frontiers | Frontiers in Marine Science

TYPEOriginat Research
PlIlUSHm09 February 2024
oc.10.3389/fmars.20241294011

!®Check for updates

OPEN ACCESS

mnto,,,
Ibon Gatparsoro,
Techndogicat Center Ex.pert in Marine and Food Imovation tAZTO, Spain

REWWm8Y
Darie4e Biarchi,
U,iversityof Catifomia. LosAngeles, Uiited States
Kely A. Kearney,
Lhiversity of Washingtol\ UMed States

"(X)ltJt£$POHDtN::t
MdrewR. Thompson
IPan<rew.thompson@.noaa.gov

RK:tMD14 September 2023
JrCctPl"B>22 January 2024
PUW$MED 09 February 2024

aTATION
lhompsa, Alt Sv.etethorp R.Alksne M, Santa-a JA.Hazen EL leisirg A. SatterthY.eite E, SydemanWJ, AndersonCR. A.lth TD, Baum.rin-Pickerirg S. BaumgardnerT, Bjorkstedt EP, Bograd SJ, BoYAin NM..Burke BJ, Daty EA. Dewar H. Re4d JC.Fisher JL Garfield N.Gidding A, Cioericke R.Gotightty R.G6mez-Ocampo E. Gomez-v..tdes J, HildebrandJA Jacobson KC.Jacox MG, Jahrcke J, Johns M, JonesJM..Lavariegos B,Mantua N. McChesney GJ, Medina ME.MeCin SR, Miranda L£, Morgan CA, Nickets CF, Oben RA.PorquezJ M..Preti A. Robertson RR.Rodrick DL Sakuma KM. Schacter CR,Schroeder ID, Scopel L SrodgrassOE, Thompson SA.Warzybok P, 'Miitaker K.Watson W, Weber ED and Weis B C202◄) Stated theCatifornia Current Ecmystem re?=)rt in 2022: a ta\e d two La Nilias.
Front Mar. Sci. U:1294011.
doi: 103389/fmars.202◄.1294011

State of the California Current Ecosystem report in 2022: a tale of two La Ninas

Andrew R. Thompson"', Rasmus Swalethorp[2], Michaela Alksne', Jarrod A. Santora•, Elliott L. Hazen5, Andrew Leising•, Erin Satterthwaite>.•, William J. Sydeman[7], Clarissa R. Anderson•, Toby D. Auth[9], Simone Baumann-Pickering', Timothy Baumgardner[10], Eric P. Bjorkstedtu[12], Steven J. Bograd[5], Noelle M. Bowlin1, Brian J. Burke[13], Elizabeth A. Daly[14], Heidi Dewar[1], John C. Field', Jemifer L. Fisherv, Newell Garfield5, Ashlyn Gidding[15], Ralf Goericke[2], Richard Golightly", Eliana G6mez-Ocampo[10], Jose Gomez-Valdes[10], John A. Hildebrand[15], Kym C. Jacobsonv, Michael G. Jacoxs.i•, Jaime Jahncke19, Michael Johns19, Joshua M. Jones15, Bertha Lavaniegos[10], Nate Mantua•, Gerard J. McChesney[20], Megan E. Medina•, Sharon R. Melin[21], Luis Erasmo Miranda[10], Cheryl A. Morgan[14], Catherine F. Nickels=, Rachael A. Orben[23], Jessica M. Porquez[24], Antonella Preti=, Roxame R. Robertson[24], Daniel L. Rudnick[25], Keith M. Sakuma•, Carley R. Schacter[16], Isaac D. Schroeder•, Lauren Scopel", Owyn E. Snodgrass[1], Sarah Ann Thompson', Pete Warzybok 19, Katherine Whitaker[2], William Watson[1], Edward D. Weber[1] and Brian Wells"·[17]

tFisheries Resources Division, Naionat Marire f;sheries Service, Southwest Fisheries ScierceCenter, LaJoi.a,.CA, United States,. lScripps Institution of Oceanograpl"o/,University of California,. San Diego, LaJoi.a,.CA, United States,. 'Scripps Acoustic Ecology La Scripps Institutionof Ocearography, University of California,. San Diego,LaJoi.a,.CA, United States,. "Fisheries Ecdogy 0Msion, National Marine Fisheries Ser\<ice,. Southwest Fisheries ScienceCenter, SantaCruz.,.CA, United States,. Environmentat Research Division, Naionat Marire f;sheries Service, Southwest Fisheries Scierce Center, Monterey,CA, United States,.4Catifomia SeaGrant Scripps Institution of Oceanograpl"o/, University of California,. San Diego,LaJoi.a,.CA, United States,. 'FaraUon InstiMe,. Peta\Jma,. CA, United States,•Southem Catifa-nia Coastat OceanObserving System. Scripps InstiMiond Oceano:;iraphy, Ul'I\Ersityof Catifomia,. San Diego, La Jola,.CA, Ul'lted States,{IPacific States Marire Fisheries Commission, Hatfietd Marine ScienceCenter, Newport, OR, Ul'lted States, toFacutta::lde Ciencias Marinas, Universidad Autonorrede BajaCatifomia,. Ensenada,. Mexico, Il-Fisheries Ecdogy Di\'ision, National Marine Fisheries Service,. Southwest Fisheries Science Center,. Arcata,.CA, United States,.0Department of Fisheries Biology, Cat Poty 1-klrrbolclt *kcata*,. CA,Ul'lted States, UFish Ecdogy Division, National Marine Fisheries Service, Northwest Fisheries ScierceCenter, Seattle, WA,United States, tAf;sh Ecology Divisiori Nationat Marire Fisheries Service, Northwest Fisheries ScienceCenter,. Hatfie4cl Marire ScierceCenter,. NeYo?Ort,OR, United States, UCooperative Institute for Marine Ecmystem Resources Studies,Oregon State Ul'I\Ersity Hatfield Marine Science Center, New?=)rt,OR, United States, UOepartment of Wildife,. Cat Poty 1-klrrbolclt Arcata,. CA Ul'lted States, uoepartment of Wildife,. 1-l.mbolclt State Unr.Ersity, Arcata,.CA, United States,. •Physic.at Sciences Laboratory, NationalOceanic and Atmospheric Adrril'lstration,Boulder, CO, Ul'lted States, t{IPoint Btue Conservation Science,. Petal.ma,.CA, United States,.,ou.S. Fish an;:t Wildlife Service,. San Frarcisco Bay NationalWildlife RefugeComplex. Fremont CA,United States,aMa-ine Mammat Laboratory, National Marine Fisheries Ser\<ice,. Alaska Fisheries Science Center, Seatle,WA.United States,. »institute of Marine Studies, Ul'I\Ersityof Catifomia,. SaitaCn.a.,. SantaCn.a.,. CA, Ul'lted States,

Jl[)epartment of Fisheries, Wildife,.and Cc:n.servation Sciences. Oregon State University, Hatfield Marine Science Center, Newport,OR, Ul'lted States.'•Cooperative Institute forMarine. Earth, and Atmospheric Systems.Cat Poty 1-klmt:ddt, Arcaa..CA, United States. I50imate, Atmospheric Scierce & Physic.i Oceanograpl"o/ Division. ScrippsInstitutionof Ocearography, Ul'Wersityof Catifomia,. San Diego, LaJola.. CA Ul'lted States

2022 marked *the* third consecutive La Ni/la and extended the longest consecutive stretch of negative Oceanic Ni/lo Index since 1998-2001. While physical andbiological conditions in winter andspring largely adhered *to* prior La Ni/la conditions. summer and fall were very different Similar *to* past La Ni/la events, in winter and spring coastal upwelling was either average or above average, temperature average or below average, salinity generally above average. In summer and fall however, upwelling and temperature were generally average or slightly below average, salinity was close *to* average and chlorophyll a wascloseto average. Again,asduring prior LaNi/la events, biomass of northern/southern copepods was above/below average off Oregon in winter, and body size of North Pacific krill in northern california was above average in winter. By *contrast,* later in *the* year the abundance of northern krill dropped off Oregonwhile southern copepods increased and body sizes of NorthPacific krill fell in northern calwornia. Off Oregon and Washington abundances of market squid and Pacific pompano (indicators of warm, non-typical La Ni/la conditions) werehigh. In *the* 20"' century, Northern anchovy recruitment *tended to* be high during cold conditions, but despite mostly warm conditions from 2015-2021 anchovy populations boomed and remained high in 2022. Resident seabird reproductive success, which *tended* in the past *to* increase during productive LaNi/la conditionswashighly variable throughout the system as commonmurre and pelagic cormorant experienced complete reproductive failure *at* Yaquina Head, Oregon while Brandt's cormorant reproduction was average. *At* three sampling locations off central california, however, common murre reproduction was close *to* or above average while both pelagic and Brandt's cormorant were above average. california sealion reproduction has been above average each year since 2016, and pup weight was also above average in 2022, likely in response *not to* La Ni/la or El Ni/lo but continuous high abundance of anchovy. The highly variable and often unpredictable physical and biological conditions in 2022 highlight a growing recognition of disconnects between basin-scale indices andlocal conditionsin *the* CCE.•July-December 2022Is *the* biggest outlier from individual 'strong·La Ni/la (events) ever going back *to the* 50s.' - NateMantua

KOWOJtDS

cautomia CurTent, marine heatwave. La Nil'la/El Nil'lo, cautomia Cooperative Oceanic Fisheries InvestigatiOr\ !job.al warming

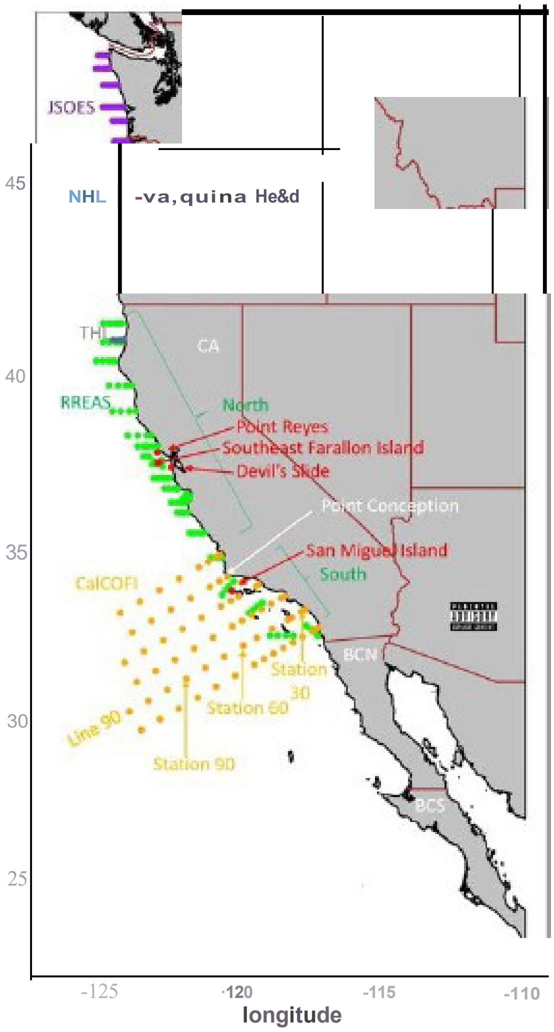
GRAPHICAL ABSTRACT

Introduction

Basin scale indices of ocean condition ha''' the potential to infurm biological dynamics at regional *scales* (Hallett et al., 2004). Since the early 1980& expectations ha\,. formed regan!ing the biological implications of El Nifto and La Nilla conditions throughout the world (Cobb et al., 2013; limmermaM et al., 2018; BroughlOn et al., 2022). NOM's National Weather Service declares that the ocean *is* in an El Nillo/1.a Nilla state when the 3-month averagesea surface temperature anomalyex fallsbelow O.S•C of averai, (between 1971 and 2000) in the east-<:entral equatorial Pacific (5°N to 5°$ and 170"W to 120"W) for five consecutive months. In El **Nifto** yean the northern and southern (poleward of 20") Pacific Ocean tends to be relati,,.ly wamt off the western coasts of North andSouth America but cool in the western Pacific and vice versa in La NitJa }'ears. In the California Current Ecosystem (CCE), which covers the coast of North America ben,,..n Vancouver Island, Canada and southern Baja California Sur, Mexico (Figure I), the ftow of the eastern boundary California Current, and upwelling tend to be high during La Nilla events (Bond eta!, 2008). This results in high nutrient inputand i,nerates cool, productive conditions that, for example, facilitate the increased spawning output, growth and survival of many zooplankton *species* such as North **Pacific** krill *Euphasia paafica* and *11rysa.noessa spinifera* that are important prey for juwnile salmon leaving their natal rivers and entering the ocean tor the first time (Peterson et al., 2014). 2022 represented the third consecutive La NitJa year, and our goal here is to evaluate oceanographic and biological *conditions* in the CCE to determine ifthe system was*similar* to prior La Nilla events (Bond et al.,2008).

In the past,there was i,neral consensus of the expected physical and biological *conditions* in the CCE during La Nilla """ts (Bond et al., 2008). For example, northerly winds that induce up"..Uing were typically high and the onset of *these* winds (ie., spring transition) was early in the year. This upwelling brings cold, saline and nutrient rich water to the surface. The nutrients fuel primary production and thus chlorophyll *was* high. At the secondary trophic lewl, large, northern, lipid-rich zooplankton abundance tended to be more abundant than sm.aller, southern zooplankton. Fish *species* that feed on the lari,r zooplankton (e.g), tended to experience high survival during La Nilla. In addition, recruitment of anchovyseemedto increase during the cold La NitJa events while sardine recruitment may haw been lower (Chavez et al., 2003). Many apex predators such as *sea* birds and marine mammals tended to have high reproductive *success* during the productive La Nifta conditions (Jones eta!.,2018; Laake et al., 2018; PislOrius et al., 2023).

Desptte the common *use* of El Nillo/La Nilla to predict biological dynamics, tt has become increasingly dear that the way El **Nifto and** La Nilla manifest locally can change through time (Park et al., 2012; Yeo et al., 2012; Yu et al, 2012; Jo et al., 2015; Ohlberi,r et al.,2022; Hong and Hsu, 2023). Forexample, Yu et al. (2012) found that Eastern Pacific types of El Niftos were more common prior to 1990 but C,entral Pacific El NitJo events were predominant &om 1990-2009. Both Eastern Pacific and Central Pacific El Nillo events begin with warming at the equator, but the



AGUJttl
Map of sam ing locations. The folowing are sea-going sur\Eys: Purple is the Ju\ElWe Sain-on Ocean EcmystemSuNey (JSOES), blJe is the Newport Hydrographic Line (NHU,green is the Rockfish Recruitment and Ecmystem Assessment Survey (RREASI grey is the Trinidad Head Line (THU,and orange is the Catifomia Cooperati\E Oceal'Ic Fisheries In\Estigation (CatCOFI) suNey. Red dots arelard-based surveys for Drds (Yaqt.ina Head. Fbint Reyesand Devrs Slide) and sea lions (San Miguel IslancO. Statesand lan<rnarks ;,e in wtite font: WA is Washington, OR is Oregon, CA is Catifomia,. BCN is Baja Catifomia Norte,.and BCS is Baja Catifomia Sur.

Eastern versions form closer to South America and tend to propagate warm water to higher latitudes than the central counterparts (Capotondi et al., 2015; Lilly and Ohman, 2021). Within the CCE, El Nillo type can greatly affect local biological **conditions.. and different woplankton communities emerge under** Eastern Pacific versus Central Pacific El Nillo events (Chave:t et al, 2002; Lilly and Ohman, 2018; Lilly and Ohman, 2021). Furthermore, marine hean--aves (MHW), which are becoming more frequent worldwide (Jacox et al., 2020; Jacox et al., 2022), can dampen telecoMection between tropical and hjgher-latitude **conditions. Indeed, despite NitJo-neutral conditions in 2017** ***sum.mer* surface water temperature was 3-4° C above awrage off** Peru and Ecuador, and this *event* was called a "coastal" El Nillo (Echevin et al, 2018).

Local conditions occurring under another popular basin-scale indicator, the Pacific Decadal Oscillation (PDO) are also proving to be hjghly dyantic (lit2owet al.,2020a). The PDO is a multivariate **index characterizingvariability in *sea* surface temperature anomaly** in the north Pacific (Mantua et al., 1997). It is hjgh when water is **relatively wanner in the eastern than the western Pacific and vice** '''''a. At decadal time scales, high and low PDO periods tend to **cluster resulting in conditions termed warm and cold regim** respectively. These warm and cold PDO regimes ha,,. been tied to biological events such as periods with low and high anchovy or sanline abundances (Chave:t et al., 2003). Howewr, lilZOw et al. (2020a) found that beginrung in 1989 there has been increasing discoMect between the value and even the magrutude of the PDO and SST anomalies in both the Bering Sea and the CCE. The persistent north Pacific MHWs chanwd the mearungof the PDO in southern Califorrua so fundamentally that Werb and Rudnick (2023) questioned its utility as an **index** that can be used to predict biological dynamics.

The potential for nonstationary local relationships under El **NitJo/La Nil\a or warm/cold POO regimes necessitates continuous** morutoring of both physical and biological conditions in marine **ecosystems to understand ecosystem status and make sensible ecosystem-based management decisions. The State of the California Current Ecosystem Report has been documenting** ecosystem conditions in the CCE *every* }"ar since 1993. *Here,* we again report on trends in physical oceanography, phytoplankton, pelagic invertebrate zooplankton, fish, birds, and marine mammals. Ourgoal is to explicitly compare physical and biological features of the CCE to determine how the system in 2022 com**pared** to past **strong La NitJa e, nts occurring over the past half century.**

Methods

The State of the Califorrua Current Ecosystem Report synthesizes data 6-om a myriad of satellite observations and land **or ship-based *surveys* that have proven over the years to be** insightful indicators of the physical or biological status of the CCE (McOatchie et al, 2016b; Thompson et al, 2019b; Weber et al., 2021). The methodology of each survey (Figure I) has been well described els"'½\ere, and here we provide a brief summary of **each data source as well as a reference for each that provides details on data collection. \Ve present timeseries of anomalies tor most of** the analyzed variables. Foreach variable we first calculated the long tenn mean across all sample points and then subtracted the gi,,en value 6-om the mean. *We* then qualitati,..ly described whether the **value in 2022 was awra (at orvery close to the mean), below or abow avera .**

Pacific climate indices

We obtained time series of the Oceanic Nillo Index (ONO and the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) indices from the California Current Integrated Ecosystem webstte (https://oceanview.pfeg.noaagov/

dashboard/). The ONI is a three-month running mean of SST anomalies ""rai,d within and around the equator at 5°$-S°N and 12.0"W-170°\V. The PDO is the fust eigenvector of a Principal **Components Analysis of sea surface temperature in 5° x 5° grids** throughout the North Pacific (Mantua et al., 1997}. The NPGO is the second eigen,.,ctor ofsea surface height (SSH} throughout this same region (Di Lorenzo et al., 2000}.

Next, we examined broad trends in SST in the North Pacific. First, we plotted a time series of Hadley SST (https://www.metoffice.!l')v.uk/hadobs/hadisst/) with a five-month running mean ofSSTanomalies averaged over JO"N-&N and 12.0"E- I10°\V to describe dynamics of SSTthroughout the North Pacific. Next, we focused on the California Current Ecosystem by plotting five-**month running means of area average SST anomalies over 30-48°** N along the coast out to I50 km.

To visualizespatial distribution ofSSTin the Pacific, we created figures ofseasonal averages ofSSTand wind anomalies from winter, spring, summer and lall 2022 using data &om NCAR/NCEP Reanalysis (downloads.psl.noaa.gov/Datasei./ncep.reanalysis/Monlhlies/surlacel}.

To contextualize the strength of the 2022 La Nilla relative to past La Nil\as, we created a figureshowing the averageSSTanomaly during the ten strongest La Ni/las from 1991-2020 veisus the SST anomalies in 2022 in the fust **and second** hal"'s of the year. We noted that conditionsseemed to varygreatly in the fust andsecond hal,.,s of 2022 and thus created separate plot, for January to June and July to December.

Marine heatwave update

Since the onset of the 2013 North Pacific Marine Heatwave (MHW}, these e"'nts,as defined byHobday et al. (2016), have been present near constantly in the North Pacific (Weber et al., 2021), and 2022 was no exception. We compared the duration and intensity of the 2022 MHW at two spatial scales. Fiist, we evaluated the size and duration of the 2022 MHW relati"' to the 235 MHWs recorded since 1982 at the scale of the North Pacific. **Next we examined the amount of area in the North Pacific that** contained a MHW through time in 2022. To evaluate the presence ofMHW's in theCCE, we dernan:ated the proportion of the ocean from theshore to theseawan!edge of the Economic Exclusi,., Zone (EEZ 370 km) that included a MHW. We further discerned the emlution of MHWs in the CCE by plotting against day of the year the proportion of the EEZwith a MHW in 2022, and in recentyeais with MHWs (2021, 2020, 2019 and 2014). Finally, we plotted the total area of MHWs in 2022 perday along with the same fouryeais as the previous graph.

Upwelling and primary production

We evaluated upwelling strength by plotting SST anomalies from the coastout ID 75 km fromshore &om *4rN* to 3l°N between January 2017 and December 2022. We coupled this panel with anomalies of the Biologically Elrecti"' Upwelling Transport Index (BEUTI), which estimates vertical ftux of nitrate ID the mixed layer, over the same temporal and spatial extent (Jacox et al., 2018). Next, we examined howcumulative upwelling progressed on a daily basis **in 2022 versus the long-term average and the most recent three** }"arS. Here, we examined the Coastal Upwelling Transport Index at *4rN,* 45°N, 42°N, 39"N, 36°N, and 33°N. In addition, we plotted imai,s ontoa 0.I° xO.I° grid ofspring (March-May) chlorophyll *a* anomalies &om 2020-2022 rela ID 2003-2022. We obtained satellite-derived (Aqua MODI$) chlorophyll *a* data off the west coast of the United States &om httpsJ/coastwatch.pfeg.noaagov/enldaplgriddap/erdMH lchlarnday.

Regional temperature, salinity and chlorophyll a

We compared anomalies of temperature,salinity**and**chlorophyll &om various locations within the CCE. Anomalies were calculated &om *in-situ* measurement, along the Newport Hydrographk line (NHL; Figure I) at stations 5 and 50 (Auth et al. 2018), Trinidad Head Line (11iI. Figure I) at station 2 (Robertson and Bjorksted 2020), and CalCOA (Figure I) line **90** at stations **30**, **60** and 90 (Robidas, 2023). For CaJCOA, we analyzed CTD data that has been sampled at 1-m depth intervals since 2003. In each location, we evaluated conditions relatively shallow (NHL: 50 m, THI.: 15 m, and CaJCOFI: mean 0-50 m) and deep (NHL ISOm, THL 65 m and CaJCOFI: mean 151-200 m) in the water column. There was no winter CaJCOA cruise in 2022 due to issues with covid and stalling

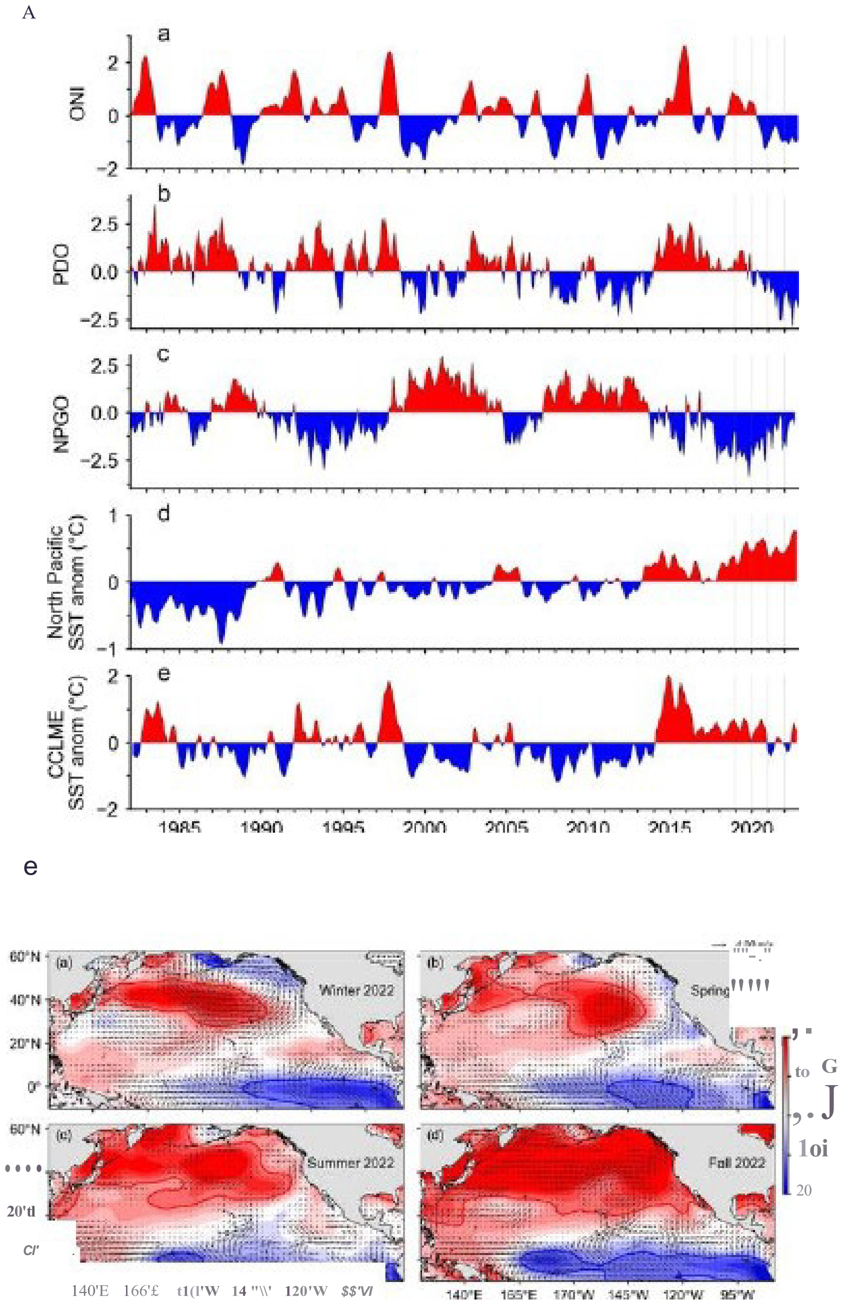
Regional zooplankton

Three indices of zooplankton were collected throughout the CCE. At the NHI. we evaluated biomass anomalies of northern and southern copepods collected with bongo nets deployed to JOO m (Peterson et al., 2014). We *also* analyzed anomalies of adult body size and total biomass of North Pacific krill collected along theTHL with Bongo nei. deployed to JOO m (Robertson and Bjorksted 2020). Finally, total krill biomass anomalies were measured north andsouth of Point Conception usingdata from rnidwatertra"1s(30 m, 15 min) collected by the Rockfish Recruitment and Ecosystem Assessment Survey (RREAS; Figure I) (Sakuma et al., 2016).

Regional fish and market squid

Various life stages offish were sampled throughout the CCE (Gallo et al., 2022). Here, we locus, from north to south, on the Juvenile Salmon and Ocean Ecosystem Survey ()SOE$; Figure I), the NHL, the RREAS and CalCOA. In each survey we delineated fishes from particular habitat types (eg., coastal, northern veisus southern offshore from NHL) that in the past were observed to respond in at least somewhat of a predictable fashion ID basin-scale dynamics (Thompson et al., 2022b). Furthest north, JSOES **conducted hori7.ontal net tows in the upper 20 m of the water** column during the day. Although many fishes were caught through

JSOES spring sampling (Barcelo *et* al., 2018), we examined **abundance anomalies &om just those that reside near the surface** during the day and do oot undeigo die!\O!rtical migration. We also distinguished *fishes* with marine versus anadromous lire histories from JSOES. Off the NHL, ichthyoplankton were collected every two weeks with bongo nets &om Janwuy to Match (Daly *et* al. 2013). The RREAS (Figure I) conducted 15 minute to"' at 30m depth in early summer (Schroeder et al. 2019) off California *since* 2004. We categorized RREAS fishes into adult or young of the year (YOY) life *phases* and plotted standardized abundance time series north and south of Point Conception (Santora *et* al., 2021; Schroeder *et* al., 2022). The Ca!COFI survey has been sampling quarterly offcentral andsouthern California consistently *since* 1951 using a ring net from 1951-1976 and then a bongo net &om 1977-present (Thompson *et* al.,2017).Springsamples tend to contain the most *species* and are the most consistently sampled (Thompson



AGUJtt2
(A) Basin-scae indices:Oceanic Niiio Index(ONI), Pacific Oecadat Osclation (POO), North Pacific G)feOscilation (NPGO), North Pacific Sea Surface Temperature (SST)anomciy, ard Catifomia Current Large Marine Ecmystem SSTaromaty. (BJ SSTanomciies in winter, s ing, st.mmer aid fal 2022across the Pacific and geostroplx a.ment flow.

et al., 2022a), *so* we focused on this *season.* Prom Ca!COFI, we distinguished ran with adult benthic, mesopelagic and pelagic habitats and plot abundance anomalies.

Given the importance of northern anchovy *Engraulis mordax* (henceforth anchovy) to ecosystem dynamics in the CCE (Pennie *et* al., 2023), and initial observations showing thatlarval abundance seawanl of the shelf break were""Y high, we also included a plotof the spatial distribution of anomalies of la,val abundance of this species in spring 2022. For each Ca!COFI station we calculated the mean number of larvae in spring from 1951•2021. \Ve then i,nerated station specilic anomalies by subtracting the number of larvae caught in 2022 from the long.term average.

Regional seabird and sea lion reproduction

Seabird monitorin& where measures of reproductiw success (number offledged chicl<s) from individual nests are recorded using standardized methodology, are conducted worldwide and from several locations in the CCE (Pistorius *et* al., 2023). We examined *time* series of reproductive success of three surface nestingspeci the common murre *Uri.a aalge,* Brandt's cormorant *Phalacrocorax pe.nicill.a.tus,* and pelagic cormorant *Phalacrocorax pe.l.a.gicus.* Fwthest north, these species were monitored at Yaquina Head. Oregon (Porquez et al., 2021). In California, we examined reproduction dynamics from Point Reyes, Southeast Farallon Island, and Devil'sSlide (Santora *et* al. 2014). California sea lions *Zalophus californianus* ha\O! been monitored at San Miguel Island for decades. We reported mean pup weight anomalies from 1997-2022. We focusedon pup weight anomaly as it has beenshown to be a robust index of pup conditions (McC!atchie *et* al., 2016a).

Regional at-sea mammals and birds

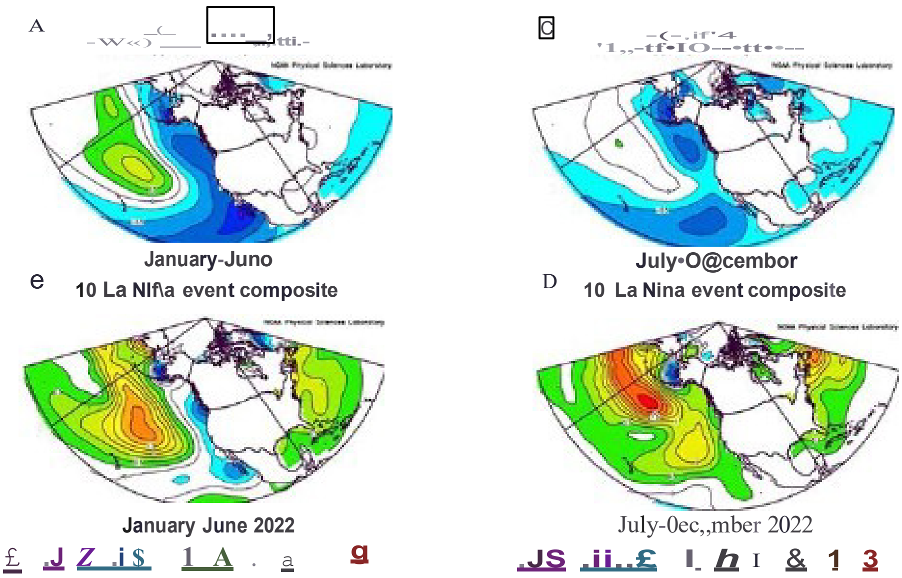
CaJCOFI marine mammal visual surveys were carried out during daylight hours while the ship was in transit between Ca!COFI sampling stations on each quarterly cruise (Campbell *et* al., 2015). Observations of seabirds were made off the RREAS in late spring and Ca!COFI in summer (Sydeman et al., 2021a; Sydeman *et* al., 2021b). For marine *mammals* we analyzed two indicator *species,* humpback whales *Megaprera novaeangliat* and blue whales *Bal.aenoptera musculus.* For seabir we tracked dynamics of resident common murre and migrant sooty shearwater off central California in late spring and cool water•associated sooty shea.rwater and warm water-associated black•wnted shearwater *Pujinus opisthomtl.a.s.*

Results

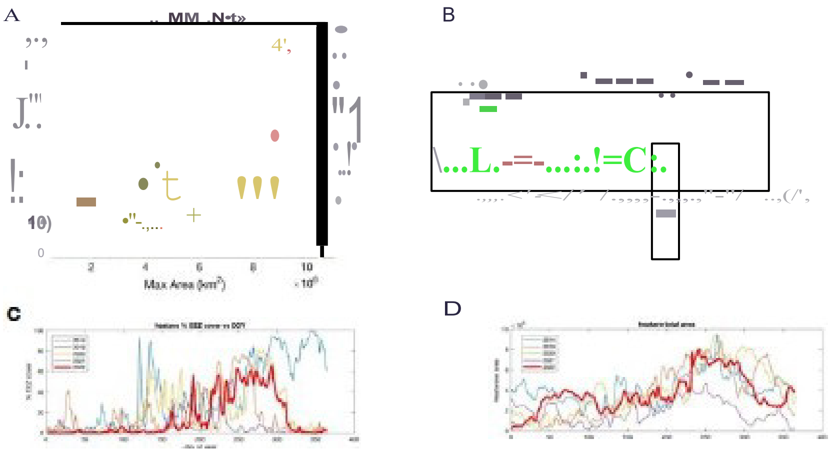
Pacific climate indices

The three major basin-sc.ale indices were all negative in 2022. The ONI was negative all}"arindicating that the Pacific Ocean was experiencing the third consecutive La Nilla in as many }"'JS. The PDO has been continuously negative *since* 2020. The NPGO has been negative *since* mid-2017 (Figure 2A).

The mean SST anom.aJy across the North Pacific Ocean however, has been positive nearly 100% of the time since 2013 and has steadily increased *since* 2018. In 2022 the SST anomaly in the North Pacific reached a record high towards the end of the year. Similacly, the SST anomaly in the CCE region has been almost exclusively positive since



AC.UJtt:S
(A) Average SSTanomaly d.Jring strong La Niria years in January.June from1991·2020, (B) Awra,ge SSTaromaly in January-June in 2022. (C)Awra,ge SSTanomatyduring strong La Niriayears in Juty.Decerrt>er from 1991·2020, (0) SSTanomaly in Juty.December in 2022.



AC.URU
(A) Durationand sizeof 235 north east Pacific marine heatw.wes (MHW) since 1982, (B)Totat areaard proportion of the U.S. Ecoromic Exdlsive Zore (EEZJencompassed bya MHWin each dayof 2022. (C) Percent of the EEZ that was ina MHW ard (0) Tota heatw.we a-ea in eachdayin 2022 and in recent years with onounced MHW.

2014. Both in 2021 and 2022, SSr wasslightly below average in the **6..rst half of the year but above average in the second** half (Figure 2A).

Visuali7.ation of SST anomalies throughout the North Pacific **contextualize the average trends.** In **winter, SSr was close toaverage near the coast of North America but well above average in the** central Pacific (Figure 2B). Inspring,conditions resembled a typical **La Nil\a asSST was below average in the eastern Pacificbut above average in the western Pacific. Inswnmerand *tall,* theSSTanomaly** was *also* hjgher in the east than the wes but the SST anomaly was hjgher than average in the entire region (Figure 2B).

The contrast between the rust half of2022 and the second half **was evident bycomparison ofaverageSSTanomalies in thestrongest** I.a Ni/la during the past 30 }"JS versus that of2022 (Figure 3). The first partof 2022 resembled a mild I.a Ni/la as SSr was below normal **along the coast of North America and above avera in the central** Pacific (Figures 3A, B). In summer and fall, howe\,.r, the SSf anomaly was well above averaw (Figures 3C. D) in the eastern **North Pacific and well above average in the western Pacific.**

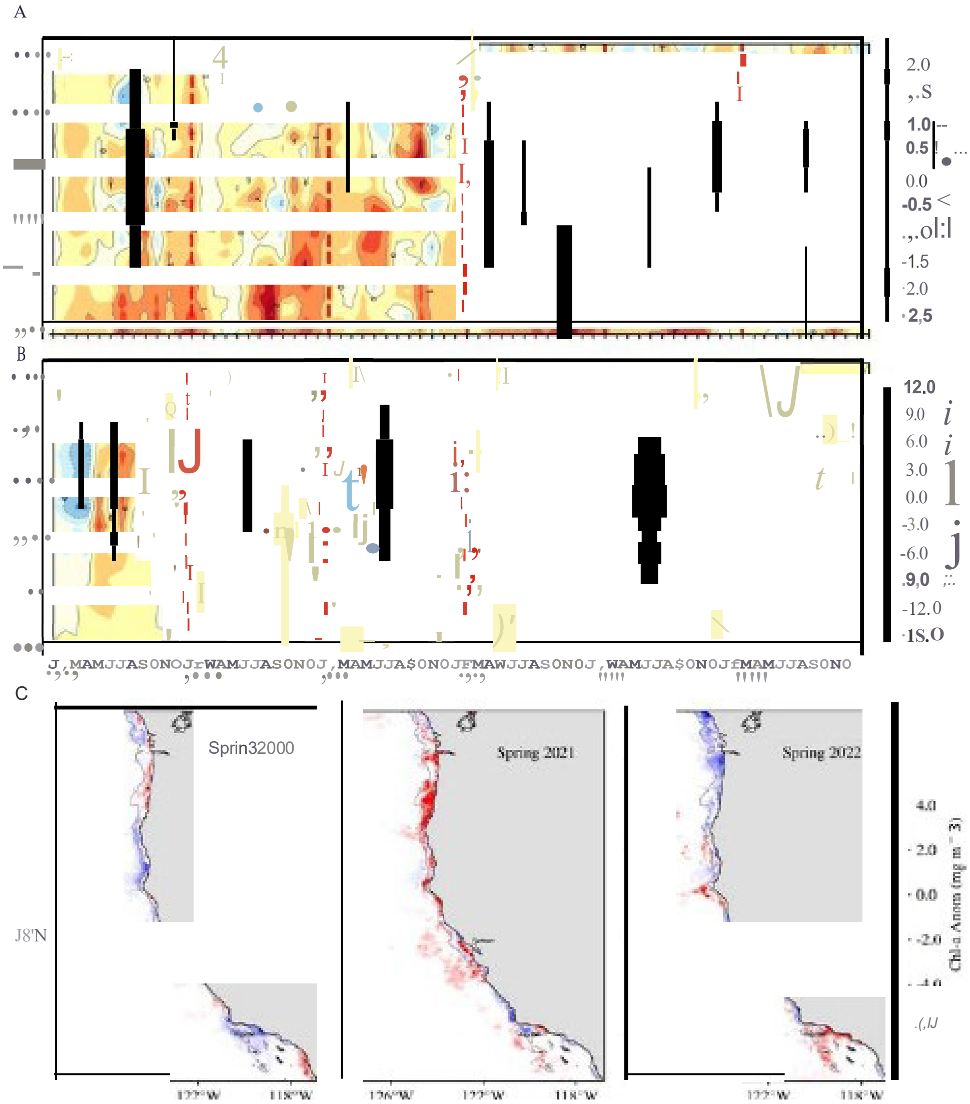
Marine heatwave update

From the perspective of the North Pacilic Ocean, the thud Iarwst MHW occurred in 2022, following only the 2018 and 2020 e,oents (Figure 4A). In January 2022, MHWs covered approxinutely half a million km' (Figure 4B). Marine heatwave coveraw increased abruptly in the North Pacific in March to about 4 million km^{1}; however, until August the MHW was mostly seaward of the EEZ **From August to November the MHW footprint increased to** approximately 7 million km', and it encroached into the CCE. By the June 9, 2022 the MHW was present in ~20% of the CCE (Figure 4C). The amount of the CCE experiencing a MHW jumped to ~50% by the middle of the year and in August approxinutely 70% of the EEZ was in an MHW (Figure4C). The MHWoccupied most of the EEZ through October but rapidly departed in late October, and was almost absent within the EEZ by late November (Figure 4C). The pattern of MHWs entering the EEZ in late spring **or early *swnmer* and then withdrawing in fall was evident in each** }"ar &om 2019-2021. By contrast, in 2014 the MHW remained in the EEZ through the end of the }oear. At the *scale* of the Eastern **Pacilie** Ocean, the *size* of the MHW in 2022 increased through the }"ar**and peaked** in September (Figure 40). Although it decreased in size in lill, it *still* occupied approximately 4 x 10^{6} km' mostly offshore from the EEZ by the end of the year. Similar dynamics, "½\ere the *size* of the MHW increased early in the }"ar, peaked in summer and decreased but clid not dissipate in fall alsooccurred in 2014, 2019 and 2020. In 2021, however, the MHW almost totally **went away in fall.**

Upwelling and primary production

Upwelling also rellected a contrast bm\..,n the two halves of 2022. In winter, upwelling was above averaw (and SST below **average) in northern California and southern Oregon while conditions were close to average in the rest of the Cfifiotf the** Uruted States (Figures SA, B). In spring upwelling was above and SST well below average between Point Conception (34°N} and Cape Mendocino (40.4°N). South of Point Conception, however, **upwelling was about average in spring and north of Cape Mendocino it was below average. In *sum.mer,* conditions changed** abruptly throughout the CCE. Sea surface temperature was above average in most of the U.S portion of the CCE &om June to late **October and upwelling was either nera or below average. In** approximately the last month of 2022, upwelling increased and temperature decreased north of Point Conception.

Surface chlorophyll *a* inspring was mostly anomalously low off the west coast of the Uruted States in 2022 (Figure SC). The few locations "½\ere chlorophyll *a* was high near the continental *shelf* break at and north of Cape Mendocino (40.4°N} into southern Or n (42.9"N) and in northern part of the Southern Ciliforrua



AGUJtt5
(A) Average SSTanomaly v.Attfo 75 km of thecoastan;:t (B} BiologicaOy EffectNe U?NE(ling Tra,sport Index (BEUTO from 20V-2022 bylatitude (y-axis) and time (){-axis). (C) satelite-deriwdchloro yt *a* anomaly d.Jring spring 2020-2022.

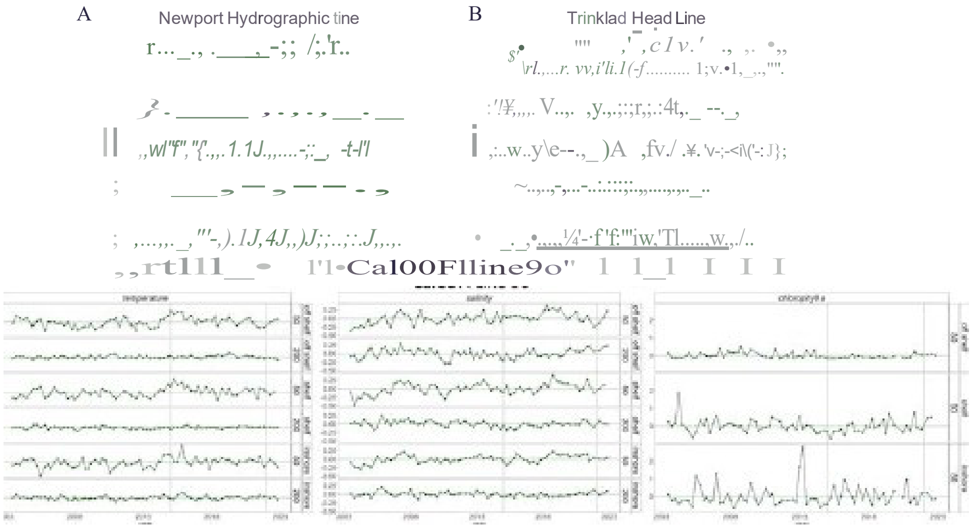
Bight (34°N}. The distribution of chlorophyll *a* in spring 2022 was markedly different than 2021 "½\en chlorophyll *a* was elevated throughout most of the central and northern CCE.

Regional temperature, salinity and chlorophyll a

Off Newport, Ore!J)n, temperatures were low and salinity high at both 50 and 150 min winter of 2022. Subsequently, conditions **reversed as temperature and salinity were close to average** (Figure 6A). Similarly, chlorophyll *a* fell to below averai, "½\en temperature increased and salinity decreased (Figure 6A). We obseived *similar* patterns in northern California. On the Tiil. temperature was generally low and salinity high early in the year. **Later in the *year,* temperature was above or close to average and** salinity below or dose to average (Figure 6B). Fluorescence on THL *also* decreased &om beginning to mid-2022 although there was a brief spike in September.

In southern California on CaJCOFl line 90 conditions differed depending on depth and distance from *shore* (Figure 6C). At the **offshore station (st.ation 90). temperature was average near the** surface (0-50 m) in spring but abo,., average in summer and fall (Figure 6C). At depth (151-200m), temperature was below average in 2022. At the *shelf* break, temperature wasslightly below average **in spring and then average in summer. Closer to shore. shallow temperature was slightly above avera in spring, average in summer and slightly below average in fall while deeper temperature was average in sprin& above average in sum.mer and below average in tall.**

Salinity in southern California was mostly awrage or above average on line 90 in 2022 with below nerage salinity only occurring in spring off the *shelf* in the upper 50 m (Figure 6C). **Chlorophyll *a* *was* close to average in the offshore region**



AGUJtt6
Temperature. satinity, and ctiorop¥f *a*Pr fk.lorescerce)at rruttiple depths from (A) Newport Hyaogra ic Line, (BJ Trinidad Head Line aid (C)CatCOFI Line 90. Note tl"e dfferences in depthsamonggeograplx locations.

throughout 2022. Near the shelf break, chlorophyll *a* was above average in spring and *summer*. Chlorophyll *a* was above average near shore in spring and below average in sum.mer and fall (Figure 6C).

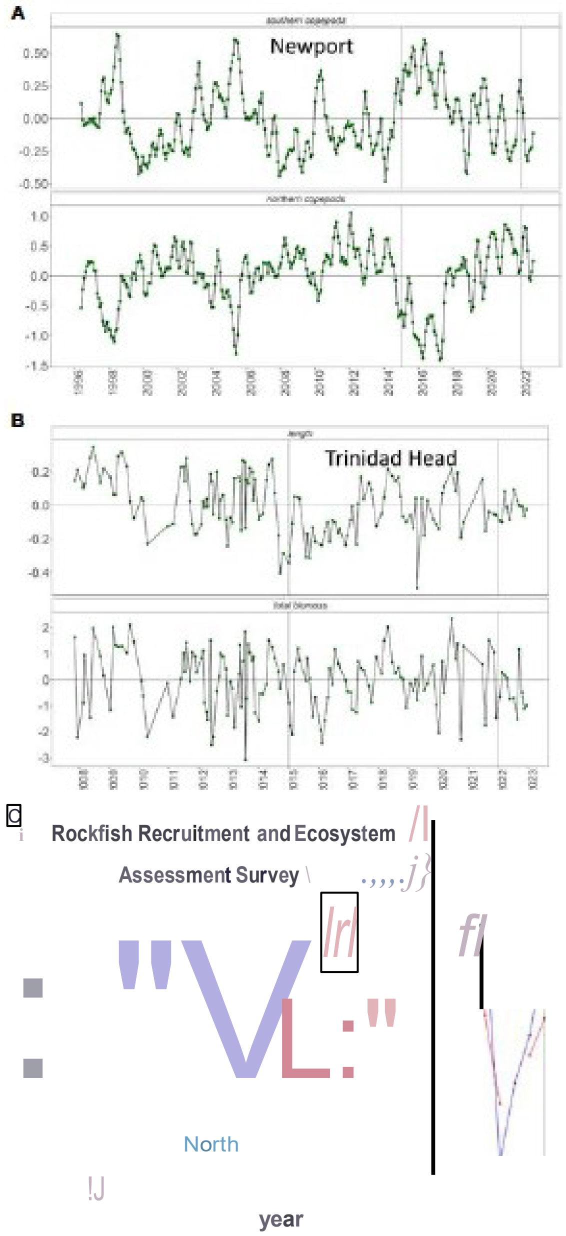
Regional zooplankton

On the NHL, northern copepod biomass was high in the beginning of the year but became slightly negative towards the middle of the and then slightly positi"' in thesecond half of theyear (Figure 7A). North Pacific krill body*size* wasslightly above-average at the beginning of the year, dropped to below-a"'rage in late spring, and returned to near-average tor the remainder of the year (Figure 7B). North of PointConception, the RREAS (earlysummer) documentedslightly abo"' average total krill while in thesouth total krill was slightly below a"'raW (Figure 7C).

Regional fish and market squid

Off Washington and Oregon,daytime suiface tra"i.s found that abundances of yearling anadrornous Coho salmon *Onrorhynchus kisutch* were abo,,. ,,.,rage "ilile chinook salmon *0. tshawytscha* were average in 2022 (Figure SA). Abundances of both monitored marine species, market *squid Doryttuthis OfXllesans* and Pacific pompano *P. simillimus* were abo, average. Off Newport, Ore3>n. larval abundances of five of six coastal species were below average with only Pacificsandlance *Ammodytts hexapttrus* coming in above average (Figure 8B). Abundances of all offshore/southern *species* were below average in 2022 off Newport In California, adult *dynamics* from the RREAS were similar north and south of Point Conception (Figure SC). Specifically, market squid abundance was above •"'rage while Myctophidae and Pacific sardine *Sardinops sagax* (henceforth sardine) were below average. Adult anchovy abundance was above average in the north but fell to awra tor the rust time*since* 2016 in the*south*. Youngof the year trends were more disjointed than adults in the northern versussouthern parts of California. Abundance ofYOY rockfishes *Stbasttsspp.* decreased to below average in the south but rose &om 2021 to remain above average in the north. Bycontrast, abundance ofYOY anchovy were well above average in southern California but below a, ra in northem/central California. Young of theyearsardine and sanddab *Citharichthys* spp. abundances were both below average throughout California "ilile Pacific hake *Merluccius produdus* (henceforth hake) decreased in 2022 relative to 2021 throughout California although this species remained above average in both regions. In southern California, CalCOFllatvaldata displayed varied trends!or the two main benthic *species* as the abundance of sanddabs increased to the highest level since 2014 while rock.fishes remained below average (Figure 80). For the mesopelagics, abundances of both northern and southern t.axa increased in 2022 and southern taxa were at close to record high abundances. Among pelagics, the larval anchovy abundance reached the highest level on record, and Jack mackerel *Trac.hurus symmetrirus* was in the top 10 highest in 2022. Market *squid* was *also* above averaw in 2022. Hake and Pacific mackerel *Sa>mbtr japcnicus* were below awra , but sardine larval abundance increased to the highest level *since* 2014, although this was still orders of nugnitude lower than peak abundances from the late 1990s to approximately 2009.

Thespatial distribution ofanchovy latvae was highly unusual in 2022 when very high abundances were found seaward of the continental shelf (Figure SE). The most extreme example of high offshore abundance was station 93.3 80 where 7000 more latvae were found in 2022 (7056) than on average (56). In addition to this station several nearby offshore *stations* had upwards of 5000 more latvae than""raw. Bycontrast, most of the outershelf stations had average anchovy abundances and a handful of stations had below



AGUJtt7
(A) Anom.iyof log biomassof southern and northem copepods at the NHL (B} Anomatyof North Pacific krl t:ody length (mm)and biomass (mg C m-2) at theTHL {C)Aromaty of log biomassof kril in Califomia rorth Iblle) and south (red) of Fbint Sat from the RREAS.

average abundances. For example, 265 fewer la.rvae were found in 2022 (110) than average (375) at station 90 45, just west of San Oemente Island (Figure SE). Ooser to shore larval anchovy abundance was generally higher than nonnal but not to the same **extent as the off-shelfstations.**

Regional seabird and sea lion reproduction

Seabird reproductive *success* was variable by *species* and location in 2022 (Figure 9A). At Yaquina Head, common murre **experienced total reproductive failure tor the fourth season *since* records began in 2007. C,om.mon murre reproduction was above** average at Point Reyes,slightly below average at Southeast Farallon Island and almost exactly average at Devil's Slide. Brandt's **cormorant experienced average reproduction at Yaquina Head and above average at the other three loc.alities. Pelagic cormorants also had complete reproductive tiilure at Yaquina Head but were** abow average in Southeast Farallon Island and Devil'sSlide. *This species* was not monitored at Pt. R")"S Headlands. In 2015, sea lion pup weight *was* the lowest on reconi. Pup weight rebounded to **abow average in 2016 and has remained abo, average through** 2022 (Figure 9B).

Regional at-sea birds and mammals

All four indicator bird species were sighted at above average rates in 2022. In centralCalifornia in latespring both the migratory **sootyshearwater and resident common murre were at record highs** dating back to 1995 (Figure JOA). In southern California in **summer, cold-water sooty shea..rwater had the sixth highest sightings and warm water black vented shearwater the second** highestsightings *since* 1995 (Figure JOB).

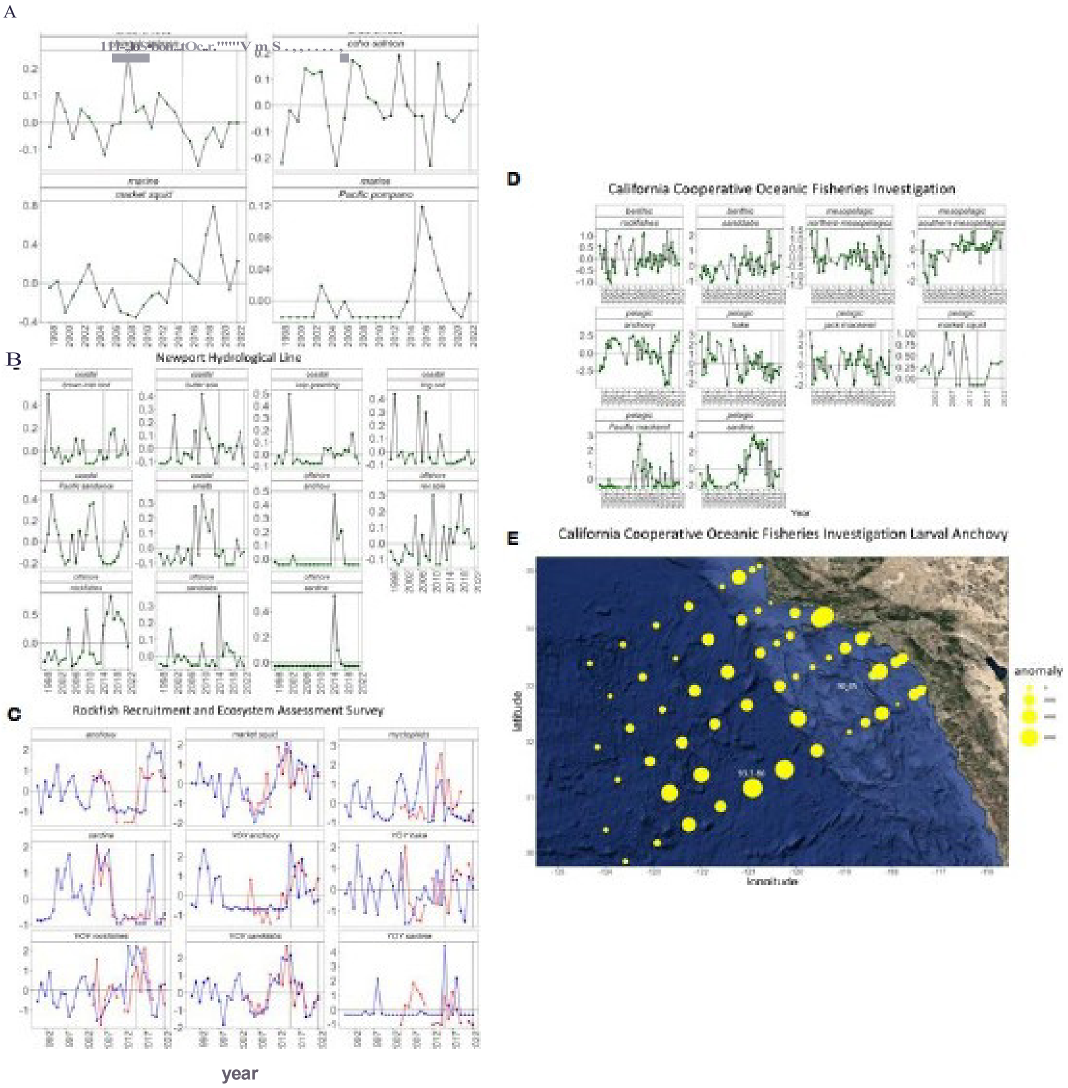
AMual humpback whale encounter rates were considerably higher in 2022 than any previous year (Figure IOC). Most of the 2022 sightings occurred during the fall surwy, and fall 2022 **encounter rates were higher than any previous survey dating back** to 2004 (pplementary Figure). Encounter rates of blue "½>ales **have ftuctuated above and below average in recent *ars* and were** average in 2022 (Figure IOC).

Discussion

Pacific climate indices

Environmental conditions differed marl<edly in the first and second halves of 2022in the CCE relati"' to basin-scale indices. The determination of El Nillo/La Nilla state is based upon SST at the equator, and during I.a Nilla events, the CCE is generally cool with high upwelling and coastal productivity (Bond *et* al., 2008). In winter the CCE seemingly rellected a weak La Nilla as SST was largely dose to average and northerly winds fueled moderately high upwellingin the northern CCE.Spring more resembled a typical La **Nifta with cool temperatures throughout most of the CCE, northerly winds and high upwelling. In summer, however,** conditions in the CCE abruptly ceased being *similar* to an average I.a Ni/la. In summer, SST in the CCE was approximately 1°C above nonnal and by fall the CCE-wide SSr anomaly *rose* to about plus **2°C. C,oncom.itantly upwelling fell to average or below average in** summer **and** fall. In all, summer and fall 2022 depicted like!y the **most anomalous La Ni.tia conditions in the CCE on record**

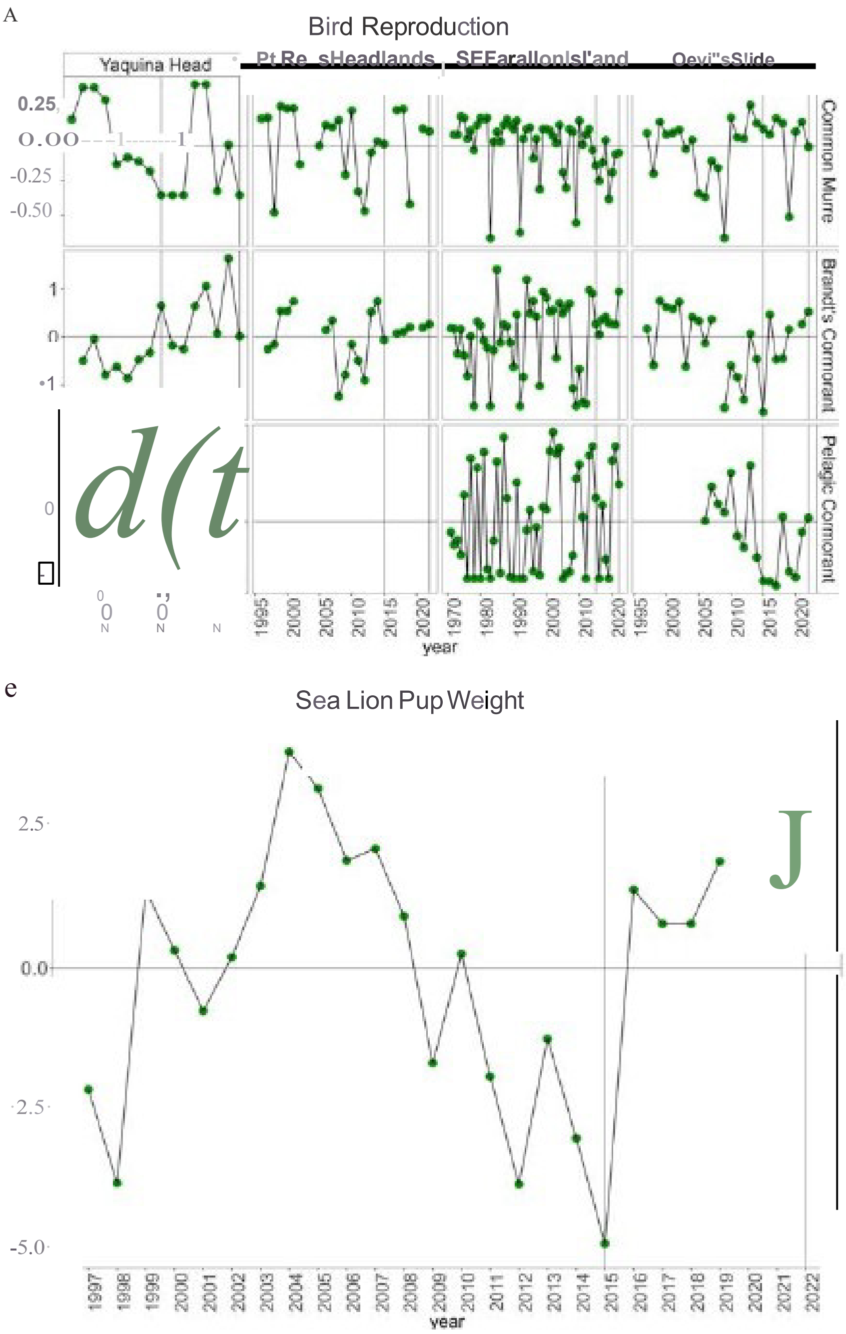
Historically, the PDO correlated positi"'1ywithSSTin the CCE (Lit2ow *et* al., 2020a). When the PDO was in a negative or "cold" phase the CCE tended to be cold and productive due to high upwelling, and the PDO negatively correlated with salmon



AGUJttl
Log a,omaty (A) at:undance of yearty salrron, market sqt.idand Pacific pompano off Washington andOregon fromtl"e JSOES, (B} at:undance of ichthyopla onoff tte NHL. (C)abondarce of atiltt ard youngof tl"e yearmarket scp.Jid and fisl"es from the RREAS.(D} abondarce of ichthyopla on froms ing CatCOFI cruises. IE} noi-transformed aromaty of lar\81a,chovyaburdance (nounder tOm2} per station in spring 2022 re4atiw to spring 1951-2021.

production (Manlllaetal., 1997}. Mean"ilile,a positive NPGO was associated with high nutrients, salinity and chlorophyll in the CCE (Di l.orenzo eta!.2008). Our finding thatit was anomalously warm in the CCE o"'r thepast threeyean and in the *second* half of2022 in particular, highlight that the relationship with the POO/NPGO and local conditions off the west coast of the U.S. and Baja California are rapidly changing Litzow et al. (2020a) found that the relationship between the NPGO/POO local climate began to **become nonst.ationary*st.a..rting* in about 1989/1990 when there was** an abrupt clinute *shift* characterized by abrupt lowering variability in the Aleutian Low and northeast Pacific wanning (Hare and Mantua, 2000; Yeh et al. 2011). They showed that relationships with *these* indices have been weakening 6-om the Bering Sea to the southern California Cuirent In addition, while the POO coirelated strongly and positively with *salmon* production in the Gulf of Alaska 6-om 1950-1988, there was no relationship 6-om 1989-2012 (lilZOw et al., 2018) and that the relationship even *became* significantly negative 6-om 2014-2019 (Litzow et al., 2020b).

While *the* relationships between *the* POO and local conditions has been changing *since the* late 1980's (litzow *et* al., 2020a), nonstationarity was punctuated with *the* onset of the 2013 North Pacilic *Marine* Hean--a"' (Werb and Rudnick, 2023). In Werb and Rudnick (2023), unlike Mantua et al. (1997), the POO was calculated without removing long-teirn trends in SSr, resulting in exclusively positive POO values from 2014-2021. This revised **wrsion of the PDO lines up better with our observations of ocean conditions as record high temperatures wererecorded atthesc.aleof** the North Pacific and *the* CCE """ almost exclusively anomalously "-aim *since* 2014. To ther, these results emphasize that naively using*the* POO asan explanau:uy variable for biological dynamics in

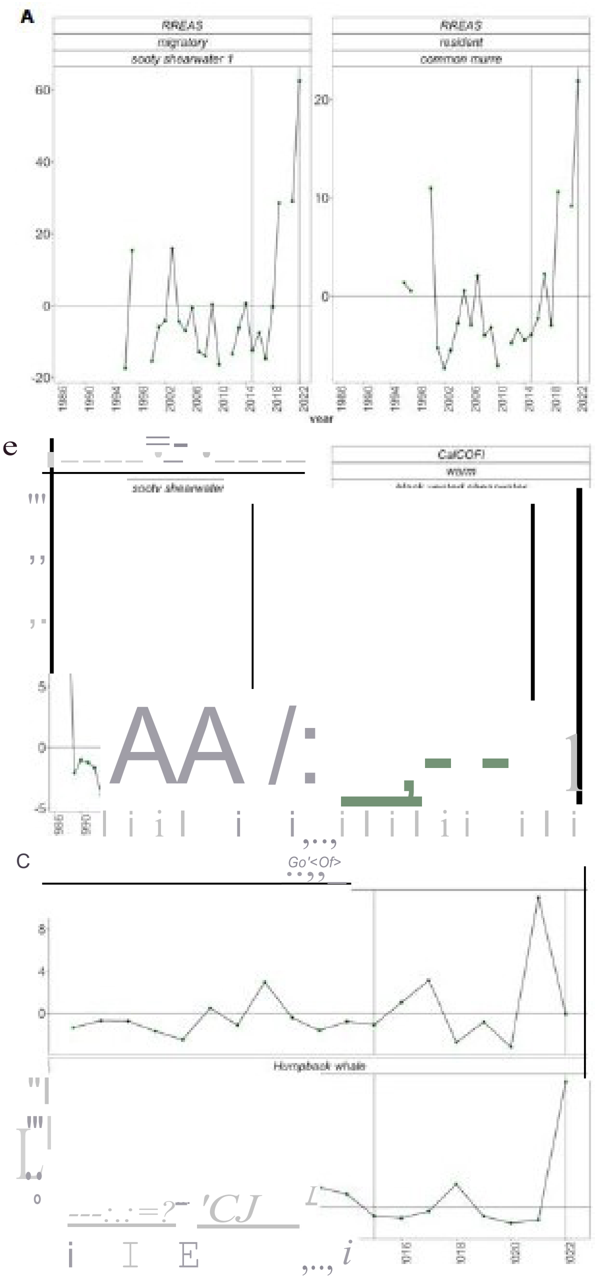


AC.UJtt9
(A) Re od.Jction anomaly (nurrt>er of fledgtings) of tlYee birds in Yaqt.ina Head,. Oegori Pt.Reyes, SE Faralon Island and Oevfs Slide near San Francisco, Catifomia. (B) Sea lion i:upweight anomaly (lt:;!) on San Miguel Island, Catiforrfa.

1he CCE is now problematic (Lit1.0wetal, 2018; lilZOwetal., 2020a; Lit1.0w et al., 2020b; Ohlberger et al., 2022; Werb and Rudnick, 2023).

Marine heatwave update

It has been predicted that the frequency, intensity and duration ofMHWwill increase under a wanning globe (Frolicheret al.,2018; Oliver et al, 2018). In 1he North Pacific, *MHWs* have essentially **become the new norm.al resulting in unprecedented temperature** *highs* in the North Pacific and the CCE. Marine heatwaves have been tracked in this region *since* 1982, and nine ofthe largest twelve occ,ured &om 2013-2022. Given the propensity ofMHWs, the new question is not "½\ether or not there *is* a MHW but how dose to shore does the MHW mo"'? In 2021, the MHW mostly stayed offshore (Thompson et al.,2022b). The 2022 MHW was similar in size and duration to the 2019 MHW, although that year there were



AGUJttIO
At sea sighting anomatyof (A) soctyshearwaterard common murre in cent.rat Catifomia from the RREAS. (B} sooty shearwaterand t:f.ack vented shearv.eter fromst.mmer C.atCOFI in southern Catifomia,. {C) Bllewhales ard 1-klmpba,ck whatesaveraged across the four seasona C.atCOFI cruises.

fewer intrusions closer to shore as upwelling winds were more constant relative to 2022. In addition, the 2019 MHW also began to dissipate and retreat much further offshore during the latesummer/ *tall,* whereas this *year,* the intrusion into coastal waters continued through the entire fall. Gi"'n the unprecedented nature of the physical conditions in the CCE *since* 2013 it is particularly important to continue closely monitoring the system as biological responses are often unpredictable based on past warming events (Schroeder et al., 2019; Schroeder et al., 2022; Thompson et al., 2022a).

Regional physical oceanography and chlorophyll a

During La NitJa events upwelling tends to be prevalent coastwide, and coastal wateis are cold and saline (Bond et al., 2008). In the first part of 2022, this expectation was largely met in the northern CCE as water was slightly abnonnally cold and *saline* and chlorophyll *a* was dose to average in NHL and TiiL By summer, however, despire the PDO and ONI being strongly n"l?tive, temperature, salinity and chlorophyll *a* mostly reverted to average. Moderate environmental conditions seem to be pervasive in the northern CCE during negative PDO yeais in recent }"ars. The PDO has been predominantly negative *since* *2019,* but environmental conditions have mostly hovered around the long.term means with the exception of early 2021 when it was relatively cool and saline (Thompson et al. 2019b; Weber et al., 2021; Thompson et al., 2022b).

CaJCOFI *samples* far off the continental shelf and thus can discern the presence of multiple water masses. There are multiple bodies of water in this region and their boundaries are highly variable through both time and*space*(Bogradet al., 2019). Central Pacific water is the furthest fromshore offsouthern California and is relatively warm, saline wrth low chlorophyll *a,* PacificSuban:tic or California Current water is cool, low salinity and high chlorophyll *a* and tends to be centered on the shelf break. Upwelled water is cool, saline and high in chlorophyll *a,* close to shore and shallow, while California Undercurrent water is wann, saline and low chlorophyll *a* and is also close to shore but deeper (100-300 m) than upwelled water. In the offshore region off southern California, temperature and salinity were above average most of the year indicating the presence of C,entral Pacific water. This saline water mass has been ubiquitous in the CCE *since* 2015 when water from the North Pacific Subtropical Gyre was advected eastward into the CCE (Ren and Rudnick, 2021). However, chlorophyll *a* was *also* high in spring and summer on the shelf which may indicate that there was a mixture of Central Pacific and Pacific Subarctic wateis in *this* region. PacificSubarctic water has *also* been common in the CCE during the 2014-2016 MHW and has apparently fueled high rock6sh recruitment before and during the MHW (Schroeder et al., 2019). Ooser toshore. temperature and salinity were close to average, but chlorophyll *a* was elevated in spring before dropping to slightly below average in summer and fall. The enhanced chlorophyll *a* was likely a remnant of upwelling prior tospringsampling before physical conditions returned toaverage.

Regional zooplankton

Zooplankton are critical food for a myriad of marine species including fish, birds, and marine mammals. During past La Nilla events in the CCE, high nutrient input &om upwelling ofren resulted in higher abundances of lipid-rich northern zooplankton. This suire of zooplankton are important prey for *species* such as arlingsalmon and increases theodds ofadultsalmon retumingto spawn in their natal rivers one to three years in the future

(Friedman eta!., 2018). Yearlingsalmon tend to enter the ocean in latesprinwearly summer (Thompson *et* al. 2019a), so zooplankton community composition is particularly important during this time of year. In 2022, biomass of northern copepods was high "½\en yearlingsalmon were entering the ocean "½\kh may have enhanced salmon survival (Daly *et* al., 2013). By midyear, howe"'r, northern copepod biomass dropped dramatically. Similarly, North Pacific krill body size and IDtal krill biomass, "½\ich were both typically high in I.a Ni/la years, dropped precipilDusly in northern California from the beginning of the year to rnid-2022. Zooplankton dynamics in the CCE are influenced byprimary production and h}drographic **conditions (Peterson et al., 2017). The decrease in northern** copepod biomass and krill body size and biomass was likely dri"'n by reduced upwelling, near- to below-average chlorophyll **a concentration, and warmer water in sum.mer (PeteC$0n et al.,** 2014; Peterson *et* al., 2017; Roberison and Bjorksted 2020).

Fish and market squid

During warm, non-La Ni/la periods, southern fishes tend to **move north and ofshore species tend to move inshore throughout** the CCE. In the Pacific northwest Pacific pompano and market **squid are bellwether indic.at:ors of warm water. Pacific pompano were absent &omsurface trawlsurveys offOregon and \Vashington** in 12 out of 16 years prior to the onset of the 2014-2016 Pacific MHW (Thompson *et* al., 2018).Subsequentto 2013 thisspecies has been present in each yearalthough abundances were low in 2021. In ***2022,* however, abundance was abo, average tor the sixth *time*** since 2015. Similarly, marketsquid were above average off Oregon and Washington in 2022 lor thesixth yearsince 2015. Market squid distribution shifted6u-north duringand after the 2014-2016 marine heatwave (Burford *et* al., 2022; Chasco eta!.,2022;Suca *et* al., 2022) **which significantly reduced commercial fishing revenue in** California (Suca *et* al., 2022; Free *et* al., 2023). Market squid **distributions differed in 2022 from recent years, however, as abundances were above average in Ore§>n/Washington as well as in northern andsouthern Califom.ia. It is thus possible that market** squid distributions expanded or beganshittingsouth in 2022 as this species was found throughout of the west coast of the UnitedStates.

Off Oregon, fishes are categorized as coastal resident veisus southern ofshore, and coastal residents tend to be elevated during La Nil\a e"'nts (Daly *et* al.,2013).1..aJvaeand juveniles of the coastal residents are important forage for both salmon and birds and tend to increase during cool conditions (Daly et al., 2013; Daly *et* al., 2021) "½\ile abundances of the southern offshorespecies rises "½\en it is wann (Auth *et* al. 2018; Nielsen *et* al. 2021). The larval fish assemblage from the NHL in 2022 was unusual as abundances of both the coastal resident and southern offshore species were either **average or low. Di.seeming the mechanisms underpinning low fish** production of Oregon in 2022 could be an important topic for **future research.**

It was previously thought that anchovy population size **increased during cool periods when La Nilla events were frequent** (Chavez *et* al. 2003), but in recent years anchovy increased greatly in warm years (e.g., 2004-2005, 2014-2016; (Thompson *et* al., 2019b)). The expectations !or anchovy during I.a Nil\a events is thus currently unclear, and our undeistanding of drivers of the populations size of this important foragespecies (McOatchie *et* al. 2016a) is erolving (Swa!ethorp *et* al.,2023). Anchovy have been in a boom state in the CCEsince 2015(Thompson *et* al., 2019b), and in 2022 adult anchovy abundance remained high in central California **but fell to avera levels in southern Califom.ia. However, patterns of }Oung of the year anchovy were opposite as values were well** abo"' averai, insouthern California but slightly below average in central California. The spatial discrepancy between }'lung of the year and adult abundance may indicate that many adults are spawning in locations that are possibly suboptimal for wval **survival. A similar dynamic seemed to take place in the Humboldt Current where Peruvian anchO\ t.a eggs were found in** locations where adult food was high but the water was also acidic while larvae were in nearby, less corrosive water (Shen *et* al., 2017). Record high densities of spawning anchovy, as those experienced since 2015, could be displacingspawneis intolower quality nuise,y habitat. Alternatively, it is possible that adult populations in **southern California were higher in southern California than** detected by the RREAS "½\kh nwnly samples stations along the shelf break. Ca!COA found that anchovy egg and wvae counts **were orders of magnitude higherthan average in locations nearand** seawanl of the continental shelf break. Regardless of the precise adult abundance insouthern California, it is dear that the anchovy regime that began in 2016 (Thompson *et* al., 2018) continued into 2022, and the high young of the year anchovy abundance in 2022 suggests that it will persist at least into 2023.

Southern mesopelagic species typically receded from southern California during I.a Ni/la """ts (Thompson *et* al., 2012), but **abundances were close to a record high there in 2022. This suite of** species resides primarily in the wann andsaline Central Pacific and **California Undercurrent, that flows from south to north, and very** predictably are abundant when the system is warm (Moser *et* al. 1987; Hsieh et al., 2009; Thompson et al., 2022a). Although mesopelagics are in deep water during the day, they vertically migrate towanls the surface at night and are thus important components of the pelagic food chain. Indeed, a recent analysis of predator diets in the CCE revealed that of 143 predator taxa 25% consumed mesopelagic fishes (Iglesias *et* al., 2023). This suite of predatois included economically valuable blue6n tuna (16% of all non-empty diet samples), albacore (19%), swordfish (50%), and Humboldt squid (52%). Between the high abundance of mesopelagic fishes and anchovy, at least the southern portion of the CCE was highly productive from the perspective of a piscivore in 2022.

Bird and sea lion reproduction

The capacity ofseabirds ID!Jedi, theiryoungis afrectedgreatly by prey available to the parents, and productive I.a Ni/la conditions tended ID be conducive for successful reproduction (Sydeman *et* al. 2001). Seabird reproduction in 2022, howe,,.r, was ve,y dilferent between Oregon and central California as two species (common murre and pelagic connorant) aperienced total reproductive failure

TABLE1 Summary of physical and biological indicators of the status of the California Current Eoosystern in the firstandseoond halwes of 2022.

Scale	Type	Variable	Sample Location	January to June	July to October
		ON !		⁝;⁝ ⁝;	neg-ati¥t
		POO			neg-ati¥t
		NP<X>		positive	po,:tili¥t
		North Pacl.6c SST ano.m.aly		positive	po,:tili¥t
'-		CCLMB ano.m.aly			po,s,ili¥t
		Mari.ne heatwave mCCB		low	h
		.... 1ssr		ntfPtlw oorth o.f PlConoeptio,n: neutn\l 91>Ulh 6f PLC6noeplbn	po,s[redacted]t
		upweJIJ"3		positive	[redacted]
		temperature	NH	ntfPIJ¥t in winter. neulral in spring:	[redacted]
		salinity	NH	hi3,h in wi.nter. neut.Q) inspring	
		<hbroph I	NH		[redacted]
	=•]- il 1 1..! -a	tempt12twt:	TH	hw in winter. high in spring:	mL,ed
		salinity	TH	hi3,h in winter. lc>win spring:	neg-ati¥t
		<hbroph I	TH	neul.121 in winter. hw in spring:	higheady uunmer. netunl late uunmer
		tempt12twt:	CaJCOFI	neutn\l 6Elhelf and at shelf. high nearshore	high68"shelf. neutral at shelf. neut.Q)6r)OW' near shore
		salinity	CaJCOFI	)OW"6r neutral in spring:	high6&'shore. neutQJ at shelf and dost toshc.e
		<hloroph I	CaJCOFI	high at shelf. neul.121 elsewhere	hi3,h at shelf, neutral elMhere
		?.OOplanl.1.on	NH	souhem cq,eopod:s negative	solllhern()()J)tpOds nt{Pti¥t
				oorthem ()()J)tpOds pos0¥t	oorlhem ()()J)tpOds neutral
		?.OOplanl.1.on	TH	&tphosio/"dfeol. potiti¥t in winter. negative in spring:	fuplut:usio pacf,£0 Jeng:th neulral
Regional				T6tal bi6mus m.lx.ed	T6tal liom.ass m.lx.ed
		?.OOplanl.1.on	RRBAS	T6tal biomass hi3,h in oorth. lc>win 91>Ulh	
		mh	_l.$OES	)'tarling: salmion positive: Warm-water mari.ne species positive	
		mh	NH	()()aS(a) and6f&hore 6shes nt{Ptive	
	1! -g, .0	mh	RRBAS	Adults: m.arl:et squid po,:ttive: m)'Cloph.ids and sardine negative: anchtwy po,:ttive in nC'rlh. neutral insatl.h	
				You.ng:6fthe year: hake and sanddabs neutral: anchovy po,:tili¥t in 9()Ulli. neutQJ in north: ruckmh ntul.121 in oorth. nt{Pti¥t in swlh:Sll"dint -alive	
		mh	CaJCOFI	Benthie: sanddat. positive. ruck&she:s neutQJ	
				Mesq,,elag,ie: ne'rthern spp. neut.121: swlhem spp. po,:tili¥t	
				Pdag,ie: Anchc,vy reoord hi3.h; jade m.adcerel. market squ.id pottive: hake. sardine neut.121: Paci6c m.adrerel ntfPIJ¥t	
		shc.e bird repruduetiM	Yaqu.ina Head	murre ntfPtlw: Bnndt's()()rmior.ant neut.121: pelagc ()()nnorant -alive	
		shc.e bird repruduetiU\	PointR.t)tl	m.U1Te positive: Brandis ecrmior.ant positive	
		shc.e bird repruduetiM	[redacted] Fa,,Doo,	murre neut.QI; B,udt's ()()nnorant positive: pelagc ()()lln012nt positive	

(O,ntinwd)

TABLE1 Continued

Scale	Type	Variable	Sample Location	January to June	July to October
		sht.-e bird repruduet.iU\	Devil's Slide	mu.rre neutral: Bnndt's()()rm,o, t pc)tili¥t	
		sealiom	S..M uell!bod	pupcatdilion po,sitive	
		at tta bird	RRBAS	migratory 900ty s.htarv4terand n?:tident()()mm,on mu.rre po,:tili¥t	
		at tta bird	CaJCOFI	()()()) 9001y *shtarwat.er*and wann black vented sh.ea.water po,sitlve	
		at ua m.arine m.ammals	RRBAS	blue whale neut.QI; humpbadc: whale po,sitlw	

at Yaquina Head, Oregon. In addition to prey availability, eagle depredation of common murre is a potential top-down forcer of common murre reproductive failure at Yaquina Head (Thompson et al., 2022b) and around the world (Hentati..Sundberg et al., 2<lZI). However, eagle interactions with common murre were unexceptional in 2022 (Supplemenmry Appendix),and eagles cypically do not afrect pelagic cormorants. It is thus likely that seabinl productivity at Yaquina Head was derailed by a lack of suitable food Murre chick diets at Yaquina Head ha"' high intraannual variability and are i,nerally dominated bysmelt (Osmeridae spp.), herring or *sardines* (Oupeidaespp.),or Pacificsand lance (Thompson et al.,2022b). Diet composition of common murre is cypically collected, but because of the reproducti\ failure of common murres in 2022 there was no associated dietary in.formation from Yaquina Head. Indeed, ichthyoplankton *S"""fS* from the NHI. which is 5 km south of Yaquina Head, suggested that fish production was low in 2022 For example. abundances of smelt were below averag?, Oupeids were absent, and Pacific *sand* lance were approxinutely •"'rage. This differed from 2021 when bothsmelt and Pacificsand lance were well above a\O!rage, and reproduction was much higher for all three species (Thompson et al., 2022b).

In central California, Brandt's cormorant and pelagic cormorant reproduction were above a, rage in all three sampling locations. Cormorants can feed their chicks regu,gitated prey *so* there is not a maxim.al anchovy bodysize that is inaccessible to the chicks and thus both young of the year or adult anchovy can be valuable prey (Thompson et al., 2018). Common murre reproductive success was close to or slightly abo, awra in central California. Unlike cormorants, they feed their *chicks* whole animals and thus adult anchovy are not suitable for nourishing ch.icks. However, common murre reproductive success has been found to be positively correlated with krill and young of the year sanddab (Saniom et al., 2014), and in 2022 krill biomass was abow average andyoung of theyearsanddab average in central California Common murre therefore likely also had a fairly robust prey field in 2022.

In the 2021 State of the California Current Ecosystem Report (Thompson et al. 2<lZ2b), we predicted that *sea* lion pup condition would be abow avera in 2022 because anchovy recruitment was high in southern California in 2021 and thus adult anchovy prey wouldlikely be available to *sea* lions in 2022.This prediction turned outto be correct assea lion pup weight was above avera once again in 2022. Indeed, *sea* lion pup weight was abo"' averai, in each year from 2016-2022, tying the previous *streak* of above averai, weights from 20<lZ-200& Sea lion pup condition is proving to be one of the most predictable indicaio,s of ecosystem condition in the CCE. McOatchie et al. (2016a) found that the combined abundance of anchovy and sardine, as well as pup sex, explained 81% of the variability in pup weight between 2004 and 2014. In 2014 abundances of both anchovy and sardine were extremely low and sea lion pups were st:a..rving because their mothers likely were malnourished and unable IO properly lactate (Laake et al., 2018). Pup condition impro dmnutically in 2016 coincident with the anchovy boom and has renwned above ""rage as the high anchovy abundance continued through 2022. Updating the analyses in McOatchie et al. (2016a) IO the present would provide deeper undemanding of d,h,.rs of sea lion condition in the CCE.

At sea birds and mammals

During previous cool-water La Ni.l\a even at sea residents such as common murre tended to be high while warm-water migrants such as sooty shearwater were low (Thompson et al., 2019b). At *sea* observations of migralOty sooty shearwater and common murre were at an all-time highs in 2022 in central California in spring. Sooty shearwater observations in this area are thought to be driven by prey (Santora eta!.,2011; Santora et al., 2017),andse,,.ral potential preyspecies*such* as marl<etsquid. adult anchovy, young of the year hake and young of the }"ar rockfishes were abow awra in 2022. C,ommon murre are resident breeders thatcan tra\O!Iup to approximately JO kmto search for food(Ainley and Boekelheide, 1990), but non-breeding birds are capable of traveling much greater distances (Loredo et al., 2019). The coupled high at-sea observations and awra to above average reproductive success suggests that common murre were forced to forai, far from the colony (Harding et al. 2007) but that they i,nerally found enough food to nourish their chicks. Altemati"'IY, non-breeding or pre-breeding birds could have moved into the sampling area from elsewhere. In summer in southern California. wa.nn-water associated black-ventedshearwater, which historic.ally were low during La Ni.tia e\ nts, were above average for the eight consecutive year *since* the 2014 MHW, suggesting that the *system* has been in a sustained warm st.ate for almost a decade. However, cool watersooty shea.rwater were also above average perhaps as a result of the relati"'1y cool and producti"' spring conditions.

AMual humpback whale encounter rates were higher in 2022 than any previous year. Humpback whales are opportunistic foragers (Baker *et* al., 1985). Stocks wintering in Central America **and Mexico migrate seasonally to southern California. where their** diets may reftect local oceanographic and climAte conditions (Calambokidis *et* al., 2000; Fleming *et* al., 2016). For instance, **du.ring cool, productive, strong upwelling periods that are characteristic of La Ni.tia events in southern California. we would** expect to see hwnpback whale diets dominated by krill, whereas, during wamt, oli trophic **periods,** humpback whale diets may be dominated by pelagic schooling fish (Fleming *et* al. 2016). Record high abundances of anchovy larvae were measured offshore of the continental shelf in 2022, adjacent to ofshore spring hwnpback "½>ale sightings (Supplementary Appendix). Additionally, an **anomalously high nwnber of anchovy larvae were measured in** the Santa BaJbara Channel, in close proximity to the record high number of hwnpback whale sighting, during the la!! Ca!COFI survey (Supplementary Appendix). The high number of humpback "½>ale sighting, this }"ar indicates that they may be aggregating in the region to exploir high density anchovy schools **during this period of wanner, oligotrophic conditions in the** CalCOA region.

Encounter rates of blue whales have fluctuated above and below average in recent years. Blue whales are seasonal migrants to southern California during summer months (Irvine *et* al. 2014). While inhabiting the CalCOA region they forage exclusively on krill, preferring *Thysanoessa spinifera* to North Pacific krill (Nickels et al. 2019). Due to their specialized foraging preferences, blue whale encounter rates may be an indicator of local productivity (Wachtendonket al. 2022). In thesummer of 2021, encounter rates **of blue whales were the highest throughout the timeseries** (Supplemenlluy Appendix). Encounter rates of blue whales were **lower in swnmer2022 than they were in*summer* 2021. Conditions** in 2021 were dominated by a strong La Nilla, driving increased productivity in the California Current Ecosystem and favorable conditions for blue whales (Thompson *et* al., 2022b). Whereas, **conditions in *summer* 2022 were *less* productive from the perspective of a blue whale, potentially driving the lower** encounter rates of blue whales throughout the Ca!COFI region.

Conclusion

The relationship between basin scale indicessuch as ONI, PDO and NPGO and local physical conditions has become oonstationa,y in the CCE (lilZOw *et* al. 2020a). Fiedler and Mantua (2017) showed that local conditions were variable during El Nillo events ben>,..n 1950 and 2016 but were more consistent during La Nilla **erents. However, 2022 marked the third consecutive La Ni.l\a and** duringmuch of *this*stretch physical and biological conditions in the CCE were unlike past La Nilla years (Weber *et* al., 2021;Thompson *et* al., 2022b), and many of the physical and biological responses **based on observations from past La Ni.tia events were not *met* in** 2022. For example, northern copepods biomass was awrai, of Oregon as was krill body *size*of oorthem California in summer. Of **Oregon and \Vashington, warm-water associated species were above average. off Oregon cool-water coast.al species were low, and off southern California southern mesopelagic fishes were** high. While many reproductive *success* of many birds was above **average in central California common murre experienced total** reproductive lailure olf Oregon. Our accounting of the *state* of the California Cuirent Ecosystem in 2022 agree with Werb and Rudnick (2023) who state that "the PDO and other EOF based ***metrics* may not be as useful in the future as climate continues to** change• (Table I).

Data availability statement

The datasets presented in this study can be found in online **repositories.The names of the repository/repositoriesand accession** nwnber(s) can be found in the article/ pplementa,y Material.

Ethics statement

The animal study was appro,,.d by Scripps Institution of Oceanography board of *ethics*. The study was conducted in **accordance with the locallegislation and institutional requirements.**

Author contributions

AT: Conceptualizati:>n, Formal analysis, ln\"5ti§ltion,Software, Writing - original draft, Wriring - review & editing. RS: Conceptuafuation, Data curation, 1n,..,ti§ltion, Writing - original draft, Writing - review & editing. MA: Conceptuali7.ation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. JS: Conceptualization, Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. EH: Conceptuali7.ation, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing AL: Data curation, Fonnal analysis, Writing - original draft. ES: Conceptuali7.ation, Fonn.al analysis, Writing - original draft. WS Conceptuali7.ation, Data curation, Fonn.al analysis, lnvesti§ltion, Methodology, Writing - original draft, \'iriring - review & editing. *Ck* Conceptualization, Data curation, Fonn.al analysis, Investigation, \'iriring - original draft, Writing - review & editing. *Tk* Conceptuali7.ation, Data curation, Formal analysis, Investigation,Methodology, Writing-originaldraft, Writing - review & editing. SB-P: Conceptuali7.ation, Data curation, Methodology, Writing - original draft \'iriring - review & editing. 113: Fonn.al analysis, Writing- original draft EB: Conceptuali7.ation, Data curation, Fonn.al analysis, Investigation, Methodol'l!}', Writing - origi'lal draft, Writing - review & editing. SB: Conceptuali7.ation, Data curation, Fonn.al analysis, Investigation, Writing - original draft, Writing - review & editing NB: Fonn.al analysis, Resources, Writing- original draft. BB: Formal analysis, Writing- originaldraft. ED: Conceptualilation,Datacuration, Fonn.al analysis, Methodol'l!}', **\Vriting - original draft, \Vriting - review & editing. HD:**

Conceptuali7.ation, Data curation, Fonnal analysis, Investi§ltion, Writing - original draft, Writing - review & editing. JCF: **Conceptualization, Data cu.ration, Form.al analysis., Funding** acquisition, Investigation, Methodology, Project administration, Resources, Software,Supervision, Validation, Visuali7.ation, Writing - original draft, Writing - review & editing JLF: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft Writing - review & editing NG: Conceptualization, Data curation, FonnaJ analysis, Methodology, Writing - original draft, Writing - review & editing. AG: Fonnal analysis, Writing - original draft. RaG: Conceptuali7.ation, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. RiG: Conceptualizition, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. EG-0: Conceptuali7.ation, Data curation, Formal analysis, Investigation, Writing - original draft Writing - review & editing JG-V: Conceptuali7.ation, Data curation, FonnaJ analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. TH: Fonnal analysis, Validation, Writing - **original draft. KJ: C,onceptualization, Data curation, Form.al** analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. MGJ: Conceptualization, Data curation, 1n,..,tigation, Writing - original draft Writing - review & editing Tia: Conceptuali7.ation, Data curation, Fonnal analysis, Investigation, Writing - original draft, Writing - review & editing MJ: Conceptuali7.ation, Data curation, Formal analysis, Investi§ltion, Writing - original draft, Writing - review & editing. Tio: Formal analysis, Writing - original draft. BL: Formal analysis, Writing - original draft Writing - review & editing NM: Conceptuali7.ation, Data curation, Formal analysis, Investi§ltion,Methodology, Writing - original draft Writing - review & editing. GM Formal analysis, Writing - original draft, Wriling - review & editing MM Formal analysis, Writing - original draft. SM: Formal analysis, Writing - original draft. LM: Formal analysis, Writing - original draft CM: Data curation, FonnaJ analysis, Writing - original draft. CN: Data curation, Formal analysis, Investigation, Writing - original draft. RO: Formalanalysis, Wriling- original draft. TP Fonnalanalysis, Wriling - original draft. AP: Data curation, Formal analysis, Investigation, Writing - original draft RR: Conceptuali7.ation, Data curation, Formal analysis, Funding acquisition, Investi§ltion, Methodology, Project administration, Resources,Software,Supervisioo, Validation, Visuali7.ation, Writing - original draft Writing - review & editing DR: Fonnal analysis, Writing - original draft, Writing - review & editing KS: Fonnal analysis, Writing - original draft CS: Formal analysis, Writing - original draft. I& Formal analysis, Writing - original draft LS:Conceptuali7.ation, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing 00 Data curation, Formal analysis, Methodology, Writing- original draft, Writing - review &editing.ST: Data curation, Fonnal analysis, Wriling - original draft. PW: Fonnal analysis, Writing - original draft. KW: Data curation, Formal analysis, Writing - original draft. WW: Formal analysis, Writing - original draft. EW: Conceptuali7.ation, Formal Analysis, Writing - original draft. BW: Conceptuali7.ation, Formal analysis, Writing - original draft.

Funding

The author(s) declare that no financial support was received ti>r the resean:h, authorship, and/or publication of this article.

Acknowledgments

We would like to primarily thank the *sea* ing*folks* that make collection of much of the data here possible. We *also* thank the CCE LTER (NSF OCE-2224726). Discussions with David Demer helped us better undeistand the nature of the PDO, NPGO and ON!. We would liketo extendour gratitude to Greg Williams ti>r *his* excellent comments on asloppy draft of this paper. Thescientific results and **conclusions, as well as any views or opinions expressed herein, are** those of the author(s) and do not necessarily rellect the vie"' of NOAA or the Department of Commerce.

Conflict of interest

The authois declare that the research was conducted in the absence of any commercial or financial relationships that could be **construed as a potentialconflict of interest.**

Publisher's note

All claims expressed in this article are*solely* those of the authors and **do** not necessarily represent those of theiraJiliated o,gani7.ations, or those of the publisher, the editors and the revieweis. Any product that may be evaluated in this article,or claim that may be made by *its* manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be round online at: ht1ps.//www.frontiersin.org/articles/I0.3389/frnars2024.l2940I I/**ful1>upp!ernenta,y-material**

References

Ainley.0.G.. and Boekelbeide, R.J..(1990).Sar.bird.s*of du Foard Ionbl ands:muctu and* **dJM.mic'J** *of an '4'Wtling I.on com.mun***ry(Stanford. California, USA: Stanilord lJNVtr.tlty Presa).**

Au1h. T. D.. Doly. E. **A.. Brodew-.** R. D.. **,od** Fl.!he,. L (2018 **Phendogi<>I""1 di.st.ributional shills in ichthyoplankton assocbted with reotnt wvining: in tht oor1heut Pacific Ootan.** *Glo&d Ou, Biol* **2.4, 259'-272. dok 10.1111/g.d,.13872**

Baker.C.S.. Hem,,,an. L M. Pu,y.A.. Lawton. W.S..St.raley. J..M_andS1..12)ey. J..H. (1985). Population dw-aeterlrticsand migration *o.f*summer andlat.e-uason hum.pbadc: whales(fh'•*MK11'4"8lio.r)* in sc>tahtas1ernAlub.Mar.MommaJ*Sci* l. lCM-323. dok JO.I II 1.1748·7692.J98S.th00018.x.

Bareelo. C_ Ci.anneDL L. and 8ndtur. R. D. (2018). Pdajj,ic m.arint refUSJ,ia and climatically sattili¥t areas in an eutern boundary oirrtnt upweDinS systtm.. *Qobol Clr.ongt Biol* 2.4, 668-t,80.dot 10.111Vsd>.13857

Bogr.ld.*S.* J..,Sduutdtr. l D.. andJacx>x. M. G. (2019). A wat.tr mas hltttry6f tht Solllhtrn Califomi.aomtnt s-ys:ttm.. *Ga,ph),. ks. Utt.* «>.6690-ti698. dot 10.1029/ 2019Gl082685

Bond. N. A. 8;atcheldtr, H. P.. and8o$r.ad. *S.* J.. (2008). fatcart.inS nor1heutern Pacific stem responses to la Nina.&u 'Jhr,u, *Am. h),.Union*89. 321-322. dok JO.J029/2008F:03S0002

BroU3.hton. J. M.. Codding. 8. F.. Faith. J.. T .. Mohltnh.68", K A.. Gruhn. R.. 8rtnntr-C61t12in,J... et .al.(X>22). EJNil\o frtqutncy tlu-eshold ()()ntru)sel'.)ast.al biotic C6m.m.uni.ties. *$dmu* 377, 1202-IX>S. dok JO.I126/sdtne1033

Burfc.d. 8. P.. Wild. LA_ Sclw,.an.R.. Gtnc>weth. p_ M. S..ttnivasan.A.. E.bhi. R.. et .al. (2022). Rapid 1211!Jt eJ:Paltsi0n6f a mad.nt «-tothtrm rt¥e.als tht c and «lOJotpc.al ()()n,equtnees6f short·ttnn variability in seawat.tr tem.ptratwt: and dissc)}vtd *otyp Am. Jliit.* 199, *S23--SSO.*dok J0.JM6/71857S

Calambolddis. J.., Stti!Jtr, G. H.. Ras-mwsen. K.. Urban. J.. R.. &Joomb. K. C_ ladni.ndt Cutv.ara. P.. et .al.(2000). Mipato,y desiinationsofhum.pbackwhaluth.at fttd68"California. Or¥n and Washington. *Mar. Ea,I. Prog.&r.* 192. 295-304. dot J0J3S./rneps19229S

Cam.pbeD. G. *S.*. Thom.as.. L. Whit.airer. K. Douglas.. A 8 .. Calambolcidis.J.., and HDdeb12nd. J.. A. (X>JS). lnttr4nnual and seuonal tmtds in ettaoean dillrl>llion. density and alundanot68",olllhtrn California. *Dttp*Sat R.c:s. Am *U: Topi£d Stud. Ouan* .112. 10-157. dot J0.1016'j.ds-r2.201.4.J0.OOS

Capotl,ndi. A. Wit nherg.A. T..Ntwman.M_Di[.()ren:o. E.. Yu.J..·Y.. Braoonnot. P.. et .al. (2015). Undtttt.anding ENSO dt¥ersity. *Bult Am. Mt:ttorol. S«.* 96. 921-938. de'i: JO.I17S'9AMS·D·13-00J17.1

Qm.oo, 8. B.. Hunsldctr. M R. Jaool,,son. K C. Welch. 0. T.. MCT31n. C. A.. Muhling. 8. A.. et .al. (2022). &-idtnot6f tem.ptr.atu.-t lvtn sh.ills in m.arl.:et squid drytttuthisq,ale:scitns dtns-ilies and dirtribtttion in tht Califomi.aoirrente(X)Jys1tm.. *Mar.CM.st. Fish.* 14.eJ0J90.dot J0.1002/rncf2.J0J90

a-e,.F.P.. P<nw"flJ•"-T..C..,..C. G. Ry.._P.. Mlchm . R.P.Sd,Jln;og.8.. et .al. (2002). 8iolot;ic.al and d)em.ic.al ()()mequenots *d* tht 1997·1998 El Nino in etnl.121Califomia w.attis. *Pn,g. O«anogr.* 5"' 205-232.de'i: 10.1016$)()?9 11(02) 00050-2

Gavtt.F.P.. Ry.an.J... Uuch-Cd.a.S. B.. and Niq.,.en. M. (2003). Frum anch&vies to sardinesand bade:Multideeadal chan!Jt in tht Pacific*Ooean.Sdmct* 299. 217-22Ldok JO.I126/sdtnot.1075880

Q)bb. K. M.. Westphal. N.. Say;anL H. R.. W.ats.on. J..T .. Di [.(),en74 B.. Ottng. H.. et .al. (2013). Hi y variablt El Nil\ osdl.btion thro thhotJooent. *$dmu* D9. *61-70.*dok JO.I 126/sdtnot.12282"6

Daly. p_ A.. Auth. T. D.. 8ndtur. R. D.. and Pettr.s()n. W. T. (2013). Winter ichthyoplanlton biom.an as a p.-tdiMr dearly *sum.mer* prey 6tlds and sunival6f jU¥tnDtsalmon in tht northtm Caliilorni.aCU1Ttnt.Mar. *&cl.Prog.Str.*<CM,203-217. de'i: Jo.J35'/rnepsl03X>

o.Jy.B.A. Bn>deu,.R. 0 .. Mo,...,.C.A.. Bw-1«!.8. . ""1 H.S-. 0. H. (2021).Prey ttltdivity and diet partitionins6fjwenilt salm,o,n in()(')as:law) *aters* in rtbtfon to prey biom.asaand im.plicatiom for s.alm.on eady m.ari.nt survival. *North Aid/I£ Ania:iromow F&h Commission Ttth.kp.* 17, 53-56.

Di [.()ren:zo. E.. Sdlntidtr. N.. Cobb.KM_ F12nks. P.J.*S.*. *Chhalc.* K. Miller. A. J..., et .al.(2<>0I). N6rth Pad6cCyrtOsdl.btion linbooeandim.at.eand stem t. *Jrys.kJ.Utt.* 35, l08607.dd: JO.J029/2007Cl032838

Bchtvin. V.. Colas-. F.. Es!pinoza•Morribtron. D.. Va,qua. L. Ancullt. T.. and Glllierrez. D. (2018). Fordnp and Nldlllion6f tht X>17 ()l'.)astal EJ Nil\o68" northtrn Puu and EODdor. Fn>nt *Mar.Sd. S.*dot JO.D89/Cmars.2018.()()J67

!unit. H.W..Seary. R.. Muhling. 8. A. Bog12d.S.J... 8ndit.S..Cim.ino. M.A..et .al. (X>23).AnanchtNy«lOis-yS:ttm. indicator6f m.arint p.-tdatorfo12tpnsand rtpruduetion. *Prtx. R. B: Biol Sd.* 290. 2022-2326.dok J0.1098/rspb.2022.2326

Fiedler. P. C. and Mantua. N. J.. (2017). Hl>w art warm and ()()()) *years* in tht CaHilomia Currtnt related to ENSO? *f. Gtoph),. R.t:s.::* ()«o,u 122. S936--59S1. dti: J0.1002/2017JO)l3

f:ltm.ing. A. H.. Clarie.CT.. Calambokidis. J.., and Baifow. J.. (X>16). Hum.pbadc: whalt diets respond to varia.not in e,oean di.matt and «Otys:ttm. ()()nditio,m in tht CalifomiaCU1Ttnt. *GloNJ Outngt: Biol 22.*1214-122.4. dot JO.JI I Vsd>.13171

Fret. C M.. Andtr.s6n. *S.* C_ HeDtntlS, E. A.. Muhling. 8. A. Nrv.arru. M. 0 .. R.iche:non. K.. et .al. (2023). Cm.pad6f thtX>l.4-2016 m.arint ht.atY4¥t 6n *11S* and Canada West Coast &shtritt Surpri.Jtsandltsl()m from *keye*:ne studies. *Fish Fish.* 2". 6S2-674.dok JO.I111/f.af.127S3

C Fritdman. W.R..Santora,J..A_Sdlroeder.1 D..Hu&".D. D.. Brodtur. R.D..Field.J.. et al (2018). Environmental and s c rtbtiomhq,,s am,o,ns salm,o,n foras.t asembJas.ts aJonsflt()()nt.intnt.al shelf6ftht California CU1Ttnt. *Mar.&ol Prag, $tr.* S96. 181-198.dok Jo.J35'/mtps12S98

Fr6lichtr. T. L. Fischer. E. M_ and Gruber. N. (2018). M.arint he.atWN!:S under s.Job.al Y4nning. *Notutt* S60.360-364'.dok J0.1038/MJS86-0l8-038J,-9

Calle'l N. D.. &Ydin. N. M_Thtmps,on. A. R.. Satterthwaite, p_ V .. 812dy. 8 .. and Stm.m,em., 8. X.(2022). FIJhtries surveys art essential e,oean <hseivinSpros,:ams in a timt6fglobaldlantft: Asynthesis*d e,oea* cand«lOdot;ic.aldat.a from U.S.West ()()asf &shtries surwys. *Front Mar. Sci* 9, 7S712".dok J0J389/fmar.s.2022.7S712.4

Hallett.T. 8 .. Coubon.T.. Pilldngi,on.J..G.. Ollltat·8rudc. T. H..oo.J.. M_ and GrtnfeD. 8. T. (2004). Why l t-sc.alt di.matt indices seem to prtdiet «lOJC1,ical pruoe:ne:s better than heal weather. *Noturt:* ◀JO. 71-7S. doi: J0.1038/n.ature02708

Harding. A. M.A.. Pl.at.I.J..F..Sdwlll1.J.. A. Shull1. M.T.. va.n Pd!.. T. l. Kettlt,A. 8.. et .al. (X>07). Prey dtnsity and tht behavitnl BtdbOity6f am.arint prtdator:Tht ()()nmo,n m.urre (Uri.a aalt,t). *&clog,83.* X>2.4-20D.dot 10.1890/06·1695.J

Hart, *S.* R.. and Mantua. N. J.. (2000). Empiric.al tvidt:not for N6rth Pad6c n?3im.t shills in 19n and 1989. *Prog. 0:l'anogr.*◀7. 103-J◀S. dok 10.1016$)()?9 11(00) OOOD.-J

Htnt.ati-Sund . J.., nd. P.·A.. Htjdstrom. A.. and OJS()n. 0. (2021). COVID-19 loclc.oown reveals tourills as seabird suardiam.. *Biel.* Counv. 2S.. 108950. dot J0.1016/j.biooon.202J.1089SO

Hobday. A J..,Altundtr. L V.. Pukim..S. R. Sm.alt. D.A_ Slraub.S.C.01i¥tr, E.C J..,et .al. (2016). A hitwduc.al approach to dt6.ninsm.arint he.atWMS.Pn,g.*0:unogr.* 1.41. 227-238.doi: J0.1016/j.pooean.2015.12.01.4

Hong. H.·J.. and Htu. H.•H. (2023). Rtmott tropic.al etnl.121 Pacific inftutnot 6n drivinstta sur&.ot ttm.ptrature vari.ab0ity in tht N6rfteast Pacllic. Emi:rvn. *R.t:s.Utt.* 18.Q.MOOS. dot 10.108&'1748·9326'aoc087

Htieh.C. Kim. H.J... W.abOn. W.. Di [.()rtn:20, B.. andSusJ,ihua. G.(Xl09).C.limatt· dri¥tn ts in abundanot and dirtribution6f larvat6f 60tanic &shes in tht ,outhtrn California rtgion. *Qobd Biol* IS. 2137-21S2. dok JO.JI I Vj.136S,· 2"86.2009.01875..x.

[gltsi.as., l.Santora,J.,and Field.J..(2023).Mesopebs,ic&shesareimport.ant prey fc. a dlvtr.tity *d* prtdator.s.. *Front.Mar.$d* JO.dok J0J389/fmatt.2023.1220088

lNint, L M.. Mate. 8. R.. Win,or, M. H.. Pabclos. D. M. *S.* J.., Cbs-l.a. D. P .. et .al. (X>14). Spatial and tem.po12I e«urrenot *dblut* whalts68"tht U.S. West Coast. with implications for manas,tmtnt. *PLoS Ont:* 9 (7). d029S9. dok 10.1371/ jourD.al.pont.01029S9

Jao()x. M. G..Altundt:r. MA.. Amaya. D.. B«lra-. R. 8o$r.ad. *S.* J.., 8rudit.S.. et al (2022). Global seas.on.al forecas-ts6f m.arint heatwa¥ts. *Notur1* 604. ◀86-◀90. dot J0.1038/s.◀JS86-022-007J..9

Jaoi>x,. M. G.. Altunder. M. A.. Bos,ad. *S.* J.., and Seott. J.. D. (2020). Therm.al ditplaotm.tnt by m.ari.nt ht.atwaves. *Noturt:* SM. 82-M. dok J0.1038/s.◀JS86-020· 253,4,

,...._ M.C.. Bdwo,-d,.C.A...............E.L"'d d.S. (2018 c-,.IupweDmg revltittd: donan.babn. andimprmoed upweDing indices ilor tht U.S. *Wt:.st* Qia.sr. *J.* Gtoplrys. *kc:s.:* O«aJtS 123. 7332-7350.doi: JO.I17S/bams ·17-0J19.J

Jo, H.-S.. Yd\.S.•W.. and lee. S.·K (X>IS). GantJt:5 in tht relatiatship in tht *SST* variability betwttn tht tropical Pacific and tht NC'rlh Pacific across flt 1998/1999 n?3im.t *shill. h),.R.t:s.Utt.* ◀2. 7171-7178.dot J0.1002/X>LSGI.065049

Jones.T .. Parrlth,J.K. Peteno,n. W.T.. Bjodest.tdt.. p_P .. &nd.N.A. 8;allanoe:, LT .. et al (2018). M.as:si¥t m.ort.ality6f a plankthorws seabird in response: to a mad.nt he.atwa¥t. *h),. ks. Utt.* ◀S,3193-3202.dok J0.1002/2017Cl07616"

Laake:. J.. L. [.()wry, M.S.. ()tl()ng, R. L. Melin. *S.* R.. and Carrett.a,J.. V. (2018). Pc)pul.at.ion wth and status6f c.alifomia sta lions../. *WadJ.M1tJtO* 82. S83-S95. dot J0.1002/jwmS,21◀05

ta}y. L R. and Oh.man. M D. (X>J8). CCB rY: EJ Nil\o•rtlat.ed ?i()()J)lankton variability in tht S()llthtrn California Currtnt System. *Dttp Su R.t:s. Arri I: 0:1anogr. R.t:s.* A1pns J◀Q. 36--SJ.dot J0.1016/j.ds-.r.2018.07.01S

ta}y. L E_and Olunan. M. D. (2021). Eupha14iidspatial dltpbotmtnts and habit.at shills in tht southtm Califomi.a Current Sys:ttm in respome to El Nino v.ari.ability. *Prag, Ckl'anot;r.* 193. 26.dok J0.1016/j.pooean.2021.1025'.4

l.b&w. M.A .. CianneDL L. P·ue:rta. P.. Wetttttin. J.. J.., Rybotw:ski. R.R.. and Opiekun. M. (X>J8). N6n-st.atfonary dirn.ate-ulm.on relationships in tht Gulf6f Alasb. Pnx. *R. B: Biol Sd.* 28S. 2018185S.doi: J0.1098/rspb.2018.185S

l.b&w. M. A.. Huns:icktr. M. E.. Bond. N. A. 8wkt. 8. J.. Cunningham. C J.., C<lnelln.J.1..et .(2020.Thech>ngJng phy,lcal ""1eoologi<al ,,mg,ofN001h Pacific Ocean dim.at.e indices.. *Pr«. Natl Amd.$d.* 117. 7665-7671. dok 10.1073/ pnas. 1921266117

'-'>ow. M. A.. M>li<k M.- Bond. N. A.. O<Mmgh>,n. C. -c.-lm. L. ""1 Ward.E. J..(X>a>b). Quanlifyins a nl'.'M) dim.at.e tluuUSJ,hdtangtsin PDO<li.mat.e and PDO-salmon rtbtiomhips. *h),. kJU tt. ,o,* t20a>Cl087972. dok 10.1029/ X>20Cl08?972

[.()redo,S.A..Orbtn.R.A.. Suryan. R.M.. lyoos.D.R. Adamr.,J.., andStephtmen.S. W. (2019). Spatial and tem.por.11 dlvinS behavior6f noo-breMing: ()()m.mo,n ll'Urrts durinstw6summ.tr.s6f()()ntmtins()(bn()()nditio,m..f.*&p. Mar.lrol.&ol.*S17.13-24. doi: J0.1016/j.jtmbt20J9 05.oo9

Mantua. N. J.., Hart, *S.* R.. Zhang. Y.. WaDaot, J..M.. and F121lds. R.(1997). A paci6c inttnlecadal d.im.at.eoteillatioo with im.paets6n s.al.iron pruduelion. *Bult Am.Mt:t.t:Ol'Ol $tr.*78, J00}-1019. doi: J0.117S/LSX>-<W77(1991.))78d069-.APIC0W>2.0.C0.2

McC.l.atchit.S.. Field,J..C.Thom.ps,on. A. R..Gtrrudettt,T.. lowry. M.. Fitdltr. P.C. et.al.(X>J6a). F<ll')d limit.at.ion6f sea lion pupsand thtdedint6fftnS.t68"()tn{QI and soulhtrn Cali.ilorni.a. *R. Q,ff1Sci.* 3. 150628. dok 10.1098/nos..l.50628

McC.lat.chit, S.. Cotrickt. R.. leiJin&, A. L. Alllh.T. D.. Bjodcs:tedt.. B.. Roberuoll. R. R..tt at(X>16b).Stat.t()ftht:Califomi.aom-tnt 201 16:()() lfom with lht 1997-98 EJNil\a. Qd(X)R hp. 57, 1-57.dok JO.l098/oos.150628

Moser. H. G.. Smith. P. E.. and Ebtr. LE. (1987). larval 6:sh anembl.atJt:! in tht C.alifomla Current region 1954H%0. a ptriod ()f dynamic environmtnt.al t. CdfrnrioCoop.Ou.o,, FWt. hTw.st. hp. 28. 97-127.

Niclctls.CF .. Sal.a. L M.. and Ohman. M. D. (2019). The: euphausiid prey 6tld for blut whales around a steep bathym,et.ric featurt in tht soulhtm C.alifomla om-tnt s-ys:ttm.. Umnol O:u .649≤Mi05.dok J0.1002/lno.JJ<W7

Nitl .J. M_Rog.tis. LA .. Brodtur. R.D..Thtmpsoll.A. R.. Auth.T. D.. Deary.A_ tt at (2021). R.e:sponu:s()fichth)()planlcton asemhl.as,es to tht reotnt marine heatY4¥t and pm-ious dim..at.t fluctuations in st¥tr.al NC'riheast Pacl.6c m..arine «lOISysttms. Global OrAngt' Biol. 21. 506--5X>.dot JO.JI I vp.1505

_J_ _ Ward.E.J.. Brenntr, R.8- Hunsidrer. ME.. HatJ3.ht.S.8 .. Finno((D.. tt at (2022). Non-utionary andi.nt.tr.adlvtdlects ()fdirn.at.t and()()mptli!JM ()npink sal productivity. Glo&d°'4ngt' Biol 28. X>26-2<WO.dot 10.11I Vg.d>.16049

0Ji¥tr, E.C.J.. Donat.MG.. Burrows.M. T.. Moore. P.J..Sm..alt, D.A.. Altundtr. L V_ tt at (2018). lDnt,r andm,ore frequtnt m..ari.ne heatY4¥e:S &¥tr tht past etnhuy. Nit.Commwt. 9, 132.4.dot J0.1038/5"1467·018-03732-9

Park,J.• Y.. Ydl. S.• W.. and Kug..J. -S.(X>12). Revisited rt:l.ationship bttwetn tropical and North Padlic tt.a s-w&ot ten-.,.er.durt v.ari.atiMs. Gtophys. R.ts. Ldt. 39, l.02703. dc:i: 10.1029/2011CL050005

Ptttn01l.W.T.. FlJhtr,J. L. Pet.aw,ll.J.0.. MCT311l.C A. Burke:. 8.J..and Fresh. K. L (X>l'). Applitd fishtries y: «lOISysttm indicators ()f o.oean ()()nditions inform 6:shtrie:s m.anag.tmtnt in tht California om-tnt. Octanognrphy 27, 80-89. de'i: J05670/o.oean OJ4118

Ptteno"- W.T.. Flthtr.J. L.St.rub. P. T..Du. X.. R.iJitn.C. Ptteno"- J.,tt al (2017). Tht pebtpc«lOISysttmin tht Northtrn CalifomlaCU1Ttnt()8'Oreg.onduring:tht 2014-2016 Y4im anomalies within tht ()()ntb.t()f tht past 20 an.. f.Gtoplrys. ks.:0:l'.oJU 122. 7267-7290.dot JO.J002/2017JO)J2952

Piltcrius. P. A. W.J Watanul.1. Y.. Tho, "-S.A. and Ois.a-a. F.(20Zl). •0..apt.u 8 • Oun.ate e The: ical backd-q> ()f seabird ()()mervatioll.• in Con',,tt'KJfo,c(MariNBinb.&ls.L Young.and f_ Vandtr\Vtrf(Acadttric Prt:s&), 2' 276.

Porqua. J.M.. Klunis. L. Kirn. E..Cox. A. Dlinajec. N.. andOrbtn. R. A (2021). Yoquino Hl'od Subi"rd Colon,: 1011 StoJOn Summ.ory (C()rvallis. OR. lJSA: Depart.mtnt ()f Fi.shtries. \VildHft. and Constrv.ation Scitnoes, Or on St.alt lJ ni¥trslty). Availablt at hnpJ::://hm tc.0rtg.onst.ate.tdu/tlte slhmJC.Oreg.onst.ate.tdu/&lesJyhon...,&oalrepo,r0021.pdC

Rtn.A.S.. and Rudnidc. D. L (2021). Temptr.aturtand salinityb::t.rtme:s from 2014,• X>J9 in tht CalifomlaCurrtntSys:ttm and i.ts swret Y4t.trs..Commwt. FmthEmi:rvn. 2.62. dc:i: 10.1038/s.02"7-021·00131·9

Roberuon. R. R.. and Bjodcs:tedt. B. P. (2020). Oimatt·drlvtn variability in Euphausi.a padlica shot: dillrbutions ()8' northtrn California. Pn,g. 0«.onogr. 188. 102' 12.dd: 10.l016/j.pooe.an.20X>.102.412

Robidas. M. L (2023). What driw:s larval C()ndition for Northan Ancb&vy (Ent,_auli.s mad.ax)! lmplications forcoaul pel.a,pc s-pecies recruit.m.tnt 8uduations and 6:shtry m.an t p12d.ioes. MastersThe:5:is(San Di¥, CA. lJSk: l!ni¥trsity()f San Oq. .

Sakuma. KM .. Fitld. J.C .. Mantua.N.J., Rals:toll.S.. M.arinovich. 8. 8.. andCarri()ll. C. N. (2016). Anonahus epipelatpc mic:runelcton antmbbt,t patttrns in tht ntritic wat.trs ()f tht califcrni.a CU1Ttnt in spring 2015 during a ptriod ()f atmnt ootan cMditions. Cd<XIFT kp. 57. 163-183.

Santtn,J.A.. Ha.ztn.E. LSduvedtr. l D.. S.J ..S.akuma. KM. and Fitld. J. C. (X>l7). Γmpaets()fo.oean dim..at.t variability ()nbiodlvtr.tlty ()f pt:Jas,ic ftngts-peclts ina.n upwdling:ffllis-ySttm..Mlrr.Eatl Pn,g.Stt 580,205-2X>.dok J6.335'/m.tps12278

Santtn.J. A. T. L.Cirnino. MA.Sakuma.KM.. Hansoll.K. D.. Didc.E.J., tt al (2021). Di i «lOISysttm approach m,tr()()m,e:s pandtmic-rt:l.at.ed 6shtrits m,onitoring challtngt:s. Not. Commwt. 12. 6'92. dok 10.1038/5"1467·021· 264S4,•5

S.n,..... A_Schroode,-.1.0 .. F;eJd. C.. W k. B. K_ -is,.ie,n.,,. w.p2014t Sp.atiMtmpo,121 dynamics ()f o,oean ()()ndltions and for.ag.t t.au rt¥t:al retponal stNdwing()f seabird-p.-ty relations &olAJY>l 2'. 1730-1747. dok 10.189<VU· 1605.J

SantC'n.J. A_Sydtm,.an. W.J..Sduvedtr. l D.. Wdls. 8. K. and Fitld. J.C.(201I). Me:soicalt structurt and0i0tanC1,12ph.icdetmninants()fkrOJ hOUpOts in tht Califcrni.a Current lmpications for trophic traosftr and()()mervatioll. Pn,g.()«.o,,•91,397◄09. de'i:10.JOJ .pooe.an20JL0t002

Schroedtr. l D.. Santora.J. A.. 8o$r.ad.S. J., Haun. E. L. Sabun.a. K. M.. Moort, A. M_ tt al. (X>19). $mu-et wat.tr variability as a dri¥trd rudc&sh recrult.mtnt in tht C.alifomi.a Current Eoo,s-ystem: implications for dim.alt changt and 6s-htries m.anag.tmtnt. Or.11. f. FiJh.Aquat.Sd. 76.9 960.dok10.1 l39/tjf:as·2017-04a>

Schroedtr.[. D..Sant.or.a.J. A.. Mantua,N.. Fltld. J.C. Wdls.8. K.. Haun.B.L.tt al (X>22). Habitat <nnp.-tsiM indices for ltoring OiOtan ()()nditJOns and fflliSysltm impacts within ooast.al upwelling systtms. &cl. Indic 1'4 109520. dok 10.1016/j.«)())ind.2022.l095X>

Shtn.S. G.. Thomp,on.A. R.. Ca"rt:.a. J., Fi P.. A)()ll. P.. and Olecldey. D. M. (X>17).Sp.atial patttrns()f Anchovet.a(6'gr.owi.s ringau) andl.arvat in rt:l.atiM to p<:1)1 in tht Peruvian upwdling s-ysttm.. Pr« k. S«. B: Biol. Sri. 284 X>170509. dc:i: J0.1098/rspb.2017.0509

$.ca,J.J., Santtn,J.A. Fitld.J.C..Curtlt.. K.A. Muhling.8.A ..Cirnino. M A,tt al (2022). Ttmptr.ature and upweDing: dynamics drlvt m.arke:t squid (Doryttuthis <>p.ales,otns) dirtribution and abundanot in tht Califcrni.a Current. ICES f. Mar.Sd. 19. 2489'-2509.dok J0.1093/ioe:sjms/&acl86

Swaltthoip. R.. Landry. M. R.. Stnuntns. 8. X.. Olunall. M D.. Aluwlhart:, L. Ga'3uabCD.. tt al (X>23).Anchovy boon andbust linl:ed totrophlcs-hibin bNal diet. Nat.Commwt. 1'. U12.dok J0.1038/M1467-023,·'2966-0

Sydtm..an. W.J., Forot:, M_Sant.or.a. J., and Thompsoll.S. A. (202Ia). Stohi:nl.s ond Marht M1tmnudJ on tJu NMFS R«'Jt/Wt Rttndtmmt .o,,d EcMy"Jfnn Aut.ssmtnt Surw,: 1021 Doto kp«t (Pet.alum.a. CA. lJSA: F.ar12Jon lrtstltutt).

Sydtm..an. W. J., Ht:s:ttr, M. M.. Thaytr, J. A.. Gress.. F_ Mart.ill. P.. and Buh J. (2001). Climatt z_ repruducti¥t pe:rfonnanot and ditt ()()mpotition ()f m..ari.ne birdsin tht nCalifcrni.aCurrent systtm 1969-1997. Prag. O:u .49. 309-329.dot 10.10J6/S()079 11(01)00028·3

Sydtm..an. W.J., Wright. C. and Thomp,oll. S. A.(2021b). Stohi:nl.s o, du OiKX>Fl/ o:::&L'IERSurwy,Swnmtr a:111'Oda ktpt,rt (Ptt.alum.a.CA. lJSA:F.arralonΓmlitut.t).

Thomp,oll. A.R.. WabOll. W.. McO.at.chit.S.. and Webtr. B.D. (2012). Multi-scalt sanvling:to tv.aluatt asttmblajJ.t dynamics in an OiOeanic marine restrvt. Pfo5 Ott 7. e:33131.dok JO.I371/jc>urnal.po,nt.003313I

Thomp,oll. AR.. McC.latch.it.S.. Webtr. E. D.. WatJOll. W_and Lenntrt<ody.C. E. (2017). C()rrect.in8forbias in ichthyoplanbon abundanott:sthn.at.esas:!OCbted with tht 19n transition foim ring tobongo ntt sampling:. CaKX>FI hp. SS. I13-123.

Thomp,oll. A R...Schroedtr. l D.. Bo$r.ad.S.J.. Hutn. E.l_Jaol)x., M.G.. leiJin&, A L. tt al. (2018).St.alt()f tht California Current 2017·I8: StiD not quilt norm.al in tht north and !Jl!lling int.trest.ing in tht south. CaKX>FI hp. 59, 1-66.

Th<>mp,oo. A. R. H>My.C.J..S,.ie,n.o. IV. .a..-ceJi>.C.d.S. . Bn>dew-. R. D.. tt al. (X>J9a). lndicat.or.s ()f pelais,ic ftngt ()()mm.unity shifts in tht Califomla Current LartJt M.ari.ne E()(),S)'sttm 1998-3)16. Eatl lndic. 105. 21 228. dc:i: 10.JOlf/j.«x)lind.a>19.05.057

Thomp,oll. A R...Schroedtr. l D.. &t,.ad.S.J.. Ho.en. E.l_Jaol)x., M.G.. leiJin&, A L.tt al(X>Hb).St.att()ftht:California Current X>18--19: a anch&vy rt3imtanda new mari.ne he.atwavt! CalCOFI kp. 60. 1-65.dok JOJ389/fmatt.2022.958727

Thcmp,oll. A. R.. Btn•Adtrd., N. J., &\'din. N. M.. Kaotv. D.. Swaletherp. R.. and WabOll. W.(2022a). Putting:tht Pacilic m..ari.ne heatwM: into ptnpeetlve The:respomt dbrval 6:sh()8',outurn Caliilomla to unpr Y4flningin 2014-2016 rt:lati¥tb tht prtvious65 yea11 Gltibd Oangt' Biol 28. I766-1785. dc:i: JO.III1/t,:b.16010

Thomp,oll. A. R.. Bjorbtedt.. E. P.. Sttvtn J. 8o$r.ad.J. L. Ho.tn. E. L. leiJin&, A-Santora.J.A..tt al (2022b).St.at.t()ftht C.alifomlaom-tnt«Otys:ttmin2021:wint.tr is ()()ming? Fro,t.Mltr. Sci 9, 958727.dok 10J389/fmar.s..2022.958727

Tirrunermann. A. All.S.·l. Kug.J.-S-Jill.F.·F-C.ai.W..Capctondi. A. tt al.(2018). EJ Nino-Southtrn ()Sci)Jation ()()mpla:ity. Notutr 559, 535-5'5.dot J0.1038/5.41586·018-0252

Wachttndonlc. R..Cal.amhdddit.,J., and Flynll.K.(2022). Blutv.halt body()()ndition as:te:ned ovtr a 14-)Ur ptriod in tht NB Pacl.6c: annual variation and()()Meet.ion to m.easuresd o.oean productivity. Frmt.M,u.Sd.9.dot 10.3389/6nar.s..a>22.M7032

Wtbtr. B. D.. Auth. T. D.. &um.ann•Pithring:. S.. &urng:.artntr, T. R.. Bjorlcst.tdl. E. P.. Bog:,r.ad. S. J .. tt al (2021). St.at.t ()f tht Califomla currtnt 2019-X>20: back to tht fltlwt: with m.ari.ne heatwave£ Front. M,u.Sri.8. 70945'. dok JO.D89/fmars..2021.70945'

Wtrb. 8. E_and Rudnidc. D. L (2023).Rtmaibblt es in tht dc:minant modes ()f North Pacl.6c tt.a s-w&ot ttmptrature. Ga>plrys. R.ts. Un. SO. a>22CU01078. dot J0.1029/2022Cll01078

Yeh.S.•W.. K"'3. Y.·J.. N6h. Y.. -1 MOie,-. A. (2011).Tht NO<th P,d6<d""" transi.tions ()f tht winttrs ()f 1976/77 and 1988/89. f. Oimafl' 2.4, I170-1183. dot J0.117S/2010JCW325.1

Yto. S.•R.. Kirn. K·Y.. Yeh. S.•W.. and Kim. W. (X>12). Decadal es in tht rt:l.ationshipbttween tht trq,ical Pad6c and tht N<rth Pacl.6c.f.G«f,lrys. kcs.:Atmos., 111. D15102.dok 10.1029JX>12j001m5

Yu.J.·Y.. lu. M.·M.. and Kirn. S. T. (X>12). A dwtt,t in tht relationship bttwetn tropical etnt.121 Pacl.6c SST v.ari.ability and tht at12tropical atm.o,s-phtrt around 1990. Envirffl. ks. Ldt. 7. 03«)25.dok J0.1088/l748-932f/7/3/03'025