Fisheries surveys are essential ocean observing programs in a time of global change: A synthesis of oceanographic and ecological data from U.S. West Coast fisheries surveys

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As climate change and other anthropogenic impacts on marine ecosystems accelerate in the 21st century, there is an increasing need for sustained ocean time series. A robust and collaborative network of regional monitoring programs can detect early signs of unanticipated changes, provide a more holistic understanding of ecosystem responses, and prompt faster management actions. Fisheries-related surveys that collect fisheries-independent data (hereafter referred to as "fisheries surveys") are a key pillar of sustainable fisheries management and are ubiquitous in the United States and other countries. From the perspective of ocean observing, fisheries surveys offer three key strengths: 1) they are sustained due to largely consistent funding support from federal and state public sector fisheries agencies, 2) they collect paired physical, biogeochemical, and biological data, and 3) they have large and frequently overlapping spatial footprints that extend into the offshore region. Despite this, information about fisheries survey data collection can remain poorly known to the broader academic and ocean observing communities. During the 2019 CalCOFI Symposium, marking the 70th anniversary of the California Cooperative Oceanic Fisheries Investigations (CalCOFI), representatives from 21 ocean monitoring programs on the North American West Coast came together to share the status of their monitoring programs and examine opportunities to leverage efforts to support regional ecosystem management needs. To increase awareness about collected ocean observing data, we catalog these ongoing ocean time series programs and detail the activities of the nine major federal or state fisheries surveys on the U.S. West Coast. We then present three case studies showing how fisheries survey data contribute to the understanding of emergent ecosystem management challenges: marine heatwaves, ocean acidification, and contaminant spills. Moving forward, increased cross-survey analyses and cooperation can improve regional capacity to address emerging challenges. Fisheries surveys represent a foundational blueprint for ecosystem monitoring. As the international community moves towards a global strategy for ocean observing needs, fisheries survey programs should be included as data contributors.

Contribution to the field

Fisheries-related surveys that collect fisheries-independent data are a key pillar of sustainable fisheries management in the U.S. and many other countries. These surveys collect abundant ecological and oceanographic data, in addition to data on fisheries species, and thus support sustained ocean time series and ocean observing goals. Despite this, information about fisheries survey data collection can remain poorly known to the broader academic and ocean observing communities. This manuscript reviews the types of oceanographic and ecological data collected by nine separate fisheries surveys on the U.S. West Coast, and discusses these within the framework being adopted by the ocean observing community regarding essential ocean, biodiversity, and climate variables. We also review how data from these fisheries surveys contributes to understanding emergent ecosystem management challenges, including marine heatwaves, ocean acidification, and contaminant spills. The main contributions of the manuscript are twofold. First, it provides the first comprehensive catalog of fisheries survey data collection relevant to ocean observing needs along the U.S. West Coast. Second, it encourages the global community to recognize the value of fisheries survey efforts to ocean observing goals, calls for closer collaboration between the fisheries and ocean observing communities, and may inspire similar synthesis efforts in other regions.

Funding statement

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15 **Abstract**

16 As climate change and other anthropogenic impacts on marine ecosystems accelerate in the 21st
17 century, there is an increasing need for sustained ocean time series. A robust and collaborative
18 network of regional monitoring programs can detect early signs of unanticipated changes, provide a
19 more holistic understanding of ecosystem responses, and prompt faster management actions.
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29 (CalCOFI), representatives from 21 ocean monitoring programs on the North American West Coast
30 came together to share the status of their monitoring programs and examine opportunities to leverage
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32 ocean observing data, we catalog these ongoing ocean time series programs and detail the activities
33 of the nine major federal or state fisheries surveys on the U.S. West Coast. We then present three
34 case studies showing how fisheries survey data contribute to the understanding of emergent
35 ecosystem management challenges: marine heatwaves, ocean acidification, and contaminant spills.

36 Moving forward, increased cross-survey analyses and cooperation can improve regional capacity to
37 address emerging challenges. Fisheries surveys represent a foundational blueprint for ecosystem
38 monitoring. As the international community moves towards a global strategy for ocean observing
39 needs, fisheries survey programs should be included as data contributors.

40 **1   Introduction**

41 Sustained ocean time series are essential for characterizing marine ecosystem shifts and
42 distinguishing between natural and anthropogenic forcing in the ocean but maintaining these time
43 series is costly and requires lasting investment (Benway et al. 2019). Fisheries-related surveys that
44 collect fisheries-independent data (hereafter referred to as "fisheries surveys") are a key pillar of
45 sustainable fisheries management in the U.S., Europe, Peru, Chile, Norway, India, Canada, Japan,
46 and other countries. In addition to collecting data on fisheries species, these surveys typically collect
47 physical, chemical, and biological oceanographic data over both long periods of time and large
48 regional scales. Fisheries surveys can provide a rich source of ocean time series data for monitoring
49 ecosystem change because surveys in a region typically sample different habitats (seafloor to upper
50 water column), life stages (eggs and larvae to adults), and rely on multiple *in situ* methodologies (e.g.
51 acoustics, plankton tows, and trawls). Differences in approaches relate to which target species or
52 species group each survey is designed to monitor. Despite the wealth of ocean observations collected
53 by fisheries surveys, they are not always integrated as part of ocean observing systems.

54 Ocean observing programs collect ocean time series data that provide baselines against which the
55 effects of human pressures and climate change may be measured and reported (Miloslavich et al.
56 2017), and thus provide important input for ecosystem management. While there is no specified time
57 length of a program that determines if it is a sustained time series, the assumption is that funding
58 mechanisms are in place to support continued and consistent sampling. The International Group for
59 Marine Ecological Time Series (IGMETS) (O'Brien et al. 2017), an effort by the Intergovernmental
60 Oceanographic Commission United Nations Educational Science and Cultural Organization to bring
61 together ship-based, biogeochemical time-series from around the world, specifies that programs
62 should ideally have five or more years of data to be considered for entry into this database. Since
63 fisheries surveys are the main sources of fisheries-independent data informing the stock assessment
64 process, fisheries surveys tend to have sustained funding and sample large spatial scales to
65 adequately sample the ranges of the fisheries species of interest. Thus, from the perspective of ocean
66 observing, fisheries surveys offer three key strengths: 1) they are sustained due to largely consistent
67 funding support by federal and state public sector fisheries agencies, 2) they collect combined
68 physical, biogeochemical, and biological data, and 3) they have large spatial footprints that extend
69 from the nearshore to offshore region.

70 In the U.S., federal fisheries surveys collect data to support the sustainable management of fish
71 stocks, as required under the Magnuson-Stevens Fishery Conservation and Management Act (NMFS
72 2007). These surveys typically have more than ten years of data collection and have consistent
73 funding mechanisms in place through the National Oceanic and Atmospheric Administration
74 (NOAA) National Marine Fisheries Service. Data from these surveys inform stock assessments,
75 integrated ecosystem assessments (IEAs) and other regional ecosystem status reports. While U.S.
76 fisheries management has traditionally focused on single-species stock assessments, the importance
77 of holistic monitoring of ecosystem dynamics is recognized and there is a movement to include more
78 ecosystem factors in fisheries management (Denit 2016, Lynch et al. 2018). Fisheries surveys are
79 instrumental in this effort because, in addition to collecting data on fisheries species, these surveys
80 also collect data on the oceanographic conditions and the distribution and abundance of species that

81   co-occur with fisheries species of interest. These physical, biogeochemical, and biological
82   observations are used to develop IEAs for different regions of the U.S., which support ecosystem-
83   based management priorities (Levin et al. 2009, Monaco et al. 2021).

84   The U.S. West Coast is one of the most extensively studied ocean regions in the world and is
85   undergoing a period of rapid change due to both climate change and increasing interests in ocean use
86   (e.g. offshore wind and aquaculture). During the 2019 CalCOFI Symposium, marking the 70th
87   anniversary of the California Cooperative Oceanic Fisheries Investigations (CalCOFI),
88   representatives from 21 ocean monitoring programs on the North American West Coast (Table 1,
89   Fig. 1) came together to share the status of their monitoring programs and examine opportunities to
90   leverage efforts to support broad U.S. West Coast ecosystem management needs for managing a
91   rapidly changing ocean. Considering that the California Current Ecosystem (CCE) represents a
92   dynamic seascape mosaic where boundaries, extent, and location of features as well as species
93   distributions and ranges can change with time, managing this "seascape" (Kavanaugh et al. 2016) can
94   be done more effectively by integrating data from multiple monitoring programs. The broad array of
95   surveys within the CCE enhance regional capacity to recognize changes and sustainably manage
96   marine resources (Holsman et al. 2020, Karp et al. 2019). Of the 21 programs represented at the
97   Symposium, eight were federal fisheries surveys (CalCOFI, CCES, GBTS, H&L, Hake ATS, JSOES,
98   PRS, and RREAS) and one was a state fisheries survey (CCFRP) (full program names are in Table
99   1).

100   The goal of this paper is to demonstrate the value and breadth of ocean observing and ecosystem
101   monitoring data collected by fisheries surveys, using the U.S. West Coast as an example. The non-
102   fisheries monitoring programs presented at the 2019 CalCOFI Symposium (Fig. 1) play an essential
103   role in understanding changes along the U.S. West Coast, but are better known within the academic
104   and ocean observing communities. Here, we provide a brief data inventory and description of each
105   U.S. West Coast fisheries survey and summarize which priority ocean observing variables these
106   surveys measure. We then present three case studies that demonstrate how U.S. West Coast fisheries
107   survey data contribute to the understanding of emergent ecosystem management challenges: marine
108   heatwaves, ocean acidification, and contaminant spills. The manuscript concludes with a discussion
109   of how improved collaboration between the fisheries and ocean observing communities can further
110   the overarching goals of both communities.

111   **2   Overview of U.S. West Coast Fisheries Surveys and Data Collected**

112   To increase awareness about the range of data collected by fisheries surveys on the U.S. West Coast
113   and the value that they add to other regional monitoring efforts, we provide a brief overview of each
114   of the nine fisheries surveys. The spatial extent (Fig. 1), timeline of survey continuity (Fig. 2),
115   sampling methodologies (Table 2, 3), and overview of which essential ocean variables (EOVs; Table
116   4), essential climate variables (ECVs; Table 5), and essential biodiversity variables (EBVs; Table 6)
117   each survey collects are provided.

118   **2.1   The California Cooperative Oceanic Fisheries Investigations (CalCOFI)**

119   CalCOFI started in 1949 to understand the drivers of the Pacific Sardine (*Sardinops sagax*) crash of
120   the 1940s. From its beginning, CalCOFI represented a partnership between federal, state, and
121   academic scientists with deep-seated roots in oceanography (Hewitt 1988, Scheiber 1990) and is
122   recognized as both an ocean observing program and a fisheries survey. At present, CalCOFI conducts
123   quarterly cruises and visits 66 core stations and 9 nearshore stations between Pismo Beach,
124   California and the U.S.-Mexico border. During the winter and spring, 38 additional northern stations

125   are sampled, going north to San Francisco. CalCOFI samples nearshore (< 3 km) to far offshore
126   (>500 km) (Fig. 1). During the early years (i.e. 1950s-60s), sampling regularly extended from
127   northern California into the Gulf of California.

128   CalCOFI collects paired physical, chemical, and biological data. Oceanographic data are currently
129   collected using vertical CTD (conductivity-temperature-depth) casts at all CalCOFI stations with
130   additional CTD-mounted sensors. Niskin bottles on the CTD rosette collect water samples at specific
131   depths to measure salinity, oxygen, nutrients, chlorophyll, phaeopigments, primary production, and
132   dissolved inorganic carbon, and water samples are taken and filtered for eDNA. Biological sampling
133   is mainly done using plankton nets. Ring nets were originally used (1949-1976), but since 1977,
134   oblique bongo net tows are conducted at each station; both nets sampled the upper ~200 m of the
135   water column (Thompson et al. 2017b, Ohman and Lavaniegos 2002). Manta nets are used to sample
136   surface water (1977-present) and pairovet nets conduct vertical tows (1982-present) from the upper
137   70 m. Net samples are preserved in formalin and ethanol, fishes and invertebrates are identified and
138   archived at the NOAA Southwest Fisheries Science Center (SWFSC; fishes and cephalopods) and
139   the Scripps Institution of Oceanography Pelagic Invertebrate Collection (invertebrate zooplankton).
140   Since 1987, marine bird and mammal observations have been made in partnership with the Farallon
141   Institute and the Office of Naval Research. Underway data are also collected including the
142   continuous underway fish egg sampler (CUFES) (Checkley et al. 1997), acoustic doppler current
143   profiler (ADCP), surface pCO2, sea surface conditions, and advanced laser fluorometry. CalCOFI
144   works in close partnership with the National Science Foundation-funded CCE LTER program which
145   contributes ship time, supports biogeochemical sampling, and identification of invertebrate
146   zooplankton from the plankton tows.

147   Data from CalCOFI contribute to academic and government research and are applied to management.
148   The CalCOFI community has published well over 1000 scientific papers on topics related to the
149   physical, chemical, and biological aspects of the CCE and how the CCE may respond to climate
150   change (McClatchie 2014). CalCOFI ichthyoplankton data show a strong regime shift during
151   1976/1977 and a general shift towards a southern and oceanic assemblage (Peabody et al. 2018,
152   McClatchie et al. 2018). In addition, CalCOFI contributes data to individual stock assessments and
153   supports ecosystem-based management by informing the California Current Integrated Ecosystem
154   Assessment (CCIEA). CalCOFI data have been used to demonstrate the effectiveness of the Cowcod
155   Conservation Area (CCA) in supporting the recovery of previously overfished rockfishes (*Sebastes*
156   *spp.*) (Thompson et al. 2017a).

157   **2.2   NOAA California Current Ecosystem Survey (CCES)**

158   The NOAA CCE survey's objective is to provide fishery-independent data in support of sustainable
159   management of coastal pelagic species (CPS), which are important forage species for many marine
160   predators. It is based out of the SWFSC. In the spring of 2006, the CCES was initiated and surveyed
161   from the Mexican border to Vancouver Island, and used the daily egg production method and
162   acoustic-trawl survey method to collect CPS data, as well as oceanographic, marine mammal, and
163   seabird observations (Zwolinski et al. 2012). In 2008, CCE surveys were conducted in both the
164   spring (April) and the summer (July), and from 2008-2021, spring surveys were conducted in some
165   and summer surveys in nearly all years. Prior to the initiation of the CCES in 2006, the California
166   Department of Fish and Game (CDFG) conducted acoustic trawl surveys (1966-1973), which
167   collected comparable data on pelagic fish species from northern California to southern Baja
168   California using an echosounder, sonar, and midwater trawls (Mais 1974). Between 1970-1975, the
169   SWFSC, CDFG, and the U.S. Navy conducted additional sonar mapping surveys to examine the

170   distribution of CPS in the Southern California Bight (Smith 1978).

171   The CCES is conducted on NOAA ships and uses acoustics, trawls, and CUFES to collect data on
172   acoustic backscatter, egg densities, and species composition of CPS, namely Northern Anchovy
173   (*Engraulis mordax*), Pacific Herring (*Clupea pallasii*), Jack Mackerel (*Trachurus symmetricus*),
174   Pacific Mackerel (*Scomber japonicus*), and Pacific Sardine (Stierhoff et al. 2019). The survey also
175   collects information about additional species captured in the trawl, although the methods for
176   quantifying these taxa has varied across cruises. In recent years, fishing vessels and uncrewed surface
177   vehicles have been integrated into the CCES to estimate the biomass of CPS in the nearshore region
178   where shallow depths are unsafe for the larger NOAA ships (Stierhoff et al. 2019). Environmental
179   data are collected using daily CTD casts, and underway measurements such as CTD casts and
180   thermosalinographs. Survey data allows for an examination of how the distribution and potential
181   habitat of CPS shifts seasonally (Demer et al. 2012), interannually, and across longer timescales
182   (2008-2019), and have informed our understanding of the habitat, distribution, recruitment, growth,
183   natural mortality, abundance, and assemblage structure of CPS. Survey data have been used to
184   investigate the relationships between the Pacific Decadal Oscillation and sardine recruitment and
185   between sardine migration and stock size. Survey data are used for stock assessments of CPS.

186   ## 2.3   NOAA West Coast Groundfish Bottom Trawl Survey (GBTS)

187   The NOAA West Coast GBTS's objective is to provide fishery-independent data to support
188   sustainable management of groundfish on the U.S. West Coast. It is based out of the Northwest
189   Fisheries Science Center (NWFSC). The survey samples depths from 55-1280 m, spanning waters
190   from Canada to Mexico, and conducts two passes (North to South) down the coast each year in the
191   summer (May-Jul) and in the fall (Aug-Oct). Chartered fishing vessels conduct 15-minute bottom
192   tows on soft, benthic habitats during daylight hours with a tow speed of 2.2 kts using a standard
193   Aberdeen-style trawl. ~700 locations are selected for each survey using a stratified random sampling
194   design, with more effort focused north of Point Conception (80%), compared to south of Point
195   Conception (20%). All fishes and invertebrates from each tow are sorted to species (or the lowest
196   possible taxon) and weighed using an electronic motion-compensated scale. Species covered under
197   fishery management plans are also subsampled, sorted by sex, individually measured, weighed, and
198   otoliths, gonads, stomachs, tissue samples, and fin clips are collected. Additionally, special cruise-
199   specific projects are supported by the survey. Environmental data including near-bottom temperature,
200   oxygen, salinity, irradiance, chlorophyll fluorescence, turbidity, depth, and seabed slope and
201   roughness are collected for each trawl using trawl-mounted sensors. Near-seafloor dissolved oxygen
202   data have been collected since 2007. Additionally, environmental data on wind speed, surface
203   irradiance, surface temperature, and bottom type (EK 60, EK 80) are continuously collected using
204   sensors on the ship.

205   The existing survey builds on a historic survey conducted by the Alaska Fisheries Science Center
206   between 1977-1997. In 1998, the NWFSC assumed responsibility for the survey, and between 1998-
207   2001, the survey footprint was between the U.S.-Canada border to Point Conception, CA, and
208   focused on the continental slope (183-1280 m). In 2002, the survey expanded to the U.S.-Mexico
209   border, and in 2003, the survey expanded to also cover the shelf and slope. Survey data have been
210   used to observe broadscale changes on the U.S. West Coast, such as recovery of overfished species,
211   decreases in near-seafloor oxygen and associated ecosystem impacts (Keller et al. 2017), trophic
212   shifts during anomalous climatic events, and species collapses with associated ecosystem effects
213   (Harvell et al. 2019). The survey is considering future opportunities to collect carbonate chemistry
214   measurements using trawl-mounted pH sensors to examine ocean acidification vulnerability of

215   seafloor communities.

2.4   NOAA Shelf Rockfish Hook and Line (H&L) Survey

217   The NOAA Shelf Rockfish H&L survey is an industry-scientist research partnership based out of the
218   NWFSC. The survey objective is to develop a time series of abundance and biological data for
219   groundfish species in untrawlable habitats of the Southern California Bight for use in stock
220   assessments. The survey began in 2004 in response to the need for fishery-independent data on
221   rockfish abundance south of Point Conception. In 2004, the survey sampled 74 stations, which grew
222   to 121 stations by 2008. In 2014, coverage was added inside the CCA, and currently the survey
223   samples 201 stations annually at depths between 35-230 m. The survey is conducted in partnership
224   with the local sportfishing industry. Gear is deployed by rod and reel with standardized effort (75
225   hooks per site; 3 anglers make 5 coordinated drops of a 5-hook gangion), and effort (soak time) is
226   tracked with stopwatches. At each station, both environmental and biological data are collected.

227   Environmental data collected include surface temperature, wind speed and direction, and a full water
228   column CTD profile is conducted at each station with temperature, salinity, dissolved oxygen,
229   chlorophyll, and turbidity sensors. Additionally, drift speed and direction, tide height, and lunar
230   conditions are recorded. Visual observations of the seafloor habitat are obtained using a towed
231   underwater video sled. Biological data collected on the captured groundfishes include species, fork
232   length, weight, and biological samples of otoliths, finclips, stomachs, and muscle tissue are taken for
233   studies on aging, genetics, diet, and trophic ecology. Project-specific data may also be collected.
234   Survey data are used for numerous stock assessments as indices of relative abundance and have been
235   used to show the effectiveness of the CCA in rockfish and lingcod (*Ophiodon elongatus*) recovery
236   (Keller et al. 2019). Survey data can also be used to document broadscale changes on the U.S. West
237   Coast including shifting species distributions and trophic changes.

2.5   NOAA Rockfish Recruitment and Ecosystem Assessment Survey (RREAS)

239   The NOAA RREAS is based out of the SWFSC and has been collecting epipelagic micronekton in
240   the California Current since 1983, with the original goal of quantifying and understanding variability
241   in recruitment of rockfish and other groundfish to inform sustainable fisheries management. The
242   overarching research objectives of the survey are three-fold and relate to informing fisheries
243   assessment, fisheries oceanography, and ecosystem oceanography. The survey initially focused on
244   central California, but in 2004 expanded to cover most CA waters (Sakuma et al. 2016). Since 2001,
245   the NWFSC has conducted a comparable survey in the Pacific Northwest off Oregon and
246   Washington, first as a collaborative effort with the Pacific Whiting Conservation Cooperative (2001-
247   2009) and more recently with NOAA research vessels (2011-present), using complementary methods
248   (see 2.7, NOAA Pre-recruit survey, below). Data from both the SWFSC and NWFSC surveys are
249   pooled to develop indices of juvenile rockfish abundance to support stock assessments (Field et al.
250   2021) as well as to support other ecosystem investigations. The RREAS is also part of a Marine
251   Biodiversity Observation Network (MBON) and works in close collaboration with other research
252   institutions on this.

253   The RREAS samples annually in late spring and collects both environmental and biological data.
254   Environmental data include CTD casts at each station with temperature, salinity, and dissolved
255   oxygen sensors. Biological samples are collected using a Cobb midwater trawl with a 3/8" codend
256   liner, typically with a 30 m headrope depth. Tows are conducted at night, and are 15 minutes in
257   duration, at a speed of 2-2.5 kts. Net and methods are comparable to historic CDFG acoustic trawl
258   surveys (Mais et al. 1974). Biological data from the midwater trawls include enumeration and lengths

259   of all captured groundfish, otolith removal and age determination for a subset of these species,
260   standardized subsampling and lengths of non-groundfish, identification of most krill and squid to
261   species level, and enumeration of some gelatinous zooplankton, including salps and pyrosomes.
262   Additional biological data are collected using acoustics, which have supported studies of krill relative
263   abundance and distribution (Santora et al. 2011). Seabird and marine mammal observations are made
264   and have been used to support a suite of studies, and recently eDNA samples have been collected and
265   analyzed (Closek et al. 2019). Data from the RREAS have been used to better understand which
266   environmental factors and processes contribute to setting year class strength for rockfishes and other
267   groundfishes (Ralston et al. 2013, Schroeder et al. 2019), and have also been used to examine the
268   effects of changes in the abundance of young of the year rockfishes on predator dynamics (Wells et
269   al. 2017). The RREAS informs the CCIEA, the State of the California Current report, and provides
270   indices of rockfish year class strength that are used for multiple stock assessments.

271   **2.6   NOAA Juvenile Salmon and Ocean Ecosystem Surveys (JSOES)**

272   The JSOES were first initiated in 1998, focusing on the northern California Current region (northern
273   Washington to Newport, Oregon). JSOES uses a combination of research, monitoring, and modeling
274   to develop a mechanistic understanding of how conditions and trophic dynamics in the ocean and
275   Columbia River plume affect early marine survival of juvenile salmonids. Survey sampling is over
276   the shelf (1-30 nm offshore) and over bottom depths of 30-200 m. The June time series has the most
277   consistent temporal and spatial coverage (1998-present), the May time series is limited to 1999-2012
278   and 2015-present, and an additional September time series was collected from 1998-2012. JSOES is
279   based out of the NWFSC.

280   Environmental data collected by JSOES include CTD casts, nutrients, and chlorophyll-a. Biological
281   data are collected using daytime surface trawls with a Nordic trawl net, which fishes in the upper 18
282   m of the water column. Vertical net plankton tows samples smaller zooplankton, especially
283   copepods, in the upper 100 m of the water column. Oblique bongo tows sample the zooplankton
284   community in the upper 30 m of the water column. The survey collects biological data on surface
285   trawl species composition, zooplankton (including ichthyoplankton) from the plankton tows, and
286   conducts observations of seabirds and marine mammals. Since the survey focuses on survival of
287   juvenile salmonids, it also collects additional data on salmonid species. Survey data have been used
288   to study variability in nekton and recent ecosystem disturbances in the Northern California Current
289   (Morgan et al. 2019) and to develop and test ecosystem models (e.g. Ruzicka et al. 2016). One
290   important output of the survey is the indicator stop light chart, which combines regional and local
291   physical and biological variables that affect juvenile salmonid survival into a simple visual. Survey
292   results are used by tribal groups, state, and federal agencies, and inform the CCIEA, and the State of
293   the California Current Report. Scientists involved with JSOES are also involved with the Newport
294   Hydrographic line (sampled biweekly, 1996-present), and the NOAA coastal cooperative pre-recruit
295   survey (PRS).

296   **2.7   NOAA Coastal Cooperative Pre-Recruit Survey (PRS)**

297   The objective of the NOAA coastal cooperative PRS is to quantify the environmental conditions and
298   organisms of the Northern California Current (off Oregon and Washington) and study ecosystem-
299   level processes affecting managed and protected marine resources. The PRS began in 2001 as a
300   collaboration between NOAA and the Pacific Whiting Conservation Cooperative and helped
301   complement survey effort by the RREAS off California (Sakuma et al. 2006, Ralston and Stewart
302   2013). Since 2011, it has been operated by the NWFSC and coordinates directly with the RREAS
303   (Brodeur et al. 2019a). Data from these two surveys are pooled to support indices for stock

304 assessments and other investigations (e.g. Friedman et al. 2018, Field et al. 2021). PRS sampling
305 occurs annually in May-July during seasonal ocean upwelling and increased southward transport.
306 Oceanographic and biological samples are collected by the survey at fixed stations along transects
307 over the continental shelf.

308 CTD casts at fixed stations measure temperature, salinity, density, chlorophyll a, turbidity, and
309 dissolved oxygen throughout the water column (to maximum depth of 500 m) (Brodeur et al. 2019a).
310 Underway acoustic data is collected continuously throughout the survey to acoustically characterize
311 the distribution and abundance of macrozooplankton, micronekton, meroplankton, and zooplankton.
312 Biological sampling is conducted using a modified Cobb midwater trawl and bongo and Manta nets
313 at fixed cross-shelf stations along ten 0.5°-latitudinal transects. The midwater trawls have a target
314 headrope depth of 30 m, are ~15 minutes in duration, and are conducted at night. Most organisms
315 captured by the trawl are sorted, measured, counted, and identified to the lowest taxonomic level
316 possible. Specimens of certain species are collected for diet analysis, growth, contaminant load,
317 stable isotope analysis, and other studies relating to the ecology and production of commercially and
318 ecologically important taxa and their relationships within the food web. Ichthyo- and zooplankton are
319 collected using a bongo net with a 60-cm diameter mouth opening and 333-μm mesh nets. The bongo
320 is fished at night as a continuous oblique tow from ~100 m (or within 5 m of the bottom at stations
321 <100 m) to the surface. Neustonic ichthyo- and zooplankton (especially crab megalopae) were also
322 collected in 2014-19 using a Manta net (1.0 × 0.4 m mouth; 300-μm mesh) fished at the surface.
323 Marine mammal and bird observations are also collected during the day, and a variety of specialized
324 projects are conducted each year. Survey data are used to parameterize ecosystem models and
325 forecast changes in species, assemblages, and ecosystems. Survey data have also been used to
326 examine shifts in the assemblage structure due to marine heat waves (Brodeur et al. 2019a).

327 **2.8   Joint U.S.-Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey (Hake**
328 **ATS)**

329 The objective of the Hake ATS is to support sustainable fisheries management for Pacific hake
330 (*Merluccius productus*), which is the largest (by volume) fishery on the U.S. West Coast and is
331 jointly managed with Canada. The survey began in 1977 and was initially conducted triennially, but
332 since 2001 has been conducted every other year. The survey samples from south (Point Conception)
333 to north (SE Alaska) and takes place in the summer (June-September) with about 90-100 days at sea.
334 The survey has a random start near Point Conception, then transects are spaced 10 nmi apart and are
335 conducted over isobaths of 50-1500 m (or 35 nmi offshore). Oceanographic, acoustic, and biological
336 samples are collected by the survey.

337 Oceanographic data are collected while underway using an ADCP and a thermosalinograph, as well
338 as at fixed and ad hoc stations using CTD profiles and an underway CTD. Acoustic data are collected
339 using Simrad EK60 and EK80 echosounders at 18, 38, 70, 120, and 200 kHz, run continuously
340 during the day and night. Backscatter data are used to examine the distribution and abundance
341 patterns of hake, euphausiids, and shelf-associated rockfishes in the water column. Regions of hake-
342 like backscatter are sampled during the day using an Aleutian Wing Midwater Trawl with video,
343 stereo cameras, and an SBE-39 temperature and pressure sensor attached to the trawl. On average,
344 104 trawls have been collected per survey (range between 63-141 trawls). Trawl-caught specimens
345 are identified to species, and lengths, weights, age, sex, and maturity are determined for certain
346 species. Samples for genetics, diet, physiology, and toxicology are also collected for certain species.
347 Zooplankton tows with a Methot net are conducted at certain stations. Saildrones have also recently
348 been used as a sampling platform, and there are hopes to add drop cameras in the future. Partner

349 projects on the survey have included harmful algal bloom research, eDNA sampling, testing of the
350 Imaging Flow CytoBot (an in-situ automated submersible imaging flow cytometer for analyzing
351 nano- and microplankton; Olson and Sosik (2007)), and collection of marine bird and mammal
352 observations. In addition to informing hake stock assessments, integrated oceanographic, acoustic,
353 and biological data from the survey have been used to develop models for forecasting hake and
354 euphausiid habitat, and to examine trophic linkages. Given the large spatial footprint of the survey,
355 the data can be used to examine broadscale changes in the CCE.

356 **2.9 California Collaborative Fisheries Research Program (CCFRP)**

357 The CCFRP is a fishery-independent monitoring program that was started to monitor and evaluate
358 the California Marine Life Protection Act (MLPA)-created Marine Protected Areas (MPAs) in
359 California and provide data for conservation and fisheries management. It began in 2007 following
360 the passage of the MLPA, and initially focused on four Central Coast MPAs (Año Nuevo, Point
361 Lobos, Piedras Blancas, and Point Buchon). In 2017, CCFRP expanded to a statewide program.
362 Sampling focuses on depths between ~10-40 m and is done by paired sampling at an MPA and a
363 nearby reference site with matching benthic substrate and depth characteristics. For each site, four
364 grid cells (500 x 500 m) are randomly selected, and a 15-min drift is conducted at three locations in
365 each grid cell, during which volunteer anglers fish. Angler number, species identity, total length
366 (cm), fish condition, tag number, and GPS coordinates are recorded for each catch, total time fishing
367 is recorded to provide a precise estimate of effort, and data are standardized to catch per angler hour,
368 as a metric of CPUE (catch-per-unit-effort). Additionally, weather is recorded and a CTD cast is
369 conducted. Between 2007-2018, 136,000 fishes from 86 species have been caught by the CCFRP.
370 Over 44,000 fishes have been tagged and released as part of this program, and genetic mark/recapture
371 methods are being explored.

372 CCFRP data are used for certain nearshore rockfish stock assessments, where other fishery-
373 independent data are unavailable, and data are used to evaluate MPA effectiveness and assess
374 recovery of certain species (Starr et al. 2015). The data have supported recovery of lingcod, blue
375 rockfish (*Sebastes mystinus*), and vermillion rockfish (*Sebastes miniatus*) in certain MPAs. By
376 incorporating the fishing community into CCFRP sampling (through contracting Commercial
377 Passenger Fishing Vessels and involving volunteer anglers), this program also works to build trust
378 between the science and fishing communities (Mason et al. 2020).

379 **3 Contributions of Fisheries Surveys to Ocean Observing Needs**

380 Fisheries surveys collect data on multiple variables that have been deemed as priorities by the ocean
381 observing community. These include essential ocean variables (EOVs), essential climate variables
382 (ECVs), and essential biodiversity variables (EBVs). EOVs have been agreed upon by the Global
383 Ocean Observing Strategy (GOOS) to build better coordination across observing programs
384 (Lindstrom et al. 2012). EOVs that relate to measuring climate change, such as sea surface
385 temperature, oxygen, and inorganic carbon, are also considered ECVs under the global climate
386 observing system (WMO 2016). ECVs contribute to the characterization of Earth's climate and
387 support the work of the United Nations Framework Convention on Climate Change and the
388 Intergovernmental Panel on Climate Change. EBVs have been defined by the Group on Earth
389 Observations Biodiversity Observation Network as derived measurements required to study, report,
390 and manage biodiversity change (Pereira et al. 2013). EBVs fall into six classes: genetic composition,
391 species populations, species traits, community composition, ecosystem functioning, and ecosystem
392 structure. To improve coordination with the international ocean observing community, we indicate

393 the EOVs (Table 4), ECVs (Table 5), and EBVs (Table 6) that are collected by U.S. West Coast
394 fisheries surveys.

395 Overall, we see that certain EOVs and ECVs are very well sampled by fisheries surveys. Since all
396 surveys conduct vertical CTD casts, all collect data on sea surface and subsurface temperature and
397 salinity (Table 4, 5). Because dissolved oxygen is an important environmental variable for
398 characterizing fish habitat, most surveys also collect subsurface oxygen data with calibrated oxygen
399 sensors, and some collect bottle measurements and conduct Winkler titrations at sea (Table 4, 5).
400 Since the objective of fisheries surveys is to support sustainable management of fish stocks, all
401 surveys collect data on fish and more than half collect data on zooplankton (Table 4). Phytoplankton
402 and microbe EOVs are only collected by certain surveys (Table 4), and the collection of these EOVs
403 tends to be supported by academic collaborations and partner projects. Similarly, nutrient data are
404 only collected by two of the nine fisheries surveys (Table 4, 5). Currently, only CalCOFI collects
405 inorganic carbon data, which is an important EOV and ECV since it supports understanding ocean
406 acidification risk (Table 4, 5). However, carbonate chemistry parameters can be estimated with
407 robust regional empirical relationships (Alin et al. 2012) using variables that are collected by most
408 surveys (i.e. temperature, salinity, oxygen). Thus, even surveys that do not directly collect inorganic
409 carbon data can contribute to understanding regional ocean acidification risk.

410 Perhaps the greatest contribution of fisheries surveys is to ocean biology and ecosystem variables,
411 and EBVs, which require at-sea, biological data collection. This can be seen by the large number of
412 biology and ecosystem EOVs (Table 4) and EBVs (Table 6) that are supported by U.S. West Coast
413 fisheries survey programs. Specifically, all surveys contribute knowledge on species distributions,
414 species abundances, community abundance, ecosystem disturbances, and ecosystem distribution
415 (Table 6). Surveys that sample in multiple seasons of the year, also contribute knowledge on species
416 and ecosystem phenology (Table 6). Fisheries surveys can also contribute to EBVs that are not
417 explicitly a focus of the survey. For example, genetic composition EBVs could be examined using
418 archived and curated ethanol preserved samples from programs like CalCOFI, and programs like
419 GBTS, H&L Survey, Hake ATS, and JSOES collect fish tissue samples for DNA analysis, which
420 could inform other genetic composition EOVs (Table 6).

421 4 Contributions of Fisheries Surveys to Understanding Emergent Ecosystem Management
422 Challenges

423 In this section, three case studies are provided that show how fisheries survey data contribute to
424 understanding and managing emergent ecosystem challenges on the U.S. West Coast, including
425 marine heatwaves, ocean acidification, and contaminant spills.

426 4.1 Fisheries survey contributions to a holistic understanding of the effects of the 2014-2016
427 Marine Heatwave on the CCE

428 Between 2014 and 2016, water temperature along the west coast of North America displayed the
429 highest 3-year average on record (Jacox et al. 2018), and similar "marine heatwave" conditions are
430 likely to become increasingly common in the future (Jacox et al. 2020). Data collected from multiple
431 marine surveys, including fisheries surveys, provided a comprehensive picture of the response of the
432 CCE across multiple trophic levels to the 2014-2016 marine heatwave.

433 Zooplankton data from the NHL, THL, PRS, CalCOFI, and IMECOCAL surveys showed that
434 zooplankton displayed similar, and rather predictable, responses to warm water across regions within
435 the CCE. Specifically, smaller-bodied individuals and species were prevalent in several surveys. In

436 the north, the abundance of relatively large crustacean zooplankton was very low off Oregon
437 (Brodeur et al. 2019a) while small and gelatinous (genus *Pyrosoma*) invertebrates were abundant in
438 both the ocean and the guts of predators (Brodeur et al. 2019b). In northern California, krill
439 *Euphausia pacifica* were much smaller than average (McClatchie et al. 2016b). In southern
440 California, CalCOFI surveys demonstrated that the 2014-2015 surface warming induced shifts in the
441 zooplankton assemblage similar to the 1992-93 El Niño, while the 2015-2016 assemblage was closer
442 to that of the 1997-98 El Niño (Lilly and Ohman 2018). Further south, two krill species, *E. pacifica*
443 and *Nematoscelis difficilis*, decreased in biomass by 95% relative to the previous decade while
444 several tropical krill species increased significantly off Baja California (Lavaniegos et al. 2019).

445 Data collected by NHL, PRS, RREAS, CalCOFI and IMECOCAL surveys also provided a look at
446 coast-wide forage fish assemblage responses to the marine heatwave. These were more nuanced than
447 for zooplankton but revealed that strong shifts in fish assemblage structure were synchronous
448 throughout the region even though the particular taxa that drove the changes differed among regions
449 (Thompson et al. 2019a). Overall, larval abundances were very high, and the assemblage was largely
450 southern and offshore species. Species such as Pacific Sardine were observed spawning in the winter
451 for the first time off Oregon (Auth et al. 2018). In central and southern California, abundances of
452 southern, mesopelagic taxa were at record highs both in RREAS (Thompson et al. 2019b, Sakuma et
453 al. 2016) and CalCOFI larval surveys (Thompson et al. 2021), which is consistent with past warm
454 water events (Peabody et al. 2018). Atypically, Northern Anchovy (Thompson et al. 2019b) and
455 multiple rockfishes (Schroeder et al. 2019) that previously flourished under cold conditions had
456 extremely high recruitment from 2014-2016, and adult abundances of anchovy rose to record highs in
457 subsequent years (Auth et al. 2018, Thompson et al. 2019b). In the southern CCE, larvae of the same
458 mesopelagic species that increased in southern California decreased in northern Baja California,
459 potentially due to a shift in preferred habitat, while larvae of demersal taxa increased (Uribe-Prado et
460 al. 2021).

461 Fisheries survey data from RREAS and CalCOFI also contributed to understanding top predator
462 dynamics during the marine heatwave. California sea lions (*Zalophus californianus*), which had
463 endured unusual mortality events due to scarce prey prior to the heatwave (McClatchie et al. 2016a),
464 fed copiously on the resurgent Northern Anchovy beginning in 2015 and had much enhanced pup
465 condition from 2015-2018 (Thompson et al. 2019b). Humpback whales (*Megaptera novaeangliae*)
466 were closer to shore than usual, likely to feed on anchovy, which caused more whale entanglements
467 in Dungeness crab (*Metacarcinus magister*) fishing gear, greater whale mortality, and intermittent
468 fishery closures (Santora et al. 2020). Catch of Pacific Bluefin tuna (*Thunnus orientalis*) by the
469 commercial passenger fleet off California was very high, as tuna associated with warm water and
470 foraged on anchovy (Runcie et al. 2019). Seabird population dynamics differed during and after the
471 marine heatwave depending on prey needs. Species such as the Brandt's cormorant (*Phalacrocorax*
472 *penicillatus*), which are capable of feeding on anchovy and provide regurgitate to nourish chicks, had
473 relative high production (Thompson et al. 2019b). In contrast, species that feed on krill and smaller
474 prey, such as Cassin's auklet (*Ptychoramphus aleuticus*), fared poorly (Jones et al. 2018).

475 **4.2 Fisheries survey contributions to characterizing and evaluating ocean acidification risk**
476   **for the CCE**

477 At the air-sea interface, the ocean absorbs atmospheric CO_2, resulting in a reduction in pH and
478 changes in seawater carbonate chemistry. This process of ocean acidification (OA) leads to a
479 reduction in available carbonate ions (and related saturation states), which are the building blocks for
480 calcifying organisms such as molluscs, crustaceans, and bivalves (Doney et al. 2009). Due to the

481   47% increase in atmospheric CO_2 since the beginning of the Industrial Age, OA is occurring faster
482   than at any other time over the past 50 Myr (Hönisch et al. 2012). The U.S West Coast is particularly
483   vulnerable to OA impacts because the CCE is an Eastern Boundary Upwelling System, and
484   upwelling events bring more acidic waters into shallow and nearshore habitats (Feely et al. 2008).
485   Studies suggest the rapid increase in atmospheric CO_2 since the Industrial Age has contributed to the
486   severity of these events (Gruber et al. 2012, Hauri et al. 2013). While fisheries surveys were not
487   initially designed to evaluate or monitor OA vulnerability, they could provide a valuable source of
488   information for the present and future.
489
490   Along the U.S. West Coast, oceanographic surveys like the NOAA Pacific Marine Ecosystem
491   Laboratory West Coast Ocean Acidification (WCOA) cruises provide important data that support OA
492   decision-making frameworks for the CCE. Data from these cruises were used to examine habitat
493   suitability in the CCE for different life stages of pteropods, which are planktonic calcifiers
494   (Bednaršek et al. 2014). Pteropods exhibited dissolution damage that scaled in severity with low
495   aragonite saturation state conditions in the survey area, implying that OA will reduce the amount of
496   optimal habitat for pteropods. An individual's previous exposure history to low aragonite saturation
497   conditions affected future survival in acidic conditions (Bednaršek et al. 2017). Life-stage specific
498   critical thresholds for pteropods were sensitive to warming conditions, OA exposure duration, and
499   other climate change stressors (Bednaršek et al. 2019). The inclusion of warming with OA exposure
500   increased vulnerability to shell dissolution and survival (Bednaršek et al. 2019).
501
502   The suite of pteropod studies conducted by Bednaršek et al. (2014, 2017, and 2019) is in large part
503   based on data collected during the NOAA WCOA cruises and provides an example of the utility of
504   ecosystem monitoring programs to investigate and ultimately enhance our understanding of emerging
505   issues, like OA. While currently, of the U.S. West Coast fisheries surveys, only the CalCOFI
506   Program collects carbonate chemistry data, fisheries surveys have the potential to add carbonate
507   chemistry monitoring to their data collection with a relatively low investment (i.e. the cost of sensors,
508   onboard flow-through pCO_2 measurement systems, or seawater analysis costs for dissolved inorganic
509   carbon and total alkalinity). Integration of these OA measurements would substantially increase
510   spatial coverage of OA information on the West Coast, where the implications of OA are of high
511   priority amongst the scientific and management communities. CalCOFI complements the WCOA
512   data collection because it provides a multidecadal time series of dissolved inorganic carbon
513   measurements starting in 1983 (Gallo et al. 2019) and it collects data during years when there are no
514   WCOA cruises (WCOA cruises were conducted in 2007, 2011, 2012, 2013, 2016, 2017, and 2021).
515
516   OA mitigation and preparedness strategies are critical for protecting ecosystems and economies and
517   rely on understanding OA risk in a region and species vulnerabilities. As part of the International
518   Alliance to Combat Ocean Acidification, the California Ocean Protection Council in cooperation
519   with the Ocean Science Trust has developed the State of California Ocean Acidification Action Plan,
520   which is the guiding document for the state to engage in strategies to mitigate and prepare for
521   impacts of ocean acidification (OPC 2018). A specific strategy in this Plan is to invest in monitoring
522   and observation systems that couple environmental and biological monitoring associated with OA.
523   Given the large spatial footprint of fisheries surveys and committed ship time, these surveys could
524   address this Action Plan strategy by providing opportunities to link carbonate chemistry
525   measurements with biological samples to examine ecosystem indicators of OA impacts. Together,
526   oceanographic and experimental data can be used to develop reliable projections of OA impacts to
527   support decision-making frameworks (Link 2005).
528

12

529 **4.3   Fisheries surveys provide environmental baselines for evaluating ecosystem impacts of**
530 **human-made and natural disasters**

531 The U.S. West Coast includes numerous important fisheries, ecologically significant areas, a broad
532 diversity of species, and a vibrant tourism industry. At the same time, it also has dense human
533 populations, the busiest marine ports in the nation, 23 offshore oil platforms, and diverse coastal
534 industrial production. In addition, the steady rise in fisheries disasters driven by climate change (e.g.
535 marine heat waves, extreme weather; Bellquist et al. 2021) reflect the intensifying ecosystem impacts
536 of greenhouse gases. The potential for environmental and economic disaster in the region's ocean
537 ecosystem, due to chance events and/or the unforeseen consequences of human activity, is therefore,
538 high. When such disasters occur, data from fisheries surveys can provide context for the extent of
539 impacts, and the short- and long-term ecosystem responses.

540 Ecosystem monitoring programs are perhaps most useful when they provide contextual information
541 for the impacts of disasters. The southern California oil spills of Torrey Canyon (1967) and Santa
542 Barbara (1969) are an iconic ocean ecosystem disaster that is at least partially responsible for the
543 modern environmental movement (Clarke and Hemphill 2002, Teal and Howarth 1984). The impacts
544 of these unanticipated events were both acute and long lasting (Spezio 2018). Following the spill,
545 several studies demonstrated high mortality in nearby seabird, marine mammal, and intertidal
546 communities (e.g. Foster et al. 1971). However, the population level impacts on subtidal taxa and
547 fishes were less clear due to a lack of long-term prior baseline information. The value of fisheries
548 surveys as an impact assessment tool was demonstrated in the aftermath of both the Exxon Valdez
549 and Deepwater Horizon oil spills. In the former case, Thorne and Thomas (2008) used a decadal
550 database of acoustic surveys of Prince William Sound Pacific Herring to demonstrate that collapse in
551 that population was consistent, in time and duration, with oil spill impacts. In the latter case, Peterson
552 et al. (2017) used catch data from two fishery-independent surveys to demonstrate a lack of spill-
553 related impacts on food-web structure among large coastal fishes. In both cases, fishery survey data
554 collected to inform routine stock assessments were used to examine ecosystem responses to the oil
555 spills.

556 In some instances, a disaster may lie undiscovered for decades, even as the impacts to ocean
557 ecosystems persist or evolve through time. In such cases, the full value of monitoring data is only
558 made clear after discovery of the disaster, when such data provide context for post hoc assessment.
559 The recent rediscovery of a vast dichloro-diphenyl-trichloroethane (DDT) waste dumping ground
560 near Santa Catalina Island in southern California is an example of such an event. In 2021, researchers
561 discovered a field of dumped barrels full of sludge laced with DDT. These barrels, disposed of by the
562 Montrose Chemical Corporation, were the product of a DDT production facility in Los Angeles,
563 California, that operated from 1947 to 1982. Understanding the spatio-temporal extent of DDT
564 penetration in the marine ecosystem is a high priority. The preserved biological samples of fisheries
565 survey programs, such as CalCOFI, hold the potential for contextualizing an old environmental
566 disaster, via decades of carefully archived and curated specimens.

567 The frequency of marine ecosystem disasters in the U.S. has increased significantly during the last 34
568 years (Smith and Katz 2013, Bellquist et al. 2021), and prevention of all unforeseen human-induced
569 disasters to California's coastal ecosystems is unlikely. In the case of a new ecosystem disaster, the
570 rich array of fisheries surveys and ocean monitoring programs along the North American coast can
571 provide detailed baseline data to identify coastal community and marine ecosystem impacts and
572 inform environmental and economic impact assessments.

573 **5   Discussion: A Healthy Ecosystem of Monitoring Programs**

574 The goal of this paper is to demonstrate the value and breadth of ocean observing and ecosystem
575 monitoring data collected by fisheries surveys, using the U.S. West Coast as an example. On the U.S.
576 West Coast, fisheries surveys provide extensive additional spatial ecosystem monitoring coverage.
577 When examining U.S. West Coast coverage of ocean monitoring based on a 0.1 degree resolution
578 grid cell (11.1 km), we find that the combined area sampled by monitoring programs represented at
579 the 2019 CalCOFI Symposium is about 189,000 km^2. Of this area, 12% is sampled by both fisheries
580 and non-fisheries surveys, 6% is sampled by only non-fisheries surveys, and 82% is sampled by only
581 fisheries survey programs (Fig. 3). Thus, including fisheries surveys as essential components of
582 ocean observing systems increases spatial coverage of ocean ecosystem monitoring on the U.S. West
583 Coast by more than 75%; the increase in coverage is especially pronounced offshore (Fig. 3).
584 Additionally, these fisheries surveys have all been sampling from 2010 onward, meeting the
585 IGMETS definition for sustained ocean time series, with four of the nine fisheries surveys having
586 over 30 years of sampling coverage (Fig. 2). Thus, fisheries surveys on the U.S. West Coast
587 contribute substantially to sustained ecosystem observing goals.

588 While the need for robust ocean time series only increases in the 21st century, both federal and
589 academic monitoring programs struggle with the realities of rising ship time costs, and the challenges
590 of maintaining historic time series while integrating new sampling approaches and revising survey
591 designs. Building tools for new monitoring needs onto the existing blueprint of fisheries surveys can
592 be a cost-effective way to address emerging regional challenges. Effective partnerships between
593 federal fisheries surveys and academic programs give rise to more integrated, thorough regional
594 monitoring by leveraging the strengths of both. For example, the partnerships between CalCOFI and
595 the CCE LTER program, and between the RREAS, PRS, and the SBC MBON, have resulted in a
596 broader breadth of EOVs being measured over a greater area on these surveys (Table 4). Fisheries
597 surveys can offer ship time, a wealth of oceanographic and biological data, and sampling consistency
598 that does not depend on shorter academic grant cycles. Academic partnerships can offer funding
599 avenues for pursuing basic scientific questions, opportunities to test newer technologies such as
600 eDNA or autonomous vehicles, and personnel time and student training opportunities through the
601 university framework. Networks like LTER, MBON, and the U.S. integrated ocean observing system
602 (IOOS), can help individual programs coordinate across larger spatial scales and connect to national
603 and international efforts.

604 By raising awareness about the different fisheries surveys and types of data collection, we hope to
605 build more cooperative opportunities for the future. During the 2019 CalCOFI Symposium, it was
606 clear that many fisheries surveys are open to collaboration with both one another and academic
607 institutions and, in some cases, can collect samples for ancillary research projects. In accordance with
608 the OPEN Government Data Act (Public Law 115-435), federal fisheries surveys in the U.S. are
609 required to make data publicly accessible and have personnel time dedicated to support database
610 upkeep and management. However, open access is not always the case for ocean time series
611 programs, specifically internationally. An IGMETS survey found that 69% of zooplankton time
612 series are controlled or restricted, meaning data are only available by contacting the data collector or
613 institutional data manager, and only 13% had full online access (Benway et al. 2019). Phytoplankton,
614 nutrient/pigment, and temperature/salinity data had slightly higher full online access availability, but
615 controlled or restricted access to those datasets was still more common (Benway et al. 2019). Though
616 U.S. fisheries survey data are required to be publicly available, there are survey-specific differences
617 in terms of data and metadata structure and ease of use. There is no single data serving tool that
618 houses all NOAA fisheries survey data, and such an effort would need to surmount considerable

619   challenges in integrating survey-specific differences in survey design and sampling, including
620   operations conducted by different regional NOAA offices (Table 2, 3).

621   As oceans warm, marine ecosystems may change in unpredictable ways (Checkley et al. 2017,
622   Thompson et al. 2019b). A robust and collaborative network of regional monitoring programs can
623   more rapidly detect early signals of unanticipated changes and changes in species distributions,
624   respond with additional focused sampling as needed, and support more informed and responsive
625   management actions. Due to their large spatial footprints and sustained sampling, fisheries surveys
626   represent a foundational blueprint for regional ecosystem monitoring in a time of global change. On
627   the U.S. West Coast, they provide multi-decade ocean time series, increase the spatial extent of ocean
628   ecosystem monitoring by over 75%, and provide coast to offshore data on multiple oceanographic
629   and ecological variables deemed essential by the ocean observing community. However, even
630   fisheries surveys are not immune to rising ship time costs and eroding agency budgets, and surveys
631   that only indirectly inform fisheries management by providing ecosystem context are often at greater
632   risk of losing funding than those directly informing fisheries stock assessments. Thus, recognizing
633   the contributions of fisheries surveys to the collection of essential ocean, climate, and biodiversity
634   data is essential, as is maintaining public support for ocean observing and ecosystem monitoring. As
635   the international community moves towards a global strategy for ocean observing, this program will
636   need to 1) be multidisciplinary and based on best practices, 2) built on existing platforms, and 3)
637   strengthen and expand the current capacities (Miloslavich et al. 2017). Fisheries surveys, both in the
638   U.S. and globally, should play an important role as data contributors in the global ocean observing
639   strategy.

6   Conflict of Interest

641   The authors declare that the research was conducted in the absence of any commercial or financial
642   relationships that could be construed as a potential conflict of interest.

7   Author Contributions

644   NDG and NMB conceptualized and led the writing of the manuscript. NDG, ART, and NMB
645   compiled information for the review. NDG and EVS produced manuscript figures and tables. NDG,
646   NMD, ART, BXS, and EVS all contributed to writing and editing the manuscript.

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Data Availability Statement

903 No new datasets were generated for this manuscript. All synthesized information is provided in tables
904 2-6. Links to all survey datasets are provided in Table 3.

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919 **Tables**

920 Table 1. These 21 North American West Coast monitoring programs, surveys, and organizations
921 participated in the 2019 CalCOFI Symposium. Shortened program names are used throughout the
922 manuscript.

Short Name	Full Program Name
ACCESS	Applied California Current Ecosystem Studies
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCE LTER	California Current Ecosystem Long-Term Ecological Research Site
CCFRP	California Collaborative Fisheries Research Program
CCES	NOAA California Current Ecosystem Survey
Farallon Institute	Farallon Institute
GBTS	NOAA West Coast Groundfish Bottom Trawl Survey
H&L	NOAA Shelf Rockfish Hook and Line Survey
Hake ATS	Joint U.S.-Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey
IMECOCAL	Investigaciones Mexicanas de la Corriente de California
JSOES	NOAA Juvenile Salmon and Ocean Ecosystem Surveys
MBARI	Monterey Bay Aquarium Research Institute
NHL	Newport Hydrographic Line
P&B	Plumes and Blooms Survey
PRS	NOAA Coastwide Cooperative Pre-Recruit Survey
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
RREAS	NOAA Rockfish Recruitment and Ecosystem Assessment Survey
SBC MBON	Santa Barbara Channel Marine Biodiversity Observation Network

SCCOOS	Southern California Coastal Ocean Observing System
SCCWRP	Southern California Coastal Water Research Project
THL	Trinidad Head Line

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946 Table 2. Overview of the key program characteristics of the nine U.S. West Coast fisheries surveys.
947 All acronyms are spelled out in the footnote and ordered alphabetically[1].

	Lead	Partnerships	Temporal	Spatial	Main Sampling Methodology
CalCOFI	NOAA SWFSC, SIO UC San Diego, CDFW	NSF CCE LTER, Farallon Institute, J. Craig Venter Institute, SCCOOS, CA SeaGrant, Farallon Institute	1949-present. Currently annual, quarterly cruises. Between 1969-1983 cruises were triennial. In the 1950s cruises were monthly.	U.S.-Mexico border to San Francisco (core grid between Pt. Conception and U.S.-Mexico border). Core grid sampled 4 times a year; northern stations sampled 2 times a year. Early CalCOFI sampling extended from N. CA to the Gulf of CA. Stations range from nearshore (<3 km) to far offshore (>500 km).	113 (winter/spring)/75 (summer/fall) stations visited each cruise. CTDs, net-based sampling for zooplankton, and eDNA collection at fixed stations. Underway marine birds and mammal observations, CUFES, and pCO2.
CCFRP	California Polytechnic State University	Moss Landing, SIO UCSD, MSI UCSB, UCD, CSU Humboldt, CA SeaGrant, OPC, CDFW	2007 - present. Sites surveyed 3 times annually between Jul and Oct.	Early emphasis on 4 Central CA MPAs. In 2017, expanded into a statewide program, including 15 MPAs. Depths generally from 10-40 m.	Fishing by volunteer anglers on CPFVs. MPA and outside of MPA reference sites selected, and 15 minutes of fishing at a time during a drift. Catch recorded as CPUE – catch per angler hour.
CCES	NOAA SWFSC	Industry (conducts nearshore acoustics)	Early coastwide ATM survey (1966-1973). ATM survey restarted in spring of 2006.	Portions of and sometimes entire U.S. West Coast; mainly over the shelf.	Nighttime surface trawls (Nordic 264 Rope Trawl), CTDs, underway TSG,

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[1] AFSC: Alaska Fisheries Science Center; ATM: Acoustic Trawl Method; AWT: Aleutian Wing Midwater Trawl; CA: California; CCE LTER: California Current Ecosystem Long-Term Ecological Research; CDFW: California Department of Fish and Wildlife; CIMEC: Cooperative Institute for Marine Ecosystems and Climate; CIMRS: Cooperative Institute for Marine Resource Studies; CPFV: Commercial Passenger Fishing Vessels; CPUE: Catch Per Unit Effort; CSU: California State University; CUFES: Continuous Underway Fish Egg Sampler; MBARI: Monterey Bay Aquarium Research Institute; MBNMS: Monterey Bay National Marine Sanctuary; MBON: Marine Biodiversity Observation Network; MPA: Marine Protected Area; MSI: Marine Science Institute; NOAA: National Oceanic and Atmospheric Administration; NSF: National Science Foundation; NWFSC: Northwest Fisheries Science Center; OPC: Ocean Protection Council; OR: Oregon; OSU: Oregon State University; PSMFC: Pacific States Marine Fisheries Commission; PWCC: Pacific Whiting Conservation Cooperative; SCB: Southern California Bight; SCCOOS: Southern California Coastal Ocean Observing System; SIO: Scripps Institution of Oceanography; SWFSC: Southwest Fisheries Science Center; TSG: thermosalinograph; UCD: University of California Davis; UCSB: University of California Santa Barbara; UCSC: University of California Santa Cruz; UCSD: University of California San Diego; UO: University of Oregon;USV: Uncrewed Surface Vehicle; UW: University of Washington; WA: Washington

			Summer surveys from 2008-present.		acoustics, USV, CUFES.
GBTS	NOAA NWFSC		Early groundfish survey by AFSC (1977-1997). Current survey by NWFSC: 1998-Present (2x a year; mid-May to Jul & mid-Aug to Oct).	Entire U.S. West Coast (SCB added since 2002); 80% effort north of Pt. Conception, 20% effort in the SCB. Depth range: 55-1280 m (shelf and slope).	Stratified random sampling design. Aberdeen Trawls (Env. sensors on trawl), Acoustics (EK60 and EK80); charter west coast fishing vessels. ~700 trawls per survey. CTD at each trawl.
H&L Survey	NOAA NWFSC	PSMFC, southern CA commercial sportfishing fleet	2004-present. Annual sampling.	SCB; "untrawlable habitat" targeting rocky, high relief habitats. Depth range: 35-230 m.	201 fixed sites visited annually. Hook and line fishing using professional anglers. CTD. Underwater camera sled.
Hake ATS	NOAA NWFSC, Fisheries and Oceans Canada	University of Washington	1977-2000 (triennial). 1977-1995 - carried out by AFSC. 2001-present (biennial) conducted Jun-Sep.	Pt. Conception into Canadian waters (north Vancouver Is.); conducted over the shelf and slope (50-1500 m isobaths).	Lines (random start near Pt. Conception, 10 nm apart) & ~104 trawls per year. Acoustics (EK60 and EK80), CTDs, trawling during the day using an AWT with video and stereo cameras on trawl and headrope sonar), zooplankton sampling during the day using a Methot net. Saildrones.
JSOES	NOAA NWFSC & Oregon State University	CIMRS, Bonneville Power Administration	1998-present: surveys in May (1999-2012, 2015-present), Jun (1998-present), and Sep (1998-2012).	N. California Current region (WA and OR; Columbia R. plume). Inshore-offshore: 1-30 nm to shelf break; bottom depths of 30-200 m. Sampling focused on upper water column.	Surveys on industry trawler. Surface daytime trawls with Nordic trawl w/ 0.8 cm liner - fishes upper 18 m. Zooplankton sampled with bongo nets (0.335 mm) (upper 30 m) and vertical (0.2 mm) plankton tows. CTD. Seabird and marine mammal observations.

PRS	NOAA NWFSC	NOAA SWFSC, PSMFC, OSU, UO, UW, UCSC	2011-present (no sampling in 2012 and 2020); annual sampling in May-Jul.	N. California Current region (WA and OR); sampling done over the continental shelf; biological sampling focused on upper midwater depths (0-100 m).	CTD casts, underway accoustics, upper water column midwater trawls and bongo nets (done at night) and neuston nets (2014-19) at fixed stations, and marine mammal and bird observations.
RREAS	NOAA SWFSC	CIMEC, UCSC, NOAA NWFSC, PWCC, Farallon Institute, Point Blue, Stanford, MBARI, MBON, MBNMS	1983-present; 37 years of epipelagic micronekton data. Approximately 100 trawls a year.	Core survey area is Central CA; survey footprint has expanded since 2004, and survey is now coastwide.	Approximately 100 midwater trawls a year (done at night), acoustics, eDNA, seabird and marine mammal observations, CTD.

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963   Table 3. Overview of the environmental and biological data collected by the nine U.S. West Coast
964   fisheries surveys, as well as access points to current data repositories. Acronyms and abbreviations
965   are spelled out in the footnote and ordered alphabetically[2].

	Environmental Variables	**Biological Variables**
CalCOFI	CTD casts (0-515 m, sometimes to 3500 m) at stations (T, S, DO, chlorophyll fluorescence, turbidity, PAR, pH, nitrate); hydrographic bottle samples for S, DO, Silicate, Nitrate, Nitrite, Phosphate, DIC; primary productivity from bottle incubations, underway data (T, S, pCO2), sea state and cloud state.	Ichthyoplankton and invertebrate zooplankton from vertical (Pairovet), oblique (Bongo, 0-210 m), and surface (Manta) plankton tows, marine seabird and mammal observations, eDNA samples (16S and 18S).
	Data Access: Hydrographic (https://new.data.calcofi.org); Ichthyoplankton (https://upwell.pfeg.noaa.gov/erddap); Invertebrate zooplankton (https://oceaninformatics.ucsd.edu/zoodb)	
CCFRP	CTD casts (T, S). Weather observations (wind speed, direction, swell size and direction).	Groundfish CPUE, species, length, condition, and some species tagging. Data only collected on fishes.
	Data Access: http://islandora.mml.calstate.edu/islandora/object/islandora%3A18032	
CCES	CTD cast done every night (2-3 casts per transect) (T, S, DO). Thermosalinograph (T, S) and meteorological sensor suite environmental data are collected underway.	Acoustics and trawl sampling. Characterization of abundance, habitat, distribution, and growth of coastal pelagic species. Uncrewed surface vehicles.
	Data Access: Acoustic (https://www.ncei.noaa.gov/access); Environmental and trawl catch (https://coastwatch.pfeg.noaa.gov/erddap/index.html)	
GBTS	Near-bottom T, DO (2007-Present), chlorophyll fluorescence, pressure, salinity, irradiance, seabed slope and roughness using trawl-mounted sensors. Continuous data collection of wind speed, irradiance, temperature, and acoustics (EK60 and EK80).	Seafloor and demersal invertebrate megafauna and vertebrates captured using Aberdeen trawl. Data on catch, distribution, size structure, and biomass. Biological subsampling of fish for otoliths, gonads, tissue (DNA, SIA), and stomachs (gut contents).
	Data Access: FRAM Data Warehouse (https://www.webapps.nwfsc.noaa.gov/data/map)	

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[2] ADCP: Acoustic Doppler Current Profiler; CPUE: Catch Per Unit Effort; DIC: Dissolved Inorganic Carbon; DNA: deoxyribonucleic acid; DO: Dissolved Oxygen; ERDDAP: Environmental Research Division Data Access Program; FRAM: Fisheries Resource Analysis and Monitoring Division; PAR: Photosynthetically Active Radiation; S: Salinity; SIA: Stable Isotope Analysis; T: Temperature; TSG: thermosalinograph

H&L Survey	Surface T, wind speed and direction, drift speed and direction, tide height and lunar conditions, full water column CTD profile at each station (T, S, DO, chlorophyll fluorescence, turbidity), habitat (visual observations from towed underwater video sled).	Catch and biological data on groundfish: species, fork length, weight, age. Biological subsampling: otoliths, tissue (finclip for DNA; muscle tissue for SIA), stomachs (gut contents), gonads. Study-specific samples.
	Data Access: FRAM Data Warehouse (https://www.webapps.nwfsc.noaa.gov/data/map)	
Hake ATS	Underway ADCP day/night, underway TSG day/night, CTD (T, S, DO) day/night, underway CTD day, sensors on trawl (day).	Aleutian Wing Midwater Trawl samples pelagic and midwater organisms (hake, euphausiids, shelf-associated rockfish, mesopelagic species). Species identification from trawls. Hake: length, weight, sex, age, maturity, DNA, SIA. Zooplankton collected at certain locations with Methot net. Continuous EK60 and EK80 and acoustic data from saildrones on certain lines.
	Data Access: FRAM Data Warehouse (https://www.webapps.nwfsc.noaa.gov/data/map)	
JSOES	CTD (T, S, DO, chlorophyll fluorescence), nutrients.	Daytime surface trawls with Nordic trawl net (upper 18 m) (trawl species composition). Juvenile salmonids: marked/unmarked, DNA, counts, size, condition, diet, parasites, otoliths, growth, timing of ocean entry and marine residence. Zooplankton and ichthyoplankton sampled using oblique bongo tows and vertical nets. Seabird and marine mammal observations.
	Data Access: https://www.webapps.nwfsc.noaa.gov/apex/parrdata/inventory/projects/project/354861	
PRS	CTD to 500 m (T, S, DO, chlorophyll fluorescence, turbidity).	Pelagic fish (larval, juvenile, and adult) and invertebrate organisms from night Cobb midwater trawls, ichthyoplankton and invertebrate zooplankton from oblique (Bongo, 0-100 m, night) and surface (Manta) plankton tows, marine seabird and mammal observations, and continuous underway acoustic data.
	Data Access: https://www.fisheries.noaa.gov/inport/item/20562	
RREAS	CTD (T, S, DO, chlorophyll fluorescence).	Cobb midwater trawls (enumeration and lengths of groundfish, standardized subsampling and lengths of non-groundfish, some enumeration of krill, squid, salps, and gelatinous zooplankton from trawls). Acoustics data. Seabird and marine mammal observations. eDNA samples.

	Data Access: ERDDAP (https://coastwatch.pfeg.noaa.gov/erddap/tabledap/FED_Rockfish_Catch.subset)

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990 Table 4. Essential ocean variables (EOVs) that are collected on the nine U.S. West Coast fisheries
991 surveys. Collection of each EOV is indicated by color and label: "Yes" (blue), "No" (orange), and
992 "Partial" or infrequent data collection (yellow). Coastal or tropical EOVs, such as hard coral,
993 seagrass, and mangrove cover, are omitted. A full list of EOVs can be found on the Global Ocean
994 Observing System website (www.goosocean.org).

Essential Ocean Variable (EOV)		CalCOFI	CCFRP	CCES	GBTS	H&L Survey	Hake ATS	JSOES	PRS	RREAS
Biology & Ecosystems	**Marine mammals**	Yes	No	Partial	No	No	From 2021	Yes	Yes	Yes
	Sea Birds	Yes	No	Partial	No	No	From 2021	Yes	Yes	Yes
	Fish	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Zooplankton	Yes	No	Yes - Krill	No	No	Yes	Yes	Yes	Yes
	Phytoplankton	Yes	No	No	No	No	Partner projects	No	No	No
	Microbes	Yes	No	No	No	No	Partner projects	No	No	Yes
Cross-disciplinary	**Ocean sound**	Partial	No	Yes	Partial	No	Yes	No	Yes	No
Biogeochemistry	**Inorganic carbon**	Yes	No	No	No	No	No	No	No	No
	Particulate matter	Yes	No	No	No	No	No	No	No	No
	Dissolved organic carbon	Yes	No	No	No	No	No	No	No	No
	Oxygen	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Nutrients	Yes	No	No	No	No	No	Yes	No	No

Physics & Climate	Sea State	Yes	Partial	Yes	Partial	Yes	Yes	Yes	No	No
	Sea surface temperature	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Subsurface temp	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Surface currents	Yes	No	Intermittently	No	Yes	Yes	No	No	No
	Subsurface currents	Yes	No	Intermittently	No	No	Yes	No	No	No
	Sea surface salinity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Subsurface salinity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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1009 Table 5. Essential climate variables (ECVs) that are collected on the nine U.S. West Coast fisheries
1010 surveys. Collection of each ECV is indicated by color and label: "Yes" (blue), "No" (red), and
1011 "Partial" or infrequent data collection (yellow). ECVs that are not collected by any of the surveys
1012 (e.g. sea ice, ocean surface heat flux, sea level) are omitted. A full list of ECVs can be found on the
1013 World Meteorological Organization website (https://public.wmo.int/en/programmes/global-climate-
1014 observing-system/essential-climate-variables).

Essential Climate Variable (ECV)		CalCOFI	CCFRP	CCES	GBTS	H&L Survey	Hake ATS	JSOES	PRS	RREAS
Surface Ocean Physics	**Sea surface temperature**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Sea surface salinity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Sea State	Yes	Partial	Yes	Partial	Yes	Yes	Yes	No	No
	Surface current	Yes	No	Intermittently	No	Yes	Yes	No	No	No
Subsurface Ocean Physics	**Subsurface temperature**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Subsurface temperature	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Subsurface currents	Yes	No	Intermittently	No	No	Yes	No	No	No
Ocean Biogeochemistry	**Inorganic carbon**	Yes	No	No	No	No	No	No	No	No
	Oxygen	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Nutrients	Yes	No	No	No	No	No	Yes	No	No
Ocean Biology/ Ecosystems	**Plankton**	Yes	No	Partial	No	No	Yes	Yes	Yes	Yes

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Table 6. Essential biodiversity variables (EBVs) that are collected on the nine U.S. West Coast fisheries surveys. Collection of each EBV is indicated by color and label: "Yes" (blue), "No" (red), and "Partial" (yellow), indicating infrequent or supporting sample collection. EBVs that are not directly collected by any of the surveys (e.g. live cover fraction) are omitted. A full list of EBVs can be found on the Group on Earth Observations Biodiversity Observation Network website (https://geobon.org/ebvs/).

Essential Biodiversity Variable (EBV)		CalCOFI	CCFRP	CCES	GBTS	H&L Survey	Hake ATS	JSOES	PRS	RREAS
Genetic Composition	**Intraspecific genetic diversity**	No	No	No	Partial	Partial	Partial	Partial	No	No
	Genetic differentiation	No	No	No	Partial	Partial	Partial	Partial	No	No
	Effective population size	No	No	No	Partial	Partial	Partial	Partial	No	No
Species Populations	**Species distributions**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Species abundances	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Species Traits	**Morphology**	Partial	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes
	Physiology	Partial	Partial	Partial	Partial	Partial	Yes	Partial	Yes	Partial
	Phenology	Yes	No	Partial	Yes	No	No	Yes	Partial	Partial
	Movement	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Partial
Community Composition	**Community abundance**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Taxonomic/phylogenetic diversity	Yes	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Yes
	Interaction diversity	No	No	No	Partial	No	Partial	No	Partial	Partial

Ecosystem Functioning	**Primary productivity**	Yes	No	No	No	No	No	No	No	No
	Ecosystem phenology	Partial	No	No	No	No	No	Yes	Partial	Partial
	Ecosystem disturbances	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ecosystem Structure	**Ecosystem distribution**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Ecosystem vertical profile	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes

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1042 **Figure Captions**

1043 Figure 1. A spatial overview of the North American West Coast monitoring programs represented
1044 during the 2019 CalCOFI Symposium. Fisheries surveys that are elaborated on in this manuscript are
1045 shown on the left, and other monitoring programs represented at the Symposium are shown on the
1046 right. See Table 1 for full survey names.

1047 Figure 2. Sampling duration of the U.S. West Coast fisheries surveys (see Table 1 for full program
1048 names). The figure displays the general temporal scope of each program, but does not represent
1049 changes in sampling frequency over time. All time periods indicate periods where programs were
1050 sampling more than once every three years, with most sampling at frequencies annually or sub-
1051 annually. Additional details on sampling frequency are included in the text and in Table 2.

1052 Figure 3. Spatial extent of U.S. West Coast ocean monitoring based on survey type, shown at a 0.1
1053 degree resolution grid cell (11.1 km). Areas sampled only by fisheries surveys are shown in teal,
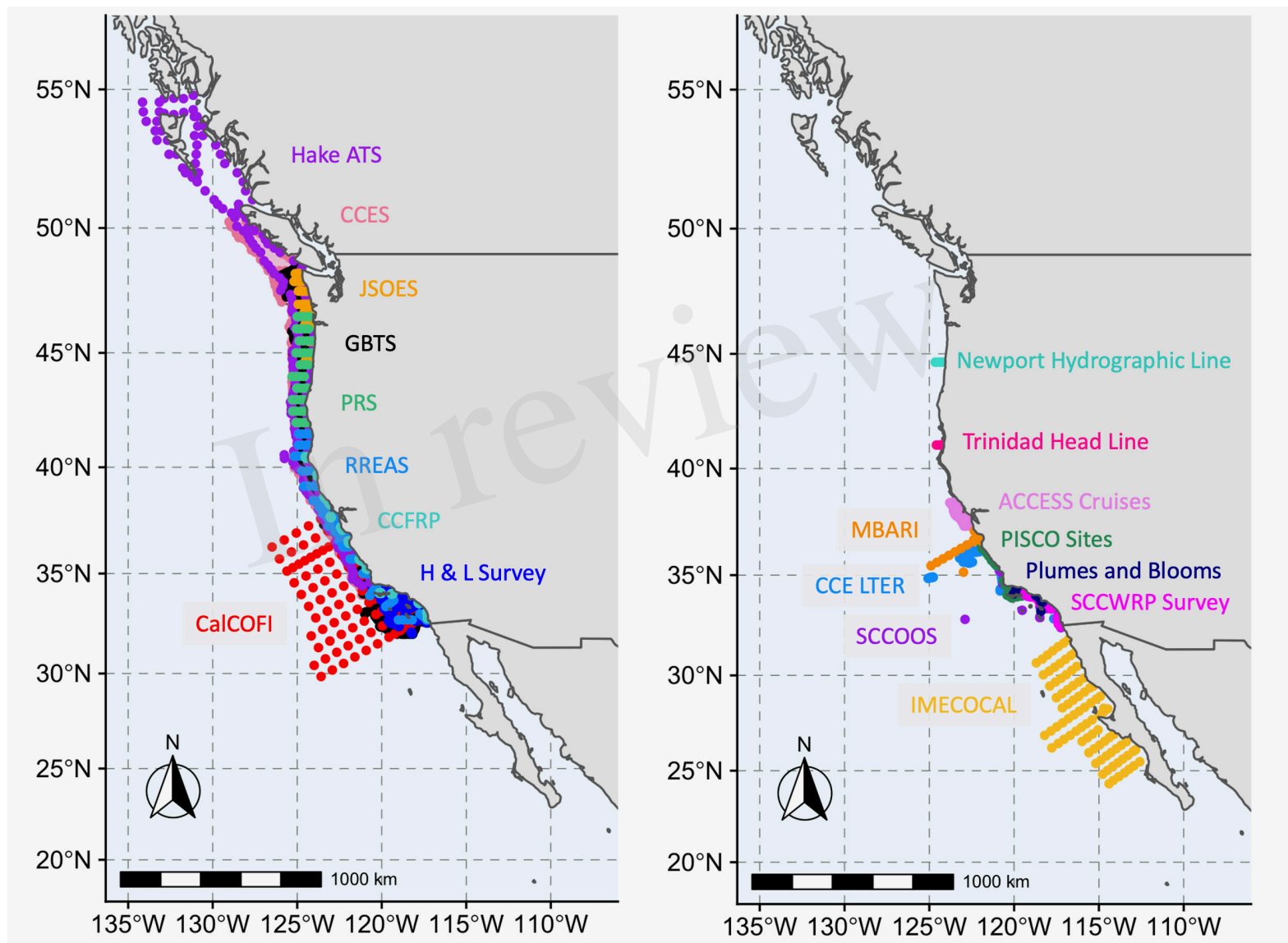1054 areas sampled only by non-fisheries surveys are shown in purple, and areas sampled by both survey
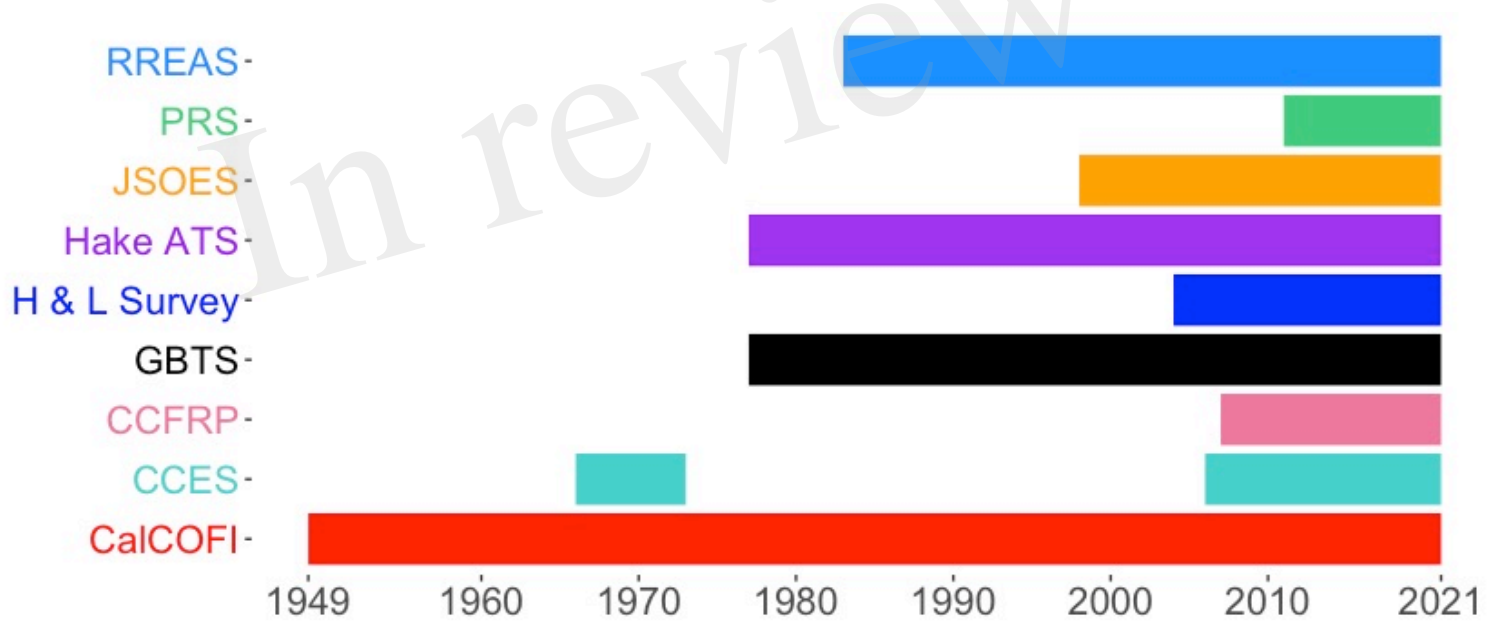1055 types are shown in red.

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Figure 1.JPEG

Figure 2.JPEG

Figure 3.JPEG

Both: fishery & other surveys

Other surveys only

Fisheries surveys only