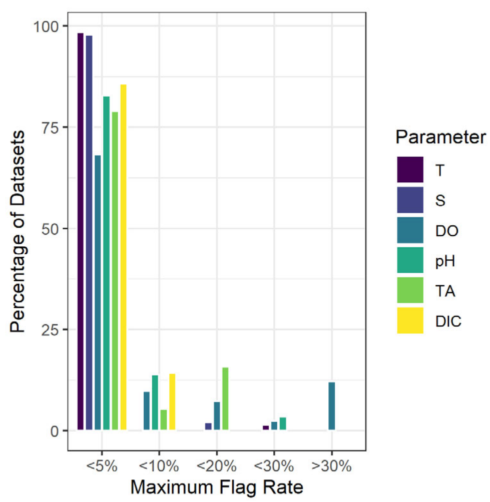


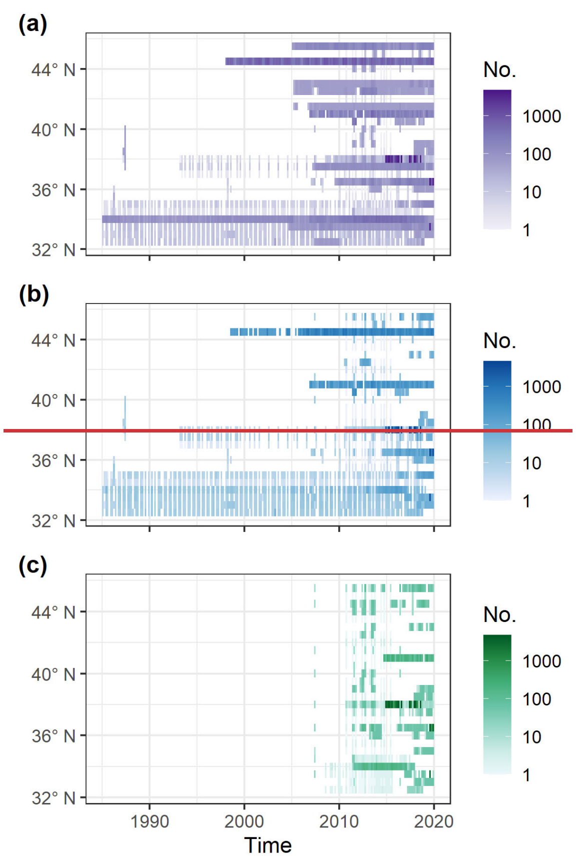
Figure 2: The rate of unreliable (“flagged”) observations varied by dataset and parameter measured between temperature (T), salinity (S), dissolved oxygen (DO), pH, total alkalinity (TA), and dissolved inorganic carbon (DIC). Maximum unreliable flag rates ~~parameter and dataset, but was~~ were generally low, especially for ~~–~~ T and S~~temperature (Temp) and salinity (Sal)~~

observations. All datasets that included dissolved oxygen (DO) observationsmeasurements with a >30% flag rates used measurement methods described by the original publishers as "not quantitative". Flag rates between 10% and 30% were uncommon, butuncommon but reflected occasional periods of fouling or equipment malfunction in high resolution autonomous sensor datasets or, in rare cases, more stringent standards applied to datasets that had not been previously published and initially quality controlled.

3.43 Spatiotemporal Data Distribution

This dataset spans the U.S. West Coast and reflects the spatiotemporal bias of observational records. Observations are more common in nearshore, near-surface environments and exhibit greater sampling effort in recent years. Fifty-sixeven percent of daily observations were collected within 50 km of shore and 237% within 5025 m of the surface. Eighty-six percent of all daily observations were collected after 1990. Carbonate -system observations are especially skewed toward recent years, with no measurements of pH, TA, DIC, or pCO_2 observations in this compilation (of pH, TA, DIC, or pCO_2) prior to 2006. By contrast, temperature, salinity, and DOdissolved oxygen records are common after 1980.

The spatiotemporal coverage of our dataset is highly variable, though generally improving through time. Mapping the density of observations within 50 km of the coastline and 25 m of the surface, nearshore (<25 m depth and <50 km from shore) observations along the coastline through time highlights the influence of dense coastal human populations and major research institutions (Fig. 3). By contrast, the region between 38° N and 44° N Point Arena, California and central Oregon is much less densely observed and lost considerable oceanographic monitoring capacity between 2015 and 2020. Temperature and DOdissolved oxygen measurements have the most extensive coverage, but are sparse outside of Southern California before 2000. Salinity measurement density hews closely to the DO distribution and, as such, is not shown here. After 2015, carbonate system observations Carbonate system records, here shown by both measured and calculated pH observations, are limited to a few locations with sporadic coverage north of 39° N which correspond to pH and pCO_2 mooringsare rare in all years north of 39° N. Overall, this data compilation demonstrates large spatial and temporal data gaps, which limit our ability to resolve rapid changes in ocean acidification, hypoxia, or warming risk or to contextualize current oceanographic carbonate-system and dissolved oxygen conditions with respect to the recent past.


(a)
(b)
(c)
44° N
40° N
36° N
32° N
No.
1000
100
10
1
1990
2000
2010
2020
Time

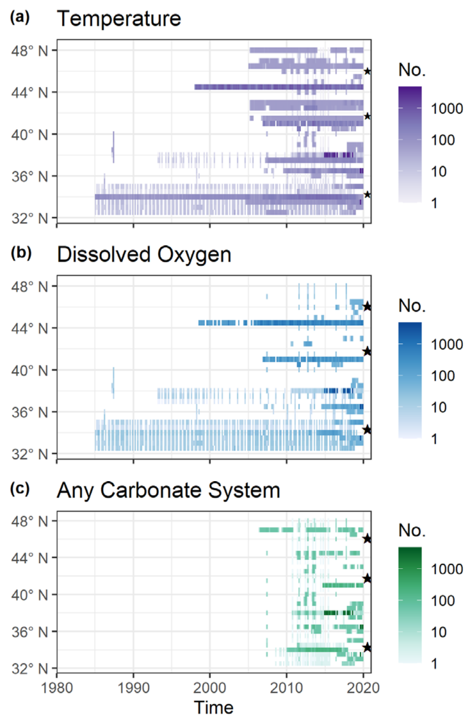
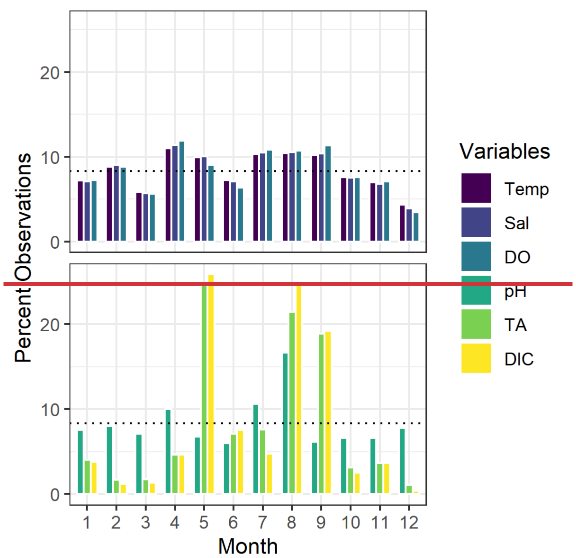


Figure 3: The number of measurements within 50 km of the shore and 25 m of the surface for temperature (a), dissolved oxygen (b), and any carbonate system measurements (c) using two-month, 0.5-degree latitude spatiotemporal blocks. Salinity (not shown) hews closely to the dissolved oxygen distribution. From north to south, stars mark the Washington-Oregon border, the Oregon-California border, and Point Conception (34.5° N). ~~nearshore (< 50 km from shore), near-surface (< 25 m) observations within a two-month period for temperature (a), dissolved oxygen (b), and pH (c) along the coast. The full carbonate system observational density is captured by pH alone.~~ Spatial data coverage was best across all parameters between 2010 and 2015, whereas overall observation quantity was highest between 2015 and 2020. Since ~~then~~2015, dissolved oxygen and carbonate system~~pH~~ measurements have become more concentrated into fewer locations along the coast~~ less common along the coast~~ despite increasing awareness of the risks of nearshore acidification and hypoxia events.

The ~~i~~intra-annual distribution of the daily data is more complex than the interannual distribution (Fig. 4). Temperature, salinity, and DO~~dissolved oxygen~~ records are common throughout the year, but have distinct peaks in abundance in April, May, and July through September~~November~~. Carbonate system records are patchier~~ more patchy~~ temporally. Nearly 50% of all TA and DIC observations were taken in May or August, with an additional 19% of observations from September, reflecting the sampling months of the NOAA West Coast Ocean Acidification c~~C~~ruises (Feely et al., 2016a). Between

October and April, no single month includes more than 8% of DIC observations or 5% of TA observations. pH observations are more evenly distributed throughout the year, with all months hosting 6-10.5% of the observations except August, which hosts 16%. The concentration of carbonate -system observations between May and September is particularly concerning, as upwelling season in Central and Southern California starts in earnest in April (Garcíaiá-Reyes and Largier, 2012; Jacox et al., 2018) and at least two carbonate- system parameters must be measured to fully constrain the carbonate system (Dickson and Sabinexon et al, 2010)., 2007), so the observational record may be missing significant low pH, low DO events from the early upwelling season.


Percent Observations
Month
Variables
Temp
Sal
DO
pH
TA
DIC

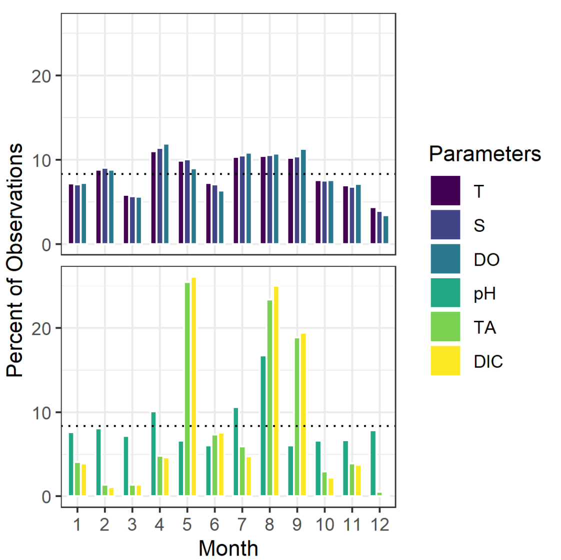

Percent of Observations
Month
Parameters
T
S
DO
pH
TA
DIC

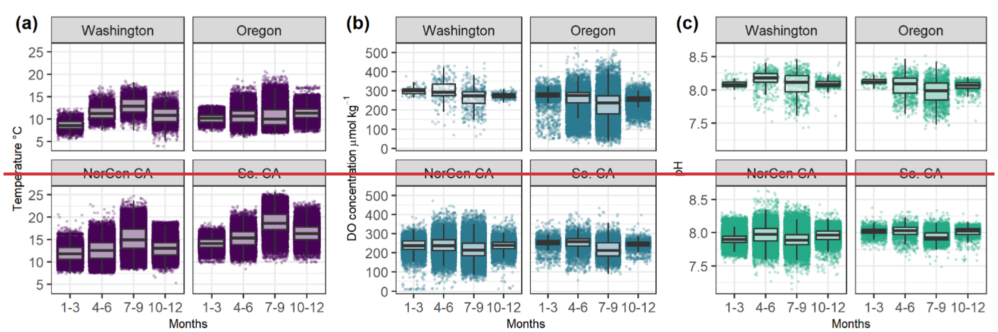
Figure 4: The distribution of daily observations by month varies substantially by parameter relative to an equal split (dashed lines). Temperature (Temp) , salinity (Sal), and dissolved oxygen (DO) observations are fairly evenly distributed across seasons, with notable observational peaks in April, May, July, August, and September. Carbonate system parameters (pH, total alkalinity or TA, and dissolved inorganic carbon or DIC) are more concentrated in the summer months, with nearly all TA and DIC observations occurring in May, August, or September. Of the carbonate -system parameters, only pH observations are nearly equitably distributed throughout the year.

3.65 Oceanographic Analysis Case ExamplesData Relationships

3.6.1 Monthly Climatology

Formatted: Heading 3

This synthesis dataset supports several avenues of investigation of the relationships between OAH parameters. For example, evaluating the variations in monthly climatology across OAH parameters in waters shoreward of the 100 m depth contour shows effectively captures seasonal and regional variability across OAH-relevant parameters (Fig. 5). Median surface, nearshore (<25 m depth and <50 km from shore) intriguing differences between regions (Fig. 5). tTemperatures rise in all regions during the spring and summer months, peaking between July and September. In Washington and Oregon, peak upwelling occurs between June and August (Bograd et al., 2009; Jacox et al., 2016), which coincides with the period of highest variability and lowest minima for pH and DO observations captured in this synthesis. In both California regions, separated at Point Conception (34.5° N), seasonal surface data areis less consistent with the expected upwelling patterns. There, peak upwelling occurs between April and June and is weakest in Southern California south of Point Conception (Bograd et al., 2009; Garcíaiá-Reyes and Largier, 2012; Jacox et al., 2016). Somewhat unexpectedly, the highest variability and lowest minimum median DO and pH observations occur between July and September in both California regions rather than during the months of expected peak upwelling. This trend may reflect intermittent upwelling into the warmer summer months or could be capturing high surface respiration as waters warm and invites further investigation. October through March conditions across all West Coast regions are more poorly sampled, but have less variability, cooler mean temperatures, and higher dissolved oxygen contenteentrations and pH..



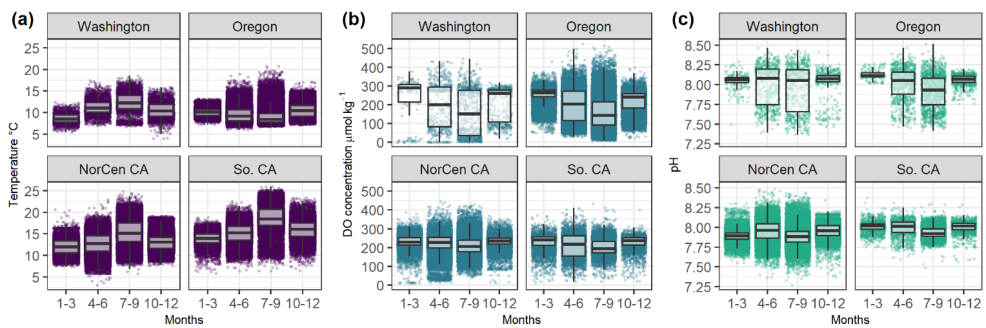


Figure 5: Measurements shoreward of the 100 m bathymetric contour ofNearshore (< 50 km from shore), near-surface (< 25m) observations of temperature (a), dissolved oxygen (DO) (b), and pH (c) capture intra-annual and regional variation. While upwelling, which brings low temperature, low DO, low pH water to the surface, is most common between April and June, median surface conditions do not reflect this phenomenon due to the episodic nature of upwelling and high variability in the system. The lowest median DO and pH conditions are found with the highest temperatures in late summer, rather than during peak upwelling periods (April – June). Here, California is split into two regions: NorCen CA, spanning the northern border to Point Conception (34.5 N), and So. CA, from Point Conception to the southern border. Ninety-nine percent of the data falls within 30 km of shore and 65% falls within 10 km of shore.

3.6.2 Shallow OAH Events

Formatted: Heading 3

Nearshore OAH vulnerability information can be particularly important for effective coastal management (Ekstrom et al., 2015; Woodson et al., 2018). Within state waters (< 5 km from shore) in the surface 50 m, there are thousands of co-occurring observations of pH below 7.8 and DO below commonly applied hypoxia thresholds (Fig. 6; e.g., Vaquer-Sunyer and Duarte, 2007; Hoffman et al., 2011). The relationships between daily measured OAH parameters illustrate the complexity of nearshore oceanographic processes. As expected in an upwelling ecosystem, low surface pH and DO conditions are most frequently associated with low temperatures, but warmer OAH events still occur (Fig. 6). pH conditions below 7.8 can be stressful for many marine organisms (e.g., Byrne and Przeslawski, 2013; Gobler and Baumann, 2016; Bednaršek et al., 2021; Kroeker et al, 2023in press) and have been observed 8,6659,928 times within 50 km of shore and 5050 m of the surface in this data compilation(Fig. 6). Of these instances, 65 observations99 events are accompanied by DO contentsconcentrations below the "coastal hypoxia" threshold of 61 µmol kg^{-1} and 400548 observationsevents have DO contentsconcentrations below the "mild hypoxia" threshold of 107 µmol kg^{-1} (Hofmann et al., 2011). An additional 220 1,765 nearshore, of these near-surface observations of DO contentsconcentrations below 61 µmol kg^{-1} in state waters have been recorded without accompanying pH information. No simultaneous surface observations of DO and pH record coastal hypoxic conditions with pH levels above 7.8. The low pH, low oxygen observations are most common off the Oregon coast and are typically associated withduring low temperature upwelling events, but simultaneous mild to moderately hypoxic low oxygen, and low pH conditions are also found occasionally throughout the coast and at a range of temperatures, especially during late summer in semi-restricted estuaries. The few simultaneous observations of DO content oncentration and pH suggest that fewer than 1only 1.0% of observations of low pH (pH < 7.8) in state waters are accompanied by hypoxic water, whereasile shallow hypoxic state waters mightare always be accompanied by low pH conditions. 99% of the time. These relationships underscore the importance of multiparameter OAH observations, the clear need for pH monitoring efforts to catch up with DOdissolved oxygen monitoring efforts, and the potential for even shallow waters to experience extreme conditions.

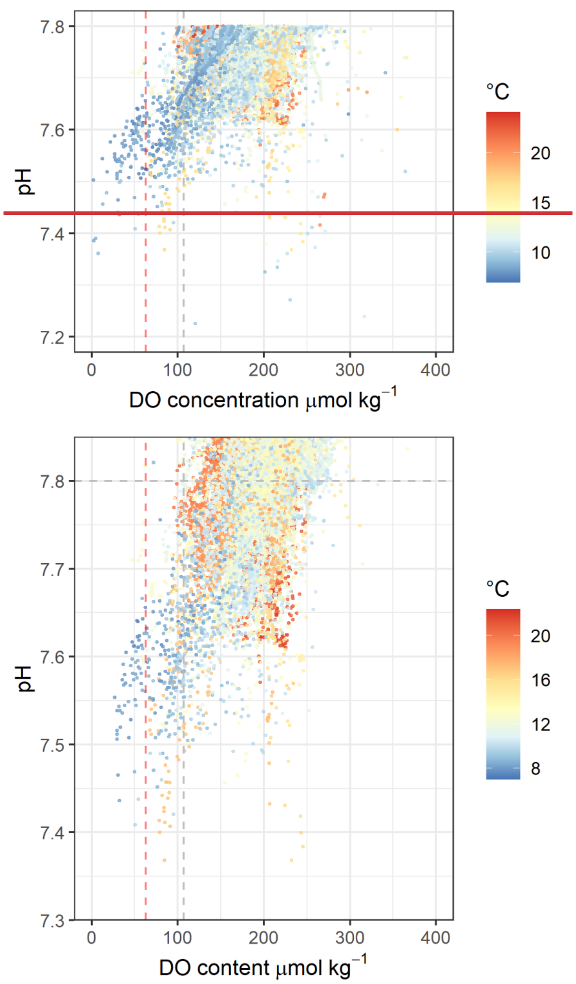


Figure 6: Low dissolved oxygen (DO) and pH conditions are frequently present in state waters (within 5 km of the shore) and 50 m of the surface. pH measurements below 7.8 (grey dashed horizontal line) are common but are more rarely accompanied by mildly hypoxic (< 107 µmol kg^{-1} or 3.5 mg L^{-1} DO, grey dashed vertical line) or hypoxic (< 61 µmol kg^{-1} or 2 mg L^{-1} DO, red dashed vertical line) conditions. Simultaneous low pH, low DO events are typically associated with low temperatures, whereas low pH conditions alone are present across a wide range of temperatures. Within 50 km of shore and the top 50 m, waters frequently have pH levels below 7.8. These conditions are most likely to be associated with hypoxic (<61 µmol kg^{-1} dissolved oxygen, red line) or

mildly hypoxic (<107 µmol kg^{-1} dissolved oxygen, gray line) conditions during upwelling events, which also bring low temperatures. Low pH conditions are also common at a range of temperatures and dissolved oxygen (DO) concentrations.

3.6.3 Total Alkalinity-Salinity Relationships

As a final example usage, we used the MOCHA synthesis to explore surface (< 25 m depth) TA-salinity relationships along the coast. Developing robust TA-salinity relationships for near-surface, nearshore waters has produced intense interest as reliable algorithms allow the full carbonate system to be calculated while only directly measuring one principle parameter, but these algorithms can be hampered by nearshore variability (e.g., Fassbender et al., 2017, Davis et al., 2018). The nearshore, near-surface data in the MOCHA synthesis also highlights the difficulty of developing accurate nearshore algorithms that can predict carbonate-system parameters from other more commonly measured hydrographic variables in coastal ecosystems, even in the absence of large freshwater inputs. The relationship between salinity and TA is regionally dependentWe examined surface (< 25 m depth) discrete TA and salinity observations from within 100 km of the shore along the Washington, Oregon, and California coasts and compared the data collected within 2 km of shore to those collected between 2 and 100 km from shore (Fig. 7). Our TA-salinity relationships were very similar when using a 50 km and 100 km cutoff distance and we show the more extensive data here for closer comparisons with previous investigators. Our TA-salinity slopes were not significantly different between any Washington and Oregon regions, though we note that Washington and Oregon both have very limited discrete TA data within 2 km of shore, which produced large standard errors in the slope terms (4.5 and 3 µmol kg^{-1}, respectively). Our observed offshore Washington TA-salinity relationship of $TA = 42.2 \pm 1.2 \times S + 823$ is more comparable to Wootton and Pfister (2012) regression, which centered off the Strait of Juan de Fuca, than that from Fassbender et al. (2017). However, we did not correct for seasonal or watershed biases in this example and focus on a more limited stretch of nearshore waters, which may account the differences between our calculated relationships and that of Fassbender et al. (2017).

Each of the two California regions, split at Point Conception (34.5° N), have TA-salinity regressions that are statistically distinct from each other and from both Pacific Northwest regions. The offshore California slope terms are much larger than in the Pacific Northwest region and significantly larger than the Cullison Gray et al. (2011) salinity coefficient of 50.8, particularly our slope for the Northern and Central region (57.4 ± 0.9 µmol kg^{-1}). At a salinity of 33.5, these differences produce an increase in estimated TA of 94.3 µmol kg^{-1} between our calculated Northern and Central California relationship and the Cullison Gray et al. (2011) relationship, which translates to an increase in estimated aragonite saturation of 0.1 at 12°C and pH = 8.1. The Cullison Gray et al. (2011) relationship was derived from unpublished pCO_2 and DIC observations, all taken prior to 2007, so there is limited temporal overlap between our sample sets and any spatial differences in sample area cannot be assessed. The California nearshore region is well-sampled relative to the Pacific Northwest and displays significant variability, potentially reflecting local differences in bedrock or organic alkalinity contributions. The variability in nearshore TA-salinity relationships will continue to present a challenge for coastal communities and state agencies,

Formatted: Heading 3

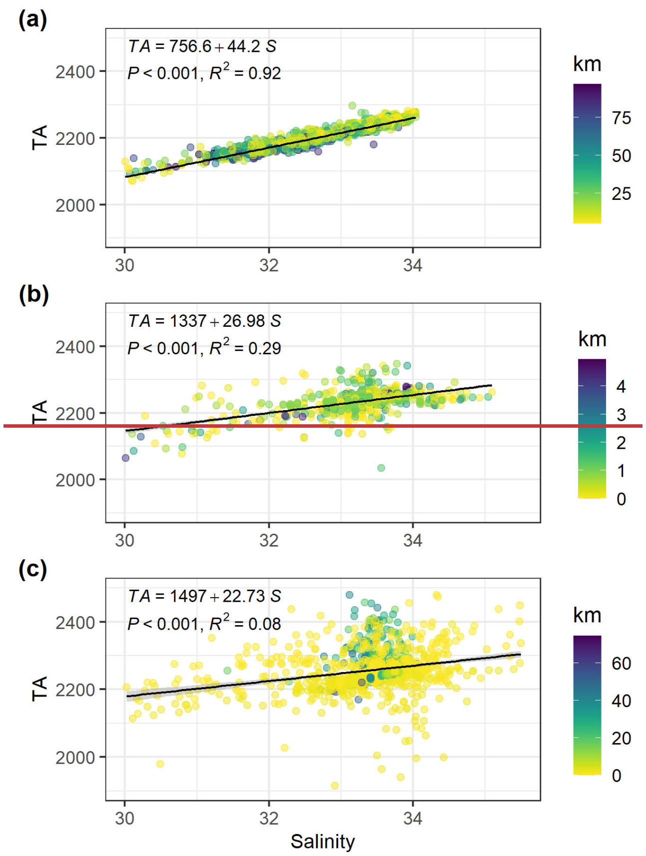
Formatted: Font: (Default) +Body (Times New Roman)

Formatted: Font: (Default) +Body (Times New Roman) underscoring the importance of monitoring multiple parameters of the carbonate system in highly nearshore environments. and less reliable in nearshore environments and near San Francisco Bay, as has been noted by investigators developing carbonate-system algorithms (Fig. 7; e.g., Alin et al., 2012; Davis et al., 2018). Excluding the San Francisco Bay area, surface TA-salinity relationships are linear and not highly dependent on distance from shore between 5 km and 100 km, though the slope term varies significantly between all regions except Washington and Oregon (Table 3). Within 5 km of shore, TA-salinity relationships in all regions have much weaker fits and have significantly different slopes than the offshore relationships in all regions except Washington. The region around the mouth of San Francisco Bay (between 37.25° N and 38.45° N), TA-salinity relationships are particularly weak, even out to 100 km offshore. The scatter at near-oceanic salinities in the TA-salinity relationship near San Francisco Bay may be a reflection of organic and urban runoff from the Bay Area, as it does not appear to be freshwater-related. While all linear relationships discussed here were significant at the $p < 0.1$ level, the high standard deviations from the TA-salinity regression lines in nearshore environments, and especially within the San Francisco Bay region, translates to 50-200 µmol kg^{-1} of uncertainty in TA concentrations. At depths below 50 m and beyond 100 km from shore, TA-salinity relationships are strong, predictable, and linear, as expected for an open ocean system and successfully leveraged by previous investigators to extrapolate carbonate-system conditions (Alin et al., 2012; Davis et al., 2018; Middelburg et al., 2020). The weakness of coastal TA-salinity relationships underscores the importance of monitoring multiple parameters of the carbonate system.

Region	**Offshore relationship**	**Nearshore relationship**
Washington	Slope: 42.29 ± 0.85 Intercept: 818.30 ± 27.45 R-squared: 0.83	Slope: 39.38 ± 4.83 Intercept: 926.28 ± 152.51 R-squared: 0.74
Oregon	Slope: 42.50 ± 0.62 Intercept: 811.9 ± 20.08 R-squared: 0.88	Slope: 36.19 ± 2.79 Intercept: 1032.11 ± 91.69 R-squared: 0.55
NorCen CA (except the San Francisco Area)	Slope: 54.70 ± 0.67 Intercept: 406.22 ± 22.30 R2: 0.92	Slope: 17.35 ± 5.37 Intercept: 1654.94 ± 179.88 R-squared: 0.04
Near San Francisco Bay	Slope: 7.92 ± 11.98 Intercept: 2011.68 ± 401.26 R-squared: 0	Slope: 25.43 ± 2.66 Intercept: 1401.19 ± 88.59 R-squared: 0.11
Southern California	Slope: 49.77 ± 1.23 Intercept: 569.06 ± 41.21 R2: 0.77	Slope: 9.12 ± 1.79 Intercept: 1933.98 ± 59.71 R-squared: 0.04

Table 3: Regional surface (<50 m) total alkalinity (TA)-salinity regression relationships for within 5 km of shore versus between 5 and 100 km of shore. All regression relationships are significant ($p < 0.01$). Offshore surface relationships are generally strong

~~**except in the San Francisco Bay region, where they are completely non-predictive. Nearshore relationships are weaker than their offshore counterparts in Washington, Oregon, and Southern California and are functionally not predictive in southern CA and the San Francisco Bay region.**~~


(a)
TA = 756.6 + 44.2 S
P < 0.001, R2 = 0.92
TA
2400
2200
2000
30
32
34
km
75
50
25
(b)
TA = 1337 + 26.98 S
P < 0.001, R2 = 0.29
TA
2400
2200
2000
30
32
34
km
4
3
2
1
0
(c)
TA = 1497 + 22.73 S
P < 0.001, R2 = 0.08
TA
2400
2200
2000
30
32
34
Salinity
km
60
40
20
0

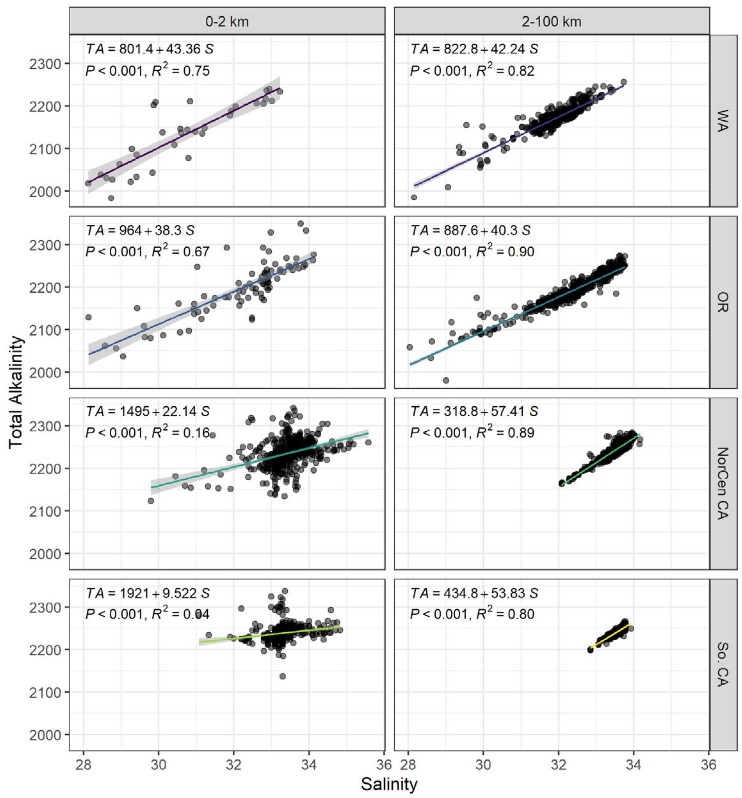


Figure 7: Regional~~Coast-wide~~ near-surface (< 25~~50~~ m) total alkalinity (TA)-salinity relationships from 0-2 km from shore and 2-100 km offshore in along the U.S. West Coast. As with Figure 5, the break between northern and southern CA is Point Conception, at 34.5° N. These relationships reflect only direct measurements of salinity and TA on discrete samples~~ from 5-100 km~~ with salinity > 28. ~~offshore (a), 0-5 km offshore (b), and near the mouth of San Francisco Bay (c). Excluding the San Francisco area, TA-salinity relationships between 5 km and 100 km offshore are strong and linear, with small differences between geographic regions. Within 5 km of shore throughout the Coast and within 100 km of San Francisco Bay (right), the TA-salinity relationships are much less reliable. This limits the utility of carbonate-system algorithms and emphasizes the need to fully characterize the carbonate-system through simultaneous measurements of two master parameters to effectively assess nearshore acidification conditions.~~

3.7~~6~~ Dataset Limitations

This data compilation reflects reliable~~high quality~~, publicly available data, and directly contributes to our ability to map coastal temperature, DO~~dissolved oxygen~~, and carbonate~~-~~system variation; however, this synthesis also encodes the limitations of the current ~~our~~ observational record and the differences in data availability, data scales, and data quality. High resolution autonomous sensors provide excellent temporal resolution for a specific location, but are vulnerable to sensor drift, are not often published with clear calibration records, and are rarely deployed in arrays that fully capture the carbonate system as well as temperature and ~~dissolved oxygen~~DO variability. Conversely, discrete samples and CTD profiles from synoptic cruises provide extremely high-precision, multiparameter observations with broad spatial resolution, but are less relatable to high-resolution sensors or hand-collected observations from the surf zone. Carbonate-system observation availability has a strong seasonal and spatial bias, with data concentrated in summer months and along coastal population centers. The MOCHA synthesis pulls these distinct data sources into a single location, but we do not claim to have fully resolved the inherent difficulties of combining data of differing quantity, resolution, and quality into a unified picture of the nearshore CCS.

Additional data streams that provide both spatial and temporal resolution could help bridge some of the divides between quality, quantity, and spatial extent in this synthesis and we acknowledge a few such potential data streams here. The temperature and dissolved oxygen records do not include CTD casts from most annual fishery-independent surveys, which could improve spatial resolution at all depths (e.g., Sakuma, 2022). This compilation also excludes some ~~potentially~~ valuable carbonate system data streams, particularly those focused on pCO_2 measurements currently available through SOCAT (Sabine et al., 2013; Bakker et al., 2016). ~~For example,~~Additional potential ~~additional~~carbonate system data sources include ~~underway pCO_2 records from transiting oceanographic ships or sail drones,~~ pH or pCO_2 records from autonomous gliders (e.g.,~~.~~ Chavez et al., 2017)~~,~~ and pCO_2 and DIC records from shore-based monitoring systems (e.g., Burke-o-Lators; Hales et al., 2004; Bandstra et al., 2006). The first would significantly improve the spatial coverage of surface pCO_2 and could improve seasonal bias, but would not have a significant impact on our ability to resolve the full carbonate system or to consider deeper water. Glider datasets would similarly improve our spatial coverage while providing additional information about water column structure. These could represent a valuable expansion to this synthesis, provided calibration records are also available, and will likely be included in updates to this synthesis product (Bushinsky et al., 2019). Shore-based monitoring systems recently deployed by the West Coast OOIs would~~will~~ also be valuable expansions to this synthesis and will also likely be included in an updated product.

4 Conclusions

The CCS is one of the most intensively monitored marine ~~eco~~systems in the world, but our ability to accurately resolve the true complexity of coastal climate stress remains limited by data fragmentation, availability, and quality. As interest has shifted from documentation of the global patterns of acidification and hypoxia to more complex coastal environments, the CCS has seen an explosion in ~~nearshore (<50 km) and very nearshore (<5 km)~~ monitoring efforts within 50 km of shore in the last 15 years. This expansion~~losion~~ has included an increase in both surface and subsurface monitoring efforts, though within 2 km of shore, monitoring efforts below 5 m depth are still much less common than surface observations~~ in very nearshore environments~~. While this situation is improving, the continued relative paucity of subsurface nearshore measurements is of particular concern given that mildly hypoxic (DO < 107 µ~~u~~mol kg^{-1}) and corrosive conditions have been documented at depths as shallow as 10 m (Kekuewa et al., 2022).

Surprisingly, the U.S. West Coast had especially continuous spatial and temporal coverage of OAH-relevant parameters between 2012 and the beginning of 2015, before a reduction in coverage that lasted through 2020 (Fig. 5). By coincidence, the reduction in DO~~dissolved oxygen~~ and carbonate ~~-~~system monitoring in 2015 coincided with the second half of the marine heatwave known as "the Blob", which stretched from 2014 through 2016 and was associated with higher surface DO and pH (Bond et al., 2015; Siedlecki et al., 2016; Gentemann et al., 2017). Assessing the interactions of an unprecedented marine heatwave with DO and carbonate s~~-s~~ystem conditions lies at the heart of multi~~-~~stressor risk management; however, our ability to resolve both Blob impacts and its recovery was very limited in Northern California and Oregon by the concurrent contraction in oceanographic monitoring. Although the CCS is well monitored compared to many other parts of the world's oceans, our synthesis here highlights that the~~t a~~ patchiness~~hwork~~ of monitoring projects, often driven by inconsistent funding, has an outsized impact on our ability to utilize that data to understand how the CCS is changing.

While increasing interest in coastal OAH monitoring and the availability of autonomous sensors has markedly enhanced CCS data availability, the frequency and footprints of synoptic oceanographic cruises has decreased in the region. Oceanographic cruises provide highly accurate and spatially broad water column measurements that can bridge the gap between the coastal and open-ocean domains and provide regional contexts for local observations. They also provide some of our only observations near remote portions of the coast. However, nearly all routine oceanographic cruises in the CCS have cut back their footprint, sampling frequency, and depth resolution. The Southern California-based CalCOFI cruises extended throughout the CCS during the 1960s, contracted to Southern and Central California by the 1980s, and now only covers the Southern California Bight while also sampling at significantly fewer depths (Bograd et al., 2003). The loss of CalCOFI cruises in Central California has been offset in part by triannual Applied California Current Ecosystem Studies cruises near San Francisco Bay, though these cruises are limited to the continental shelf between 37.3° N and 38.4° N. The NOAA West Coast Ocean Acidification c~~C~~ruises took place along the entire CCS five times from 2007 to ~~-~~2016, but did not occur again until 2021 ~~but a 2017 cruise only included Washington ~~(Feely et al., 2016a; Feely et al., 2022~~Alin et al., 2019~~). The shift towards high-resolution, nearshore monitoring is a significant improvement over a wholesale reduction in oceanographic monitoring, but the concurrent erosion of consistent oceanographic cruises means the ability to resolve large-scale regional patterns is being traded for highly~~-~~ specific understanding of a few select locations.

This synthesis dataset provides one of the largest compilations to date of West Coast nearshore acidification and deoxygenation related data. This dataset highlights monitoring gaps, but equally provides opportunities for insight into coastal conditions. With the updated spatiotemporal resolution our this effort affords, this dataset offers a wealth of opportunities to investigate questions about coastal oceanography and evaluate localized patterns of marine climate stress. We expect the MOCHA synthesis to also be of use for new projects combining temperature and DOdissolved oxygen records into species metabolic indices (e.g., Howard et al., 2020b), for investigating the frequency and interaction of individual and overlapping ocean acidification and hypoxic events (e.g., Burger et al., 2022), and for developing updated carbonate system algorithms more suited to coastalnearshore environments (e.g., Alin et al., 2012; Davis et al., 2018).; and for evaluating the efficacy of spatial management zones such as Marine Protected Areas (Hamilton et al., in press). By archiving this dataset at the National Centers for Environmental Information (https://doi.org/10.25921/2vve-fh39; Kennedy et al., 2023) in an easily manipulated, consistent format that includes relevant metadata and quality assurance, we provide an important tool for scientists across ecological, oceanographic, and social disciplines as well asnd coastal decision-makers to address the environmental, economic, and cultural needs of coastal communities.

5 Data Availability

The full Multistressor Observations of Coastal Hypoxia and Acidification dataset, parameter metadata, and datasetetailed metadata tables are publicly available for download at NCEI as Accession 0277984 with the DOI 10.25921/2vve-fh39 (Kennedy et al., 2023). The downloadable content includes the full MOCHA dataset available as a text file, the daily summarized dataset discussed extensively above available as a text file (aggregated_daily_dataset.csv), standard NCEI accession parameter metadata which provides an overview for each variable included in the text files ("SubmissionForm_carbon_v1_428.xlsx"), and a bespoke dataset metadata table describing each included dataset with citations and links to reference papers (MOCHA_dataset_metadata_table_v2.csv). This data package is discoverable via the NOAA Ocean Acidification Portal, NCEI Geoportal (https://www.ncei.noaa.gov/metadata/geoportal/#searchPanel), and other online discovery tools. The dataset metadata table is also available in the Supplemental Information for this paper. This data set is discoverable via the NOAA Ocean Acidification Portal, NCEI Geoportal (https://www.ncei.noaa.gov/metadata/geoportal/#searchPanel), and other online discovery tools.

6 Fair Use Data Statement

We request that all users of the MOCHA compilation also fully credit the constituent datasets supporting their work. This helps ensure that the ocean monitoring systems that this, and other, compilations depend on receive trackable citations and continued funding. We also recommend contacting the original principal investigators to discuss collaboration opportunities and to enthusiastically look for opportunities to further include or credit these data providers. Full citation information, dataset DOIs, and reference papers (where available) for each individual dataset in the MOCHA compilation can be found in the References as well as in the MOCHA_dataset_metadata_table.csv available at NCEI (https://www.ncei.noaa.gov/data/oceans/ncei/ocads/data/0277984/).

76 Code Availability

Code for performing carbonate -system calculations with the formatted dataset, creating a summarized dataset aggregated by day, and making all included figures is available on GitHub at https://github.com/egkennedy/DSP_public_codehttps://github.com/egkennedy/DSP_public_code.

Formatted: Default Paragraph Font

Competing Interests

The authors declare that they have no conflicts of interest.

Author Contributions

After the first four, authors are listed alphabetically in two groups: those who contributed significantly to data acquisition, interpretation, and overall project direction and those who contributed to data curation. All authors read, edited and approved of the manuscript. EGK wrote original draft and led data curation and quality control methodology. MZ and SLH provided substantial manuscript reviews, data curation, and methodology insights. TMH led project conceptualization, funding acquisition, and supervision, and provided substantial manuscript review. TMH, KJK, JJ, CF, and ME provided previously unpublished data for inclusion. KJK, AKS, BG, ES, and MW contributed to funding acquisition and project conceptualization. HMP, MW, AMR, GVG, CNR, GC, MD, MIW, EH, and SW provided data curation and sourced new datasets for inclusion.

Acknowledgements

This project received funding from the following sources: California Ocean Protection Council (Hill, Sanford, Gaylord, Kroeker, Spalding) Lenfest Ocean Program (to Hill, Sanford, Gaylord, Kroeker, Spalding), NOAA Ocean Acidification Program (to Hill and Spalding), Packard Foundation (Hill, Sanford, Gaylord, Kroeker), and National Park Service (to Hill) and National Science Foundation (to Kennedy, Grant No. 1734999). We value the partnership of the Applied California Current Ecosystem Studies Partnership (ACCESS, www.accessoceans.org), an ongoing collaboration between Point Blue Conservation Science and Greater Farallones and the Cordell Bank National Marine Sanctuaries to support healthy oceans in north-central California. Brady O'Donnell, Priya Shukla, Lena Capece, Seth Miller, Sarah Merolla, Daphne Bradley and Danielle Lipski assisted with data collection and management. We thank Rachel Carlson and Alyssa Griffin for sharing their advice, expertise, and feedback at key points in the project. We also thank the UC Davis Data Lab for their assistance with data management and coding.

References

Alin, S. R., Feely, R. A., Dickson, A. G., Hernández-Ayón, J. M., Juranek, L. W., Ohman, M. D., and Goericke, R.: Robust empirical relationships for estimating the carbonate system in the southern California Current System and application to CalCOFI hydrographic cruise data (2005–2011), J. of Geophys. Res.: Oceans, 117, https://doi.org/10.1029/2011JC007511, 2012.

Alin, S. R., Newton, J., Sutton, A. J., and Mickett, J.: Dissolved inorganic carbon, total alkalinity, phosphate, silicate, and other variables collected from profile and discrete sample observations using CTD, Niskin bottle and other instruments in the northwest coast of the United States near the ChÃ¡ BÄƒ mooring off La Push, Washington from 2011-05-22 to 2014-10-24 (NCEI Accession 0145160), NOAA National Centers for Environmental Information [data set], https://doi.org/10.7289/v5b27sbj, 2016.

Alin, S. R., Feely, R. A., Hales, B., Byrne, R. H., Cochlan, W., Liu, X., and Greely, D.: Dissolved inorganic carbon, total alkalinity, pH on total scale, and other variables collected from profile and discrete sample observations using CTD, Niskin bottle, and other instruments from NOAA Ship Ronald H. Brown in the U.S. West Coast California Current System from 2016-05-08 to 2016-06-06 (NCEI Accession 0169412), NOAA National Centers for Environmental Information [data set], https://doi.org/10.7289/v5v40shg, 2017.

Alin, S. R., Feely, R. A., Newton, J., Trainer, V. L., Adams, N. G., Greeley, D., Curry, B., Herndon, J., and Ostendorf, M. L.: Dissolved inorganic carbon (DIC), total alkalinity (TA), temperature, salinity, oxygen, and nutrient data collected from discrete profile measurements during the National Oceanic and Atmospheric Administration Harmful Algal Blooms (NOAA HABs) program cruise SH1709 (EXPOCODE 3322220170918) in Pacific Northwest marine waters on NOAA Ship Bell M. Shimada from 2017-09-18 to 2017-09-28. (NCEI Accession 0208230), NOAA National Centers for Environmental Information, ~~NCEI Accession number 0208230~~ [data set], https://doi.org/doi.org/10.25921/3qa5-v720, 2019.

Aylesworth, L., Fields, S. A., Fields, R. T., and Kane, C.: Oceanography Appendix Report, Oregon Department of Fish and Wildlife Marine Resources Program, Newport, OR, https://ecologyreports.oregonmarinereserves.com/Data_Files/6.%20Across%20Reserves/Oceanography/Oceanography_Appendix.html, 2022.

Bakker, D. C. E., Pfeil, B., Landa, C. S., Metzl, N., O'Brien, K. M., Olsen, A., Smith, K., Cosca, C., Harasawa, S., Jones, S. D., Nakaoka, S., Nojiri, Y., Schuster, U., Steinhoff, T., Sweeney, C., Takahashi, T., Tilbrook, B., Wada, C., Wanninkhof, R., Alin, S. R., Balestrini, C. F., Barbero, L., Bates, N. R., Bianchi, A. A., Bonou, F., Boutin, J., Bozec, Y., Burger, E. F., Cai,

Formatted: English (United Kingdom)

W.-J., Castle, R. D., Chen, L., Chierici, M., Currie, K., Evans, W., Featherstone, C., Feely, R. A., Fransson, A., Goyet, C., Greenwood, N., Gregor, L., Hankin, S., Hardman-Mountford, N. J., Harlay, J., Hauck, J., Hoppema, M., Humphreys, M. P., Hunt, C. W., Huss, B., Ibánhez, J. S. P., Johannessen, T., Keeling, R., Kitidis, V., Körtzinger, A., Kozyr, A., Krasakopoulou, E., Kuwata, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lo Monaco, C., Manke, A., Mathis, J. T., Merlivat, L., Millero, F. J., Monteiro, P. M. S., Munro, D. R., Murata, A., Newberger, T., Omar, A. M., Ono, T., Paterson, K., Pearce, D., Pierrot, D., Robbins, L. L., Saito, S., Salisbury, J., Schlitzer, R., Schneider, B., Schweitzer, R., Sieger, R., Skjelvan, I., Sullivan, K. F., Sutherland, S. C., Sutton, A. J., Tadokoro, K., Telszewski, M., Tuma, M., van Heuven, S. M. A. C., Vandemark, D., Ward, B., Watson, A. J., and Xu, S.: A multi-decade record of high-quality *f*CO_2 data in version 3 of the Surface Ocean CO_2 Atlas (SOCAT), Earth Syst. Sci. Data, 8, 383–413, https://doi.org/10.5194/essd-8-383-2016, 2016.

Bakun, A., Black, B. A., Bograd, S. J., García-Reyes, M., Miller, A. J., Rykaczewski, R. R., and Sydeman, W. J.: Anticipated effects of climate change on coastal upwelling ecosystems, Curr. Clim. Change Rep., 1, 85–93, https://doi.org/10.1007/s40641-015-0008-4, 2015.

Bandstra, L., Hales, B., and Takahashi, T.: High-frequency measurements of total CO2: Method development and first oceanographic observations, Mar. Chem., 100, 24–38, https://doi.org/10.1016/j.marchem.2005.10.009, 2006.

Baptista, A. M., Seaton, C., Wilkin, M. P., Riseman, S. F., Needoba, J. A., Maier, D., Turner, P. J., Kärnä, T., Lopez, J. E., Herfort, L., Megler, V. M., McNeil, C., Crump, B. C., Peterson, T. D., Spitz, Y. H., and Simon, H. M.: Infrastructure for collaborative science and societal applications in the Columbia River estuary, Front. Earth Sci., 9, 659–682, https://doi.org/10.1007/s11707-015-0540-5, 2015.

Barth, J. A., Erofeev, A., and Chan, F.: Oceanographic data across Oregon's marine reserves, Oregon State University, Oregon Department of Fish and Wildlife Marine Resources Program, Newport, OR, 2021.

Barton, A., Waldbusser, G. G., Feely, R. A., Weisberg, S. B., Newton, J. A., Hales, B., Cudd, S., Eudeline, B., Langdon, C. J., Jefferds, I., King, T., Suhrbier, A., and McLaughlin, K.: Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response, Oceanography, 28, 146–159, 2015.

Bauer, J. E., Cai, W.-J., Raymond, P. A., Bianchi, T. S., Hopkinson, C. S., and Regnier, P. A. G.: The changing carbon cycle of the coastal ocean, Nature, 504, 61–70, https://doi.org/10.1038/nature12857, 2013.

Bednaršek, N., Feely, R. A., Howes, E. L., Hunt, B. P. V., Kessouri, F., León, P., Lischka, S., Maas, A. E., McLaughlin, K., Nezlin, N. P., Sutula, M., and Weisberg, S. B.: Systematic review and meta-analysis toward synthesis of thresholds of ocean acidification impacts on calcifying pteropods and interactions with warming, Front. Mar. Sci., 0, https://doi.org/10.3389/fmars.2019.00227, 2019.

Bednaršek, N., Ambrose, R., Calosi, P., Childers, R. K., Feely, R. A., Litvin, S. Y., Long, W. C., Spicer, J. I., Štrus, J., Taylor, J., Kessouri, F., Roethler, M., Sutula, M., and Weisberg, S. B.: Synthesis of thresholds of ocean acidification impacts on decapods, Front. Mar. Sci., 8, https://doi.org/10.3389/fmars.2021.651102, 2021.

Bjorkstedt, E. P. and Peterson, W. T.: Chapter 8 - Zooplankton Data from High-Frequency Coastal Transects: Enriching the Contributions of Ocean Observing Systems to Ecosystem-Based Management in the Northern California Current, in: Coastal

Ocean Observing Systems, edited by: Liu, Y., Kerkering, H., and Weisberg, R. H., Academic Press, 119–142, https://doi.org/10.1016/B978-0-12-802022-7.00008-0, 2015.

Bjorkstedt, E. P. and Peterson, W. T.: Zooplankton data from high-frequency coastal transects, in: Coastal Ocean Observing Systems, Elsevier, 119–142, https://doi.org/10.1016/B978-0-12-802022-7.00008-0, 2015.Bezalel S., Davis, J., Featherston, T., Flores, L., Grosso, C., Hale, T., Shusterman, G., Sutton, R., Weaver, M., Wong, A., and Yee, D.: Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), San Francisco Estuary Institute (SFEI) [data set], https://www.sfei.org/programs/sf-bay-regional-monitoring-program, 2021.

Bjorkstedt, E. P.: Trinidad Head Line CTD Hydrogeography [data set], https://oceanview.pfeg.noaa.gov/erddap/tabledap/swfscTrinidadCTD.html, 2023.

Bograd, S. J., Checkley, D. A., and Wooster, W. S.: CalCOFI: a half century of physical, chemical, and biological research in the California Current System, Deep Sea Res. Part II: Topical Studies in Oceanography, 50, 2349–2353, https://doi.org/10.1016/S0967-0645(03)00122-X, 2003.

Bograd, S. J., Castro, C. G., Lorenzo, E. D., Palacios, D. M., Bailey, H., Gilly, W., and Chavez, F. P.: Oxygen declines and the shoaling of the hypoxic boundary in the California Current, Geophys. Res. Lett., 35, https://doi.org/10.1029/2008GL034185, 2008.

Bograd, S. J., Schroeder, I., Sarkar, N., Qiu, X., Sydeman, W. J., and Schwing, F. B.: Phenology of coastal upwelling in the California Current, Geophys. Res. Lett., 36, https://doi.org/10.1029/2008GL035933, 2009.

Bond, N. A., Cronin, M. F., Freeland, H., and Mantua, N.: Causes and impacts of the 2014 warm anomaly in the NE Pacific, Geophys. Res. Lett., 42, 3414–3420, https://doi.org/10.1002/2015GL063306, 2015.

Borges, A. V. and Gypens, N.: Carbonate chemistry in the coastal zone responds more strongly to eutrophication than ocean acidification, Limnol. Oceanogr., 55, 346–353, https://doi.org/10.4319/lo.2010.55.1.0346, 2010.

Breitburg, D. L., Salisbury, J., Bernhard, J. M., Cai, W.-J., Dupont, S., Doney, S. C., Kroeker, K. J., Levin, L. A., Long, W. C., Milke, L. M., Miller, S. H., Phelan, B., Passow, U., Seibel, B. A., Todgham, A. E., and Tarrant, A. M.: And on top of all that…: Coping with ocean acidification in the midst of many stressors, Oceanography, 28, 48–61, 2015.

Burger, F. A., Terhaar, J., and Frölicher, T. L.: Compound marine heatwaves and ocean acidity extremes, Nat. Commun., 13, 4722, https://doi.org/10.1038/s41467-022-32120-7, 2022.

Bushinsky, S. M., Takeshita, Y., and Williams, N. L.: Observing changes in ocean carbonate chemistry: Our autonomous future, Curr. Clim. Change Rep., 5, 207–220, https://doi.org/10.1007/s40641-019-00129-8, 2019.

Bushnell, M.: Quality Control of Real-Time Water Level Data: The U.S. IOOS® QARTOD Project, Mar. Technol. Soc. J., 52, 13–17, https://doi.org/10.4031/MTSJ.52.2.2, 2018.

Byrne, M. and Przeslawski, R.: Multistressor impacts of warming and acidification of the ocean on marine invertebrates' life histories, Integr. Comp. Biol., 53, 582–596, https://doi.org/10.1093/icb/ict049, 2013.

Formatted: English (United Kingdom)

Cai, W.-J., Hu, X., Huang, W.-J., Murrell, M. C., Lehrter, J. C., Lohrenz, S. E., Chou, W.-C., Zhai, W., Hollibaugh, J. T., Wang, Y., Zhao, P., Guo, X., Gundersen, K., Dai, M., and Gong, G.-C.: Acidification of subsurface coastal waters enhanced by eutrophication, Nat. Geosci., 4, 766–770, https://doi.org/10.1038/ngeo1297, 2011.

Caldeira, K. and Wickett, M. E.: Anthropogenic carbon and ocean pH, Nature, 425, 365–365, https://doi.org/10.1038/425365a, 2003.

California Cooperative Oceanic Fisheries Investigations (CalCOFI): Bottle Database [data set], https://calcofi.org/data/oceanographic-data/bottle-database/, 2020.

California Polytechnic State University, Center for Coastal Marine Sciences: Morro Bay - BS1 [data set], https://data.cencoos.org/#metadata/100050/station, 2023.

Carter, M. L., Flick, R. E., Terrill, E., Beckhaus, E. C., Martin, K., Fey, C. L., Walker, P. W., Largier, J. L., and McGowan, J. A.: Shore Stations Program Data Archive: Current and historical coastal ocean temperature and salinity measurements from California stations, UC San Diego Library Digital Collections [data set], https://doi.org/10.6075/J06T0K0M, 2021.

Cavole, L., Demko, A., Diner, R., Giddings, A., Koester, I., Pagniello, C., Paulsen, M.-L., Ramirez-Valdez, A., Schwenck, S., Yen, N., Zill, M., and Franks, P.: Biological impacts of the 2013–2015 warm-water anomaly in the Northeast Pacific: Winners, losers, and the future, Oceanography, 29, https://doi.org/10.5670/oceanog.2016.32, 2016.

Chan, F. and Menge, B. A.: SH70 SAMI pCO2 from SH70 mooring 2009-MI_LOCO-Lander, 2010-MI_LOCO-Lander in the SH70 mid-shelf time series station (Strawberry Hill): 44.25N, 124.50W from 2009-2010 (EAGER project), December 2012 ver 04, Biological and Chemical Oceanography Data Management Office (BCO-DMO) [data set], http://lod.bco-dmo.org/id/dataset/3812, 2012.

Chan, F., Barth, J. A., Lubchenco, J., Kirincich, A., Weeks, H., Peterson, W. T., and Menge, B. A.: Emergence of anoxia in the California Current Large Marine Ecosystem, Science, 319, 920–920, https://doi.org/10.1126/science.1149016, 2008.

Chan, F., Barth, J. A., Blanchette, C. A., Byrne, R. H., Chavez, F., Cheriton, O., Feely, R. A., Friederich, G., Gaylord, B., Gouhier, T., Hacker, S., Hill, T., Hofmann, G., McManus, M. A., Menge, B. A., Nielsen, K. J., Russell, A., Sanford, E., Sevadjian, J., and Washburn, L.: Persistent spatial structuring of coastal ocean acidification in the California Current System, Sci. Rep.-U.K., 7, 1–7, https://doi.org/10.1038/s41598-017-02777-y, 2017.

Chan, F., Barth, J. A., Kroeker, K. J., Lubchenco, J., and Menge, B. A.: The dynamics and impact of ocean acidification and hypoxia: Insights from sustained investigations in the Northern California Current Large Marine Ecosystem, Oceanography, 32, 62–71, 2019.

Chavez, F., Pennington, J. T., Michisaki, R., Blum, M., Chavez, G., Friederich, J., Jones, B., Herlien, R., Kieft, B., Hobson, B., Ren, A., Ryan, J., Sevadjian, J., Wahl, C., Walz, K., Yamahara, K., Friederich, G., and Messié, M.: Climate variability and change: Response of a coastal ocean ecosystem, Oceanography, 30, 128–145, https://doi.org/10.5670/oceanog.2017.429, 2017.

Chavez, F. P. and Messié, M.: A comparison of Eastern Boundary Upwelling Ecosystems, Prog. Oceanogr., 83, 80–96, https://doi.org/10.1016/j.pocean.2009.07.032, 2009.

Cheresh, J. and Fiechter, J.: Physical and biogeochemical drivers of alongshore pH and oxygen variability in the California Current System, Geophys. Res. Lett., 47, e2020GL089553, https://doi.org/10.1029/2020GL089553, 2020.

805 Cheung, W. W. L. and Frölicher, T. L.: Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific, Sci. Rep.-U.K., 10, 6678, https://doi.org/10.1038/s41598-020-63650-z, 2020.

Clements, J. C. and Chopin, T.: Ocean acidification and marine aquaculture in North America: potential impacts and mitigation strategies, Rev. Aquacult., 9, 326–341, https://doi.org/10.1111/raq.12140, 2017.

Coastal Data Information Program (CDIP): Cabrillo Point, Monterey Bay, CA - 158 (46240) [data set],
810 https://data.cencoos.org/#metadata/18373/station, 2023.

Columbia River Intertribal Fish Commission Center for Coastal Margin Observation and Prediction.: SATURN Observation Network Endurance Stations: SATURN-02 [data set], https://cmop.critfc.org/datamart/observation-network/fixed-station/?id=saturn02&tab=inventory#anchor_38, 2023.

Connolly, T. P., Hickey, B. M., Geier, S. L., and Cochlan, W. P.: Processes influencing seasonal hypoxia in the northern
815 California Current System, J. Geophys. Res.: Oceans, 115, https://doi.org/10.1029/2009JC005283, 2010.

Davis, C. V., Hewett, K., Hill, T. M., Largier, J. L., Gaylord, B., and Jahncke, J.: Reconstructing aragonite saturation state based on an empirical relationship for Northern California, Estuaries Coast., 41, 2056–2069, https://doi.org/10.1007/s12237-018-0372-0, 2018.

Cullison Gray, S. E., DeGrandpre, M. D., Moore, T. S., Martz, T. R., Friederich, G. E., and Johnson, K. S.: Applications of
820 in situ pH measurements for inorganic carbon calculations, Mar. Chem., 125, 82–90, https://doi.org/10.1016/j.marchem.2011.02.005, 2011.

DeGrandpre, M.: pCO2, pH, salinity and temperature data collected off the coast of Oregon, USA by a SAMI-CO2 sensor on the Shelf Break Mooring located below the National Data Buoy Center's meteorological Buoy 46050; 2007-2011 (NH10_ShelfBreak_MLR project), January 2016 ver 12, Biological and Chemical Oceanography Data Management Office
825 (BCO-DMO) [data set], http://lod.bco-dmo.org/id/dataset/632498, 2016.

Dewitt, L.: SFSU EOS YSI Raw data [data set], https://oceanview.pfeg.noaa.gov/erddap/tabledap/rtcctdRTCysirt.html, 2022.

Dickson, A. G. and Sabine, C. L.: The carbon dioxide system in seawater: Equilibrium chemistry and measurements, 199,
830 2010.

Dickson, A. G.: The carbon dioxide system in seawater: Equilibrium chemistry and measurements, in: Guide to best practices for ocean acidification research and data reporting, 17–40, 2010.

Doney, S. C.: The growing human footprint on coastal and open-ocean biogeochemistry, Science, 328, 1512–1516, https://doi.org/10.1126/science.1185198, 2010.

835 Doney, S. C., Fabry, V. J., Feely, R. A., and Kleypas, J. A.: Ocean acidification: The other CO_2 Problem, Annu. Rev. of Mar. Sci., 1, 169–192, https://doi.org/10.1146/annurev.marine.010908.163834, 2009.

Formatted: English (United Kingdom)

Formatted: English (United Kingdom)

Donham, E., Strope, L., Hamilton, S., and Kroeker, K.: Coupled changes in pH, temperature and dissolved oxygen impact the physiology and ecology of herbivorous kelp forest grazers, Dryad [data set], https://doi.org/10.5061/dryad.8sf7m0cq7, 2022a.

Donham, E. M., Strope, L. T., Hamilton, S. L., and Kroeker, K. J.: Coupled changes in pH, temperature, and dissolved oxygen impact the physiology and ecology of herbivorous kelp forest grazers, Glob. Change. Biol., 28, 3023–3039, https://doi.org/10.1111/gcb.16125, 2022b.

Donham, E. M., Flores, I., Hooper, A., O'Brien, E., Vylet, K., Takeshita, Y., Freiwald, J., and Kroeker, K. J.: Population-specific vulnerability to ocean change in a multistressor environment, Sci. Adv., 9, eade2365, https://doi.org/10.1126/sciadv.ade2365, 2023.

Ekstrom, J. A., Suatoni, L., Cooley, S. R., Pendleton, L. H., Waldbusser, G. G., Cinner, J. E., Ritter, J., Langdon, C., van Hooidonk, R., Gledhill, D., Wellman, K., Beck, M. W., Brander, L. M., Rittschof, D., Doherty, C., Edwards, P. E. T., and Portela, R.: Vulnerability and adaptation of US shellfisheries to ocean acidification, Nature Clim. Change, 5, 207–214, https://doi.org/10.1038/nclimate2508, 2015.

Fassbender, A. J., Sabine, C. L., Feely, R. A., Langdon, C., and Mordy, C. W.: Inorganic carbon dynamics during northern California coastal upwelling, Cont. Shelf Res., 31, 1180–1192, https://doi.org/10.1016/j.csr.2011.04.006, 2011.

~~Duarte, C. M., Hendriks, I. E., Moore, T. S., Olsen, Y. S., Steckbauer, A., Ramajo, L., Carstensen, J., Trotter, J. A., and McCulloch, M.: Is ocean acidification an open-ocean syndrome? Understanding anthropogenic impacts on seawater pH, Estuaries Coast., 36, 221–236, https://doi.org/10.1007/s12237-013-9594-3, 2013.~~Fassbender, A. J., Alin, S. R., Feely, R. A., Sutton, A. J., Newton, J. A., and Byrne, R. H.: Estimating Total Alkalinity in the Washington State Coastal Zone: Complexities and Surprising Utility for Ocean Acidification Research, Estuar. Coast., 40, 404–418, https://doi.org/10.1007/s12237-016-0168-z, 2017.

Feely, R. A., Sabine, C. L., Hernandez-Ayon, J. M., Ianson, D., and Hales, B.: Evidence for upwelling of corrosive "acidified" water onto the continental shelf, Science, 320, 1490–1492, https://doi.org/10.1126/science.1155676, 2008.

Feely, R. A. and Sabine, C. L.: Dissolved inorganic carbon, alkalinity, temperature, salinity and other variables collected from discrete sample and profile observations using Alkalinity titrator, CTD and other instruments from WECOMA in the U.S. West Coast California Current System from 2007-05-11 to 2007-06-14 (NCEI Accession 0083685), NOAA National Centers for Environmental Information [data set], https://doi.org/10.3334/cdiac/otg.clivar_nacp_west_coast_cruise_2007, 2013.

Feely, R. A., Alin, S. R., Hales, B., Johnson, G. C., Byrne, R. H., Peterson, W. T., Liu, X., and Greeley, D.: Dissolved inorganic carbon, total alkalinity, pH on total scale and other variables collected from profile and discrete sample observations on NOAA Ship Fairweather (EXPOCODE 317W20130803) and R/V Point Sur (EXPOCODE 32P020130821) in the U.S. West Coast California Current System during the 2013 West Coast Ocean Acidification Cruise (WCOA2013) from 2013-08-03 to 2013-08-29 (NCEI Accession 0132082), NOAA National Centers for Environmental Information [data set], https://doi.org/10.7289/v5c53hxp, 2015a.

Formatted: English (United Kingdom)

Field Code Changed

Feely, R. A., Alin, S. R., Hales, B., Johnson, G. C., Juranek, L. W., Byrne, R. H., Peterson, W. T., Goni, M., Liu, X., Greeley, D.: Dissolved inorganic carbon, total alkalinity, pH, temperature, salinity and other variables collected from profile and discrete sample observations using CTD, Niskin bottle, and other instruments from R/V Wecoma in the U.S. West Coast California Current System during the 2011 West Coast Ocean Acidification Cruise (WCOA2011) from 2011-08-12 to 2011-08-30 (NCEI Accession 0123467), NOAA National Centers for Environmental Information [data set], https://doi.org/10.7289/v5jq0xz1, 2015b.

Feely, R. A., Sabine, C. L., Hernandez-Ayon, J. M., Ianson, D., and Hales, B.: Evidence for upwelling of corrosive "acidified" water onto the continental shelf, Science, 320, 1490–1492, https://doi.org/10.1126/science.1155676, 2008.

Feely, R. A., Alin, S. R., Carter, B., Bednaršek, N., Hales, B., Chan, F., Hill, T. M., Gaylord, B., Sanford, E., Byrne, R. H., Sabine, C. L., Greeley, D., and Juranek, L.: Chemical and biological impacts of ocean acidification along the west coast of North America, Estuar. Coast. Shelf Sci., 183, 260–270, https://doi.org/10.1016/j.ecss.2016.08.043, 2016a.

Feely, R. A., Alin, S. R., Hales, B., Johnson, G. C., Juranek, L. W., Peterson, W. T., and Greeley, D.: Dissolved inorganic carbon, alkalinity, temperature, salinity and other variables collected from discrete sample and profile observations using Alkalinity titrator, CTD and other instruments from NOAA Ship Bell M. Shimada in the Columbia River estuary - Washington/Oregon, Gulf of the Farallones National Marine Sanctuary and others from 2012-09-04 to 2012-09-17 (NCEI Accession 0157445), NOAA National Centers for Environmental Information [data set], https://doi.org/10.25921/e7m6-gh32, 2016b.

Feely, R. A., Carter, B. R., Greeley, D., McCabe, R. M., and Herndon, J.: Dissolved inorganic carbon (DIC), total alkalinity (TA), pH, temperature, salinity, oxygen, and nutrient data collected from discrete profile measurements during the National Oceanic and Atmospheric Administration Ocean Acidification Program (OAP) program cruise WCOA2021 (EXPOCODE 33RO20210613) in the northeast Pacific marine waters on NOAA Ship Ronald H. Brown from 2021-06-13 to 2021-07-26 (NCEI Accession 0260718). NOAA National Centers for Environmental Information [data set], https://doi.org/10.25921/tzxh-n954, 2022.

Field, J. C. and Francis, R. C.: Considering ecosystem-based fisheries management in the California Current, Mar. Policy, 30, 552–569, https://doi.org/10.1016/j.marpol.2005.07.004, 2006.

Frieder, C. A., Nam, S. H., Martz, T. R., and Levin, L. A.: High temporal and spatial variability of dissolved oxygen and pH in a nearshore California kelp forest, Biogeosciences, 9, 3917–3930, https://doi.org/10.5194/bg-9-3917-2012, 2012.

Frölicher, T. L. and Laufkötter, C.: Emerging risks from marine heat waves, Nat. Commun., 9, 650, https://doi.org/10.1038/s41467-018-03163-6, 2018.

Free, C. M., Anderson, S. C., Hellmers, E. A., Muhling, B. A., Navarro, M. O., Richerson, K., Rogers, L. A., Satterthwaite, W. H., Thompson, A. R., Burt, J. M., Gaines, S. D., Marshall, K. N., White, J. W., and Bellquist, L. F.: Impact of the 2014–2016 marine heatwave on US and Canada West Coast fisheries: Surprises and lessons from key case studies, Fish. Fish., 24, 652–674, https://doi.org/10.1111/faf.12753, 2023.

Formatted: English (United Kingdom)

Field Code Changed

Formatted: Default Paragraph Font

Formatted: English (United Kingdom)

Fumo, J. T., Carter, M. L., Flick, R. E., Rasmussen, L. L., Rudnick, D. L., and Iacobellis, S. F.: Contextualizing marine heatwaves in the Southern California Bight under anthropogenic climate change, J. Geophys. Res. Oceans, 125, https://doi.org/10.1029/2019JC015674, 2020.

García-Reyes, M. and Largier, J.: Observations of increased wind-driven coastal upwelling off central California, J. Geophys. Res. Oceans, 115, https://doi.org/10.1029/2009JC005576, 2010.

García-Reyes, M. and Largier, J. L.: Seasonality of coastal upwelling off central and northern California: New insights, including temporal and spatial variability, J. Geophys. Res.~~-~~Oceans, 117, https://doi.org/10.1029/2011JC007629, 2012.

Gattuso, J.-P., Epitalon, J.-M., Lavigne, H., and Orr, J.: seacarb: Seawater Carbonate Chemistry. R package version 3.2.16, 2023.

~~Gattuso, J. P., Epitalon, J. M., Lavigne, H., and Orr, J.: seacarb: seawater carbonate chemistry. R package version 3.2.10., 2018.~~

Gentemann, C. L., Fewings, M. R., and García-Reyes, M.: Satellite sea surface temperatures along the West Coast of the United States during the 2014–2016 northeast Pacific marine heat wave, Geophys. Res. Lett., 44, 312–319, https://doi.org/10.1002/2016GL071039, 2017.

Gobler, C. J. and Baumann, H.: Hypoxia and acidification in ocean ecosystems: coupled dynamics and effects on marine life, Biol. Lett., 12, 20150976, https://doi.org/10.1098/rsbl.2015.0976, 2016.

Grantham, B. A., Chan, F., Nielsen, K. J., Fox, D. S., Barth, J. A., Huyer, A., Lubchenco, J., and Menge, B. A.: Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific, Nature, 429, 749–754, https://doi.org/10.1038/nature02605, 2004.

Gruber, N., Hauri, C., Lachkar, Z., Loher, D., Frölicher, T. L., and Plattner, G.-K.: Rapid progression of ocean acidification in the California Current System, Science, 337, 220–223, https://doi.org/10.1126/science.1216773, 2012.

Hales, B., Chipman, D., and Takahashi, T.: High-frequency measurement of partial pressure and total concentration of carbon dioxide in seawater using microporous hydrophobic membrane contactors, Limnol. Oceanogr. Methods, 2, 356–364, https://doi.org/10.4319/lom.2004.2.356, 2004.

Hamilton, S. L., Kennedy, E. G., Zulian, M., Hill, T. M., Gaylord, B., Sanford, E., Ricart, A. M., Ward, M., Spalding, A. K., and Kroeker, K.: Variable exposure to multiple climate stressors across the California marine protected area network and policy implications, ICES J. Mar. Sci., fsad120, https://doi.org/10.1093/icesjms/fsad120, 2023.

Hauri, C., Gruber, N., Vogt, M., Doney, S. C., Feely, R. A., Lachkar, Z., Leinweber, A., McDonnell, A. M. P., Munnich, M., and Plattner, G.-K.: Spatiotemporal variability and long-term trends of ocean acidification in the California Current System, Biogeosciences, 10, 193–216, https://doi.org/10.5194/bg-10-193-2013, 2013.

Hickey, B. M.: The California current system—hypotheses and facts, Prog. Oceanogr., 8, 191–279, https://doi.org/10.1016/0079-6611(79)90002-8, 1979.

Hodgson, E. E., Kaplan, I. C., Marshall, K. N., Leonard, J., Essington, T. E., Busch, D. S., Fulton, E. A., Harvey, C. J., Hermann, A. J., and McElhany, P.: Consequences of spatially variable ocean acidification in the California Current: Lower pH drives strongest declines in benthic species in southern regions while greatest economic impacts occur in northern regions, Ecol. Modell., 383, 106–117, https://doi.org/10.1016/j.ecolmodel.2018.05.018, 2018.

Hofmann, A. F., Peltzer, E. T., Walz, P. M., and Brewer, P. G.: Hypoxia by degrees: Establishing definitions for a changing ocean, Deep Sea Res. Part I: Oceanographic Research Papers, 58, 1212–1226, https://doi.org/10.1016/j.dsr.2011.09.004, 2011a.

Hofmann, G. E., Smith, J. E., Johnson, K. S., Send, U., Levin, L. A., Micheli, F., Paytan, A., Price, N. N., Peterson, B., Takeshita, Y., Matson, P. G., Crook, E. D., Kroeker, K. J., Gambi, M. C., Rivest, E. B., Frieder, C. A., Yu, P. C., and Martz, T. R.: High-Frequency dynamics of ocean pH: A multi-ecosystem comparison, PLoS ONEne, 6, e28983, https://doi.org/10.1371/journal.pone.0028983, 2011b.

~~Hollarsmith, J. A., Sadowski, J. S., Picard, M. M. M., Cheng, B., Farlin, J., Russell, A., and Grosholz, E. D.: Effects of seasonal upwelling and runoff on water chemistry and growth and survival of native and commercial oysters, Limnol. Oceanogr., 65, 224–235, https://doi.org/10.1002/lno.11293, 2020.~~

Howard, E. M., Penn, J. L., Frenzel, H., Seibel, B. A., Bianchi, D., Renault, L., Kessouri, F., Sutula, M. A., McWilliams, J. C., and Deutsch, C.: Climate-driven aerobic habitat loss in the California Current System, Sci. Adv., 6, eaay3188, https://doi.org/10.1126/sciadv.aay3188, 2020.

Huyer, A.: Coastal upwelling in the California current system, Prog. Oceanogr., 12, 259–284, https://doi.org/10.1016/0079-6611(83)90010-1, 1983.

IPCC: IPCC special report on the ocean and cryosphere in a changing climate, 1st ed., edited by: Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegria, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., and Weyer, N. M., Cambridge University Press, Cambridge, UK and New York, NY, USA, 755 pp., https://doi.org/10.1017/9781009157964, 2019.

Jacox, M. G., Hazen, E. L., Zaba, K. D., Rudnick, D. L., Edwards, C. A., Moore, A. M., and Bograd, S. J.: Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events, Geophys. Res. Lett., 43, 7072–7080, https://doi.org/10.1002/2016GL069716, 2016.

Jacox, M. G., Edwards, C. A., Hazen, E. L., and Bograd, S. J.: Coastal upwelling revisited: Ekman, Bakun, and improved upwelling indices for the U.S. West Coast, J. Geophys. Res.-–Oceans, 123, 7332–7350, https://doi.org/10.1029/2018JC014187, 2018.

Kekuewa, S. and Andersson, A.: Monthly cross-shore transects of biogeochemical properties in La Jolla, CA, Biological and Chemical Oceanography Data Management Office (BCO-DMO) [data set], doi:10.26008/1912/bco-dmo.839175.1, 2022.

Kekuewa, S. A. H., Courtney, T. A., Cyronak, T., and Andersson, A. J.: Seasonal nearshore ocean acidification and deoxygenation in the Southern California Bight, Sci. Rep., 12, 17969, https://doi.org/10.1038/s41598-022-21831-y, 2022.

Kelly, M. W. and Hofmann, G. E.: Adaptation and the physiology of ocean acidification, Funct. Ecol., 27, 980–990, https://doi.org/10.1111/j.1365-2435.2012.02061.x, 2013.

Formatted: English (United Kingdom)

Kennedy, E. G., Zulian, M., Hamilton, S. L., Hill, T. M., Delgado, M., Fish, C. R., Gaylord, B., Kroeker, K. J., Palmer, H. M., Ricart, A. M., Sanford, E., Spalding, A. K., Ward, M. A., Carrasco, G., Elliott, M., Grisby, G. V., Harris, E., Jahncke, J., Rocheleau, C. N., Westerink, S., Wilmot, M. I.: Multistressor Observations of Coastal Hypoxia and Acidification (MOCHA) Synthesis (NCEI Accession 0277984), NOAA National Centers for Environmental Information [data set], https://doi.org/10.25921/2vve-fh39, 2023.

Field Code Changed

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., Duarte, C. M., and Gattuso, J.-P.: Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming, Glob. Change Biol., 19, 1884–1896, https://doi.org/10.1111/gcb.12179, 2013.

~~Kennedy, E. G., Zulian, M., Hamilton, S. L., Hill, T. M., Delgado, M., Fish, C. R., Gaylord, B., Kroeker, K. J., Palmer, H. M., Ricart, A. M., Sanford, E., Spalding, A. K., Ward, M. A., Carrasco, G., Elliott, M., Grisby, G. V., Harris, E., Jahncke, J., Rocheleau, C. N., Westerink, S., Wilmot, M. I.: Multistressor Observations of Coastal Hypoxia and Acidification (MOCHA) Synthesis (NCEI Accession 0277984), NOAA National Centers for Environmental Information [data set], https://doi.org/10.25921/2vve-fh39, 2023.~~

Field Code Changed

Kroeker, K. J., Donham, E. M., Vylet, K., Warren, J. K., Cheresh, J., Fiechter, J., Freiwald, J., and Takeshita, Y.: Exposure to extremes in multiple global change drivers: Characterizing pH , dissolved oxygen, and temperature variability in a dynamic, upwelling dominated ecosystem, Limnol. Oceanogr., 1–13, https://doi.org/10.1002/lno.12371, 2023.

Kudela, R.: CeNCOOS in situ Water monitoring data at the Santa Cruz municipal wharf [data set], https://data.cencoos.org/#metadata/48323/station, 2020.

Formatted: English (United Kingdom)

Lai, C.-Z., DeGrandpre, M. D., and Darlington, R. C.: Autonomous optofluidic chemical analyzers for marine applications: Insights from the Submersible Autonomous Moored Instruments (SAMI) for pH and pCO_2, Front. Mar. Sci., 4, 2018.

Low, N. H. N., Micheli, F., Aguilar, J. D., Arce, D. R., Boch, C. A., Bonilla, J. C., Bracamontes, M. Á., De Leo, G., Diaz, E., Enríquez, E., Hernandez, A., Martinez, R., Mendoza, R., Miranda, C., Monismith, S., Ramade, M., Rogers-Bennett, L., Romero, A., Salinas, C., Smith, A. E., Torre, J., Villavicencio, G., and Woodson, C. B.: Variable coastal hypoxia exposure and drivers across the southern California Current, Sci. Rep., 11, 10929, https://doi.org/10.1038/s41598-021-89928-4, 2021.

Marchesiello, P., McWilliams, J. C., and Shchepetkin, A.: Equilibrium structure and dynamics of the California Current System, J. Phys. Oceanogr., 33, 753–783, https://doi.org/10.1175/1520-0485(2003)33<753:ESADOT>2.0.CO;2, 2003.

Marshall, K. N., Kaplan, I. C., Hodgson, E. E., Hermann, A., Busch, D. S., McElhany, P., Essington, T. E., Harvey, C. J., and Fulton, E. A.: Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections, Glob. Change Biol., 23, 1525–1539, https://doi.org/10.1111/gcb.13594, 2017.

Martz, T. R., Connery, J. G., and Johnson, K. S.: Testing the Honeywell Durafet® for seawater pH applications, Limnol. Oceanogr. Methods, 8, 172–184, https://doi.org/10.4319/lom.2010.8.172, 2010.

Martz, T. R., Daly, K. L., Byrne, R. H., Stillman, J. H., and Turk, D.: Technology for ocean acidification research: Needs and availability, Oceanography, 28, 40–47, 2015.

Menge, B. A., Chavez, F., Chan, F., Russell, A. D., Blanchette, C. A., Sanford, E., Friederich, G., McManus, M. A., Raimondi, P. T., Barth, J., Hill, T. M., Nielsen, K. J., Hacker, S. D., Washburn, L., and Gaylord, B.: Moorings temperature and pH from multiple sites in the California Current System starting 2008 (OMEGAS-MaS project, ACIDIC project), May 2015 ver 28, Biological and Chemical Oceanography Data Management Office (BCO-DMO) [data set], http://lod.bco-dmo.org/id/dataset/3650, 2015.

Formatted: English (United Kingdom)

~~Middelburg, J. J., Soetaert, K., and Hagens, M.: Ocean alkalinity, buffering and biogeochemical processes, Rev. Geophys., 58, e2019RG000681, https://doi.org/10.1029/2019RG000681, 2020.~~National Data Buoy Center: National Oceanic and Atmospheric Administration [data set], https://www.ndbc.noaa.gov/historical_data.shtml#ocean, 2023.

NSF Ocean Observatories Initiative: Coastal Endurance Washington Shelf Surface Mooring from June, 2016 to December, 2022 [data set], https://dataexplorer.oceanobservatories.org/#ooi/array/CE/subsite/CE07SHSM, 2022.

Formatted: English (United Kingdom)

Ricart, A. M., Ward, M., Hill, T. M., Sanford, E., Kroeker, K. J., Takeshita, Y., Merolla, S., Shukla, P., Ninokawa, A. T., Elsmore, K., and Gaylord, B.: Coast-wide evidence of low pH amelioration by seagrass ecosystems, Glob. Change Biol., 27, 2580–2591, https://doi.org/10.1111/gcb.15594, 2021.

Palevsky, H., Clayton, S., Atamanchuk, D., Battisti, R., Batryn, J., Bourbonnais, A., Briggs, E. M., Carvalho, F., Chase, A. P., Eveleth, R., Fatland, R., Fogaren, K. E., Fram, J. P., Hartman, S. E., Le Bras, I., Manning, C. C. M., Needoba, J. A., Neely, M. B., Oliver, H., Reed, A. C., Rheuban, J. E., Schallenberg, C., Vardaro, M. F., Walsh, I., and Wingard, C.: OOI Biogeochemical Sensor Data Best Practices and User Guide. Version 1.0.0., Ocean Observatories Initiative, Biogeochemical Sensor Data Working Group, https://doi.org/10.25607/OBP-1865, 2022.

Risien, C. M., Fewings, M. R., Fisher, J. L., Peterson, J. O., and Morgan, C. A.: Spatially gridded cross-shelf hydrographic sections and monthly climatologies from shipboard survey data collected along the Newport Hydrographic Line, 1997–2021, Data Brief, 41, 107922, https://doi.org/10.1016/j.dib.2022.107922, 2022a.

Risien, C. M., Fewings, M. R., Fisher, J. L., Peterson, J. O., Morgan, C. A and Peterson, W..: Spatially gridded cross-shelf hydrographic sections and monthly climatologies from shipboard survey data collected along the Newport Hydrographic Line, 1997-2021 (1.0), Zenodo [data set], https://doi.org/10.5281/zenodo.5814071, 2022b.

Formatted: English (United Kingdom)

Rogers-Bennett, L. and Catton, C. A.: Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens, Sci. Rep., 9, 15050, https://doi.org/10.1038/s41598-019-51114-y, 2019.

Rosenau, N. A., Galavotti, H., Yates, K. K., Bohlen, C., Hunt, C. W., Liebman, M., Brown, C. A., Pacella, S. R., Largier, J. L., Nielsen, K. J., Hu, X., McCutcheon, M. R., Vasslides, J. M., Poach, M., Ford, T., Johnston, K., and Steele, A.: High-resolution coastal acidification monitoring data collected in seven estuaries along the US East Coast, US West Coast and Gulf of Mexico from 2015-04-23 to 2020-07-29 (NCEI Accession 0225225), NOAA National Centers for Environmental Information [data set], https://doi.org/10.25921/xg33-1n83, 2021a.

Formatted: English (United Kingdom)

Rosenau, N. A., Galavotti, H., Yates, K. K., Bohlen, C. C., Hunt, C. W., Liebman, M., Brown, C. A., Pacella, S. R., Largier, J. L., Nielsen, K. J., Hu, X., McCutcheon, M. R., Vasslides, J. M., Poach, M., Ford, T., Johnston, K., and Steele, A.: Integrating high-resolution coastal acidification monitoring data across seven United States estuaries, Front. Mar. Sci., 8, 2021b.

Ruhl, H. A., Brown, J. A., Harper, A. R., Hazen, E. L., deWitt, L., Daniel, P., DeVogelaere, A., Kudela, R. M., Ryan, J. P., Fischer, A. D., Muller-Karger, F. E., and Chavez, F. P.: Integrating biodiversity and environmental observations: In support of National Marine Sanctuary and Large Marine Ecosystem assessments, Oceanography, 34, 142–155, 2021.

Sabine, C. L., Hankin, S., Koyuk, H., Bakker, D. C. E., Pfeil, B., Olsen, A., Metzl, N., Kozyr, A., Fassbender, A., Manke, A., Malczyk, J., Akl, J., Alin, S. R., Bellerby, R. G. J., Borges, A., Boutin, J., Brown, P. J., Cai, W.-J., Chavez, F. P., Chen, A., Cosca, C., Feely, R. A., González-Dávila, M., Goyet, C., Hardman-Mountford, N., Heinze, C., Hoppema, M., Hunt, C. W., Hydes, D., Ishii, M., Johannessen, T., Key, R. M., Körtzinger, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lourantou, A., Merlivat, L., Midorikawa, T., Mintrop, L., Miyazaki, C., Murata, A., Nakadate, A., Nakano, Y., Nakaoka, S., Nojiri, Y., Omar, A. M., Padin, X. A., Park, G.-H., Paterson, K., Perez, F. F., Pierrot, D., Poisson, A., Ríos, A. F., Salisbury, J., Santana-Casiano, J. M., Sarma, V. V. S. S., Schlitzer, R., Schneider, B., Schuster, U., Sieger, R., Skjelvan, I., Steinhoff, T., Suzuki, T., Takahashi, T., Tedesco, K., Telszewski, M., Thomas, H., Tilbrook, B., Vandemark, D., Veness, T., Watson, A. J., Weiss, R., Wong, C. S., and Yoshikawa-Inoue, H.: Surface Ocean CO_2 Atlas (SOCAT) gridded data products, Earth Syst. Sci. Data, 5, 145–153, https://doi.org/10.5194/essd-5-145-2013, 2013.

Sakuma, K.: Project report: Rockfish Recruitment and Ecosystem Assessment (NOAA Ship Reuben Lasker, RL-22-02, April 28 - June 16, 2022), NMFS Southwest Fisheries Science Center, Santa Cruz, CA, 2022.

Salop, P. and Herrmann, C.: 2019 RMP Water cruise report, Regional Monitoring Program for Water Quality in San Francisco Bay, San Francisco Estuary Institute, Richmond, CA, 2019.

Sanford, E. and Kelly, M. W.: Local adaptation in marine invertebrates, Annu. Rev. Mar. Sci., 3, 509–535, https://doi.org/10.1146/annurev-marine-120709-142756, 2011.

Sanford, E., Sones, J. L., García-Reyes, M., Goddard, J. H. R., and Largier, J. L.: Widespread shifts in the coastal biota of northern California during the 2014–2016 marine heatwaves, Sci. Rep., 9, 4216, https://doi.org/10.1038/s41598-019-40784-3, 2019.

Santa Barbara Coastal LTER, Hofmann, G.E. and Washburn, L.: SBC LTER: Ocean: Time-series: Mid-water SeaFET pH and CO2 system chemistry at Alegria(ALE), ongoing since 2011-06-21, Environmental Data Initiative [data set], https://doi.org/10.6073/pasta/1bd1491475ff6afee4be10d054d1ef0b, 2018

Santa Barbara Coastal LTER, Hofmann, G. and Washburn, L.: SBC LTER: Ocean: Time-series: Mid-water SeaFET pH and CO2 system chemistry with surface and bottom Dissolved Oxygen at Arroyo Quemado Reef(ARQ), 2012-2017 ver 5, Environmental Data Initiative [data set], https://doi.org/10.6073/pasta/6a81dcaaa9931c31dfa59132c7c5f829, 2020a.

Santa Barbara Coastal LTER, Hofmann, G., and Washburn, L.: SBC LTER: Ocean: Time-series: Mid-water SeaFET pH and CO2 system chemistry with surface and bottom Dissolved Oxygen at Mohawk Reef(MKO), 2012 - 2017 ver 5, Environmental Data Initiative [data set], https://doi.org/10.6073/pasta/23b8070eb65bae7aedc82fae8ee38b9f, 2020b.

Santa Barbara Coastal LTER, Hofmann, G., and Washburn, L.: SBC LTER: Ocean: Time-series: Mid-water SeaFET pH and CO2 system chemistry with surface and bottom Dissolved Oxygen at Santa Barbara Harbor/Stearns Wharf(SBH), 2012-2017 ver 4, Environmental Data Initiative [data set], https://doi.org/10.6073/pasta/6322ad40dfbc0bbc037994490218e28e, 2020c.

Santa Barbara Coastal LTER, Hofmann, G., Blanchette, C., Passow, U., Washburn, L., Lunden, J., Rivest, E., Kapsenberg, L. and Kui, L.: SBC LTER: pH time series: Water-sample pH and CO2 system chemistry, ongoing since 2011, ver 6, Environmental Data Initiative [data set], https://doi.org/10.6073/pasta/8efa600f49c3a171b13d05d70fad1d98, 2022.

Schar, D., Atkinson, M., Johengen, T., Pinchuk, A., Purcell, H., Robertson, C., Smith, G. J., and Tamburri, M.: Performance demonstration statement: Sunburst Sensors SAMI-CO2, Alliance for Coastal Technologies, Chesapeake Biological Laboratory, Solomons, Maryland, USA, 2009.

Send, U., Ohman, M., Lankhorst, M., and Kim, H-J.: Dissolved inorganic carbon, total alkalinity, nutrients, and other variables collected from profile and discrete observations using CTD, Niskin bottle, and other instruments from R/V New Horizon and R/V Robert Gordon Sproul in the U.S. West Coast for calibration and validation of California Current Ecosystem (CCE) Moorings from 2009-12-15 to 2015-04-29 (NCEI Accession 0146024), NOAA National Centers for Environmental Information [data set], https://doi.org/10.7289/v57d2s6c, 2016.

Sharp, J. D., Fassbender, A. J., Carter, B. R., Lavin, P. D., and Sutton, A. J.: A monthly surface pCO_2 product for the California Current Large Marine Ecosystem, Earth Syst. Sci. Data, 14, 2081–2108, https://doi.org/10.5194/essd-14-2081-2022, 2022.

Shaughnessy, F: CeNCOOS in situ water monitoring data at Trinidad Head, California [data set], https://data.cencoos.org/#metadata/48097/station, 2023.

Siedlecki, S., Bjorkstedt, E., Feely, R., Sutton, A., Cross, J., and Newton, J.: Impact of the Blob on the Northeast Pacific Ocean biogeochemistry and ecosystems, US Clivar Variations, 14, 2016.

Siedlecki, S. A., Pilcher, D., Howard, E. M., Deutsch, C., MacCready, P., Norton, E. L., Frenzel, H., Newton, J., Feely, R. A., Alin, S. R., and Klinger, T.: Coastal processes modify projections of some climate-driven stressors in the California Current System, Biogeosciences, 18, 2871–2890, https://doi.org/10.5194/bg-18-2871-2021, 2021.

Sunday, J. M., Howard, E., Siedlecki, S., Pilcher, D. J., Deutsch, C., MacCready, P., Newton, J., and Klinger, T.: Biological sensitivities to high-resolution climate change projections in the California Current marine ecosystem, Glob. Change Biol., 1–15, https://doi.org/10.1111/gcb.16317, 2021.

Sutton, A. J., Sabine, C. L., Send, U., Ohman, M., Musielewicz, S., Maenner Jones, S., Dietrich, C., Bott, R., and Osborne, J.: High-resolution ocean and atmosphere pCO2 time-series measurements from Mooring CCE2_121W_34N in the North Pacific Ocean from 2010-01-17 to 2021-06-16 (NCEI Accession 0084099), NOAA National Centers for Environmental Information [data set], https://doi.org/10.3334/cdiac/otg.tsm_cce2_121w_34n, 2012.

Sutton, A. J., Sabine, C. L., Musielewicz, S., Maenner Jones, S., Dietrich, C., Bott, R., and Osborne, J.: High-resolution ocean and atmosphere pCO2 time-series measurements from mooring WA_125W_47N in the North Pacific Ocean (NCEI Accession 0115322), NOAA National Centers for Environmental Information [data set], https://doi.org/10.3334/cdiac/otg.tsm_wa_125w_47n, 2013.

Sutton, A. J., Sabine, C. L., Maenner-Jones, S., Lawrence-Slavas, N., Meinig, C., Feely, R. A., Mathis, J. T., Musielewicz, S., Bott, R., McLain, P. D., Fought, H. J., and Kozyr, A.: A high-frequency atmospheric and seawater pCO$_2$ data set from 14 open-ocean sites using a moored autonomous system, Earth Syst. Sci. Data, 6, 353–366, https://doi.org/10.5194/essd-6-353-2014, 2014.

Sutton, A. J., Sabine, C. L., Hales, B., Musielewicz, S., Maenner Jones, S., Dietrich, C., Bott, R., and Osborne, J.: High-resolution ocean and atmosphere pCO2 time-series measurements from mooring NH10_124W_44N in the North Pacific Ocean (NCEI Accession 0157247), NOAA National Centers for Environmental Information [data set], https://doi.org/10.3334/cdiac/otg.tsm_nh10_124w_44n, 2016a.

Sutton, A. J., Sabine, C. L., Send, U., Ohman, M., Dietrich, C., Maenner Jones, S., Musielewicz, S., Bott, R., and Osborne, J.: High-resolution ocean and atmosphere pCO2 time-series measurements from mooring CCE1_122W_33N in the North Pacific Ocean from 2008-11-11 to 2020-06-11 (NCEI Accession 0144245), NOAA National Centers for Environmental Information [data set], https://doi.org/10.3334/cdiac/otg.tsm_cce1_122w_33n, 2016b.

Sutton, A. J., Hales, B., Musielewicz, S., Maenner Jones, S., Bott, R., and Osborne, J.: High-resolution ocean and atmosphere pCO2 time-series measurements from mooring CB-06_125W_43N in the North Pacific Ocean (NCEI Accession 0190840), NOAA National Centers for Environmental Information [data set], https://doi.org/10.25921/rr8z-se53, 2019.

Swiney, K. M., Long, W. C., Foy, R. J., Fields, D. M.: Decreased pH and increased temperatures affect young-of-the-year red king crab (*Paralithodes camtschaticus*), ICES J. Mar. Sci., 74, 1191-1200, https://doi.org/10.1093/icesjms/fsw251, 2017.

Sydeman, W. J., Thompson, S. A., García-Reyes, M., Kahru, M., Peterson, W. T., and Largier, J. L.: Multivariate ocean-climate indicators (MOCI) for the central California Current: Environmental change, 1990–2010, Prog. Oceanogr., 120, 352–369, https://doi.org/10.1016/j.pocean.2013.10.017, 2014.

Takeshita, Y., Frieder, C. A., Martz, T. R., Ballard, J. R., Feely, R. A., Kram, S., Nam, S., Navarro, M. O., Price, N. N., and Smith, J. E.: Including high-frequency variability in coastal ocean acidification projections, Biogeosciences, 12, 5853–5870, https://doi.org/10.5194/bg-12-5853-2015, 2015.

Taylor-Burns, R., Cochran, C., Ferron, K., Harris, M., Thomas, C., Fredston, A., and Kendall, B. E.: Locating gaps in the California Current System ocean acidification monitoring network, Sci. Prog., 103, 0036850420936204, https://doi.org/10.1177/0036850420936204, 2020.

Terrill, E., Peck, S., Hazard, L., Davis, R. E., DiGiacomo, P. M., Jones, B. H., Keen, C., Moline, M., Orcutt, J., Stolzenbach, K., Washburn, L., Helling, H., Long, J., Magdziarz, S., Laughlin, M., and Kasschau, J.: The Southern California Coastal Ocean Observing System, Oceans 2006, 1–8, https://doi.org/10.1109/OCEANS.2006.306877, 2006.

Formatted: English (United States)

Formatted: English (United Kingdom)

Trowbridge, J., Weller, R., Kelley, D., Dever, E., Plueddemann, A., Barth, J. A., and Kawka, O.: The Ocean Observatories Initiative, Front. Mar. Sci., 6, 2019.

Vaquer-Sunyer, R. and Duarte, C. M.: Thresholds of hypoxia for marine biodiversity, P. Natl. Acad. Sci. U.S.A., 105, 15452–15457, https://doi.org/10.1073/pnas.0803833105, 2008.

Walter, R.: CeNCOOS in situ water quality monitoring at Morro Bay [data set], https://data.cencoos.org/#metadata/20679/station, 2023.

Wang, D., Gouhier, T. C., Menge, B. A., and Ganguly, A. R.: Intensification and spatial homogenization of coastal upwelling under climate change, Nature, 518, 390–394, https://doi.org/10.1038/nature14235, 2015.

Ward, M., Spalding, A. K., Levine, A., and Wolters, E. A.: California shellfish farmers: Perceptions of changing ocean conditions and strategies for adaptive capacity, Ocean Coast Manag., 225, 106155, https://doi.org/10.1016/j.ocecoaman.2022.106155, 2022.

Weisberg, S., Chan, F., Barry, J., Boehm, A., Noaa, S. B., Cooley, S., Feely, R., Levin, L., Carter, H., Abderrahim, M., and Kimball, J.: Enhancing California's ocean acidification and hypoxia monitoring network: Recommendations to the Ocean Protection Council from the California Ocean Acidification and Hypoxia Science Task Force, California Ocean Science Trust, Sacramento, California, USA, 2020.

Wilkinson, M. D., Dumontier, M., Aalbersberg, Ij. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., Gonzalez-Beltran, A., Gray, A. J. G., Groth, P., Goble, C., Grethe, J. S., Heringa, J., 't Hoen, P. A. C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S. J., Martone, M. E., Mons, A., Packer, A. L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M. A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., and Mons, B.: The FAIR Guiding Principles for scientific data management and stewardship, Sci. Data, 3, 160018, https://doi.org/10.1038/sdata.2016.18, 2016.

Woodson, C. B., Micheli, F., Boch, C., Al-Najjar, M., Espinoza, A., Hernandez, A., Vázquez-Vera, L., Saenz-Arroyo, A., Monismith, S. G., and Torre, J.: Harnessing marine microclimates for climate change adaptation and marine conservation, Conserv. Lett., 12, e12609, https://doi.org/10.1111/conl.12609, 2019.

~~Woodson, C. B., Micheli, F., Boch, C., Al-Najjar, M., Espinoza, A., Hernandez, A., Vázquez-Vera, L., Saenz-Arroyo, A., Monismith, S. G., and Torre, J.: Harnessing marine microclimates for climate change adaptation and marine conservation, Conserv. Lett., 12, e12609, https://doi.org/10.1111/conl.12609, 2019.~~Wootton, J. T. and Pfister, C. A.: Carbon System Measurements and Potential Climatic Drivers at a Site of Rapidly Declining Ocean pH, PLoS ONE, 7, e53396, https://doi.org/10.1371/journal.pone.0053396, 2012.

Formatted: English (United Kingdom)