Proceedings from

Innovative techniques and novel applications of time series data to marine resource management

CalCOFI Conference 2022
December 5th-7th, 2022

Hosted by: Scripps Institution of Oceanography, UCSD
Partners: California Department of Fish and Wildlife &
Southwest Fisheries Science Center, NOAA

Innovative techniques and novel applications of time series data to marine management

A poem

Time series data, a precious gift,
Innovative techniques, a new lift,
For marine management, it's a tool,
A way to understand, to be cool.

The oceans have secrets, they hold so tight,
But with time series data, they come to light.
From water temperature, to fish migration,
Data helps us to conserve, our ocean nation.

With novel applications, the story evolves,
From monitoring the sea, to problem-solving resolves.
For predicting tides, and understanding storms,
Data give us insights, to prevent harm.

The future of the ocean is in our hands,
With time series data, our understanding expands.
From managing marine life, to preserving its health,
Innovative techniques and data, is our wealth.

So let us embrace, this powerful tool,
To protect our oceans, to make them cool.
For the benefit of all, both land and sea,
Time series data, the key to sustainability.

Written by: Chat GPT (Version Jan 30, 2022)

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Introduction

Methodological innovations in the collection, use, and application of ocean ecosystem data are needed to meet the challenge of evaluating the current state and predicting future conditions of rapidly changing marine ecosystems. The goal of the CalCOFI Conference 2022, *Innovative techniques and novel applications of time series data to marine resource management*, was to explore and refine data collection, processing, techniques, analysis, and serving tools used to support the management of marine resources, including fisheries, energy, aquaculture, sanctuaries, cultural heritage, and climate mitigation and adaptation.

The conference explored ways to apply non-traditional data to fisheries assessments, renewable energy & aquaculture siting, cultural heritage, and other marine management applications. New technologies that could augment the utility of existing long-term sampling techniques, such as through innovations in sampling platforms and methods (e.g., uncrewed systems, aerosol sampling, participatory monitoring); biodiversity sensor technologies (e.g., Imaging FlowCytobot, CytoBuoy, Video Plankton Recorder, and passive/active acoustic sensors); and novel forms of data collection (e.g, environmental DNA, chemical tracers, and larval fish otolith analysis) were shared.

Additionally, the conference provided insight into the structure, functioning, and dynamics of the California Current Ecosystem and other Eastern Boundary Upwelling Systems, including the biophysical and human dimensions.

The 2022 CalCOFI Conference was the latest milestone in a series of conferences over the 73-year history of the CalCOFI program. The overarching aims of the CalCOFI conferences are to share information on emerging priorities, the current state, and recent changes to California's marine and coastal environment and to continue to build a community of researchers and practitioners working toward holistically understanding, mitigating, and addressing coastal and marine resource issues along the West Coast.

Overview

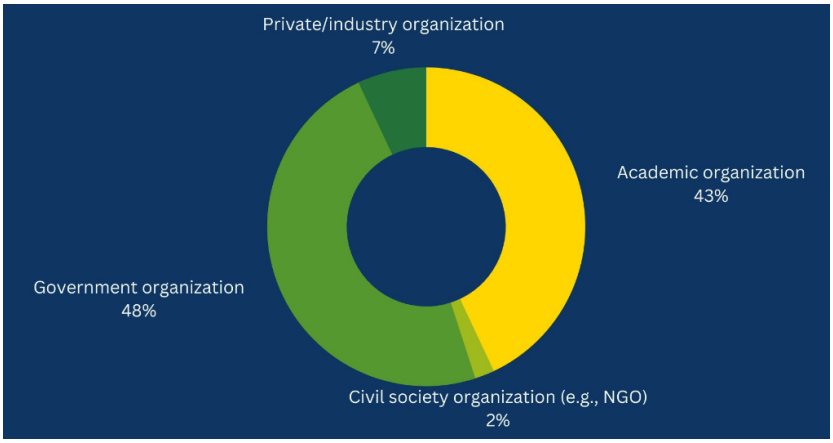
The annual California Cooperative Oceanic Fisheries Investigations (CalCOFI) Conferences bring together diverse stakeholders, including researchers, practitioners, fishermen, and industry representatives, from California, the West Coast of North America, and internationally, to share knowledge on the status and trends of the California Current Ecosystem. Over 1,000 people have participated in the CalCOFI Conferences over the past three years (2019 - 2022).

Opening to the CalCOFI Conference 2022

This year the conference was held December 5th-7th, 2022 at Southwest Fisheries Science Center (SWFSC) and hosted by Scripps Institution of Oceanography in association with California Department of Fish and Wildlife (CDFW) and NOAA Southwest Fisheries Science Center (SWFSC). For the first time, a hybrid format was offered for attendance with over 150 total attendees (~100 in-person and 50 remote participants).

The goal of this year's conference, *Innovative techniques and novel applications of time series data to marine resource management*, was to explore innovative tools and techniques in the data collection, processing, techniques, analysis, and serving tools used to support the management of marine resources, including fisheries, energy, aquaculture, sanctuaries, cultural heritage, and climate mitigation and adaptation.

The theme was selected based on the previous year's conference registration survey of over 300 members of the CalCOFI community who indicated ecosystem and climate change indicators as the most interesting topic to explore.



Sectors of participants involved in the CalCOFI Conference 2022

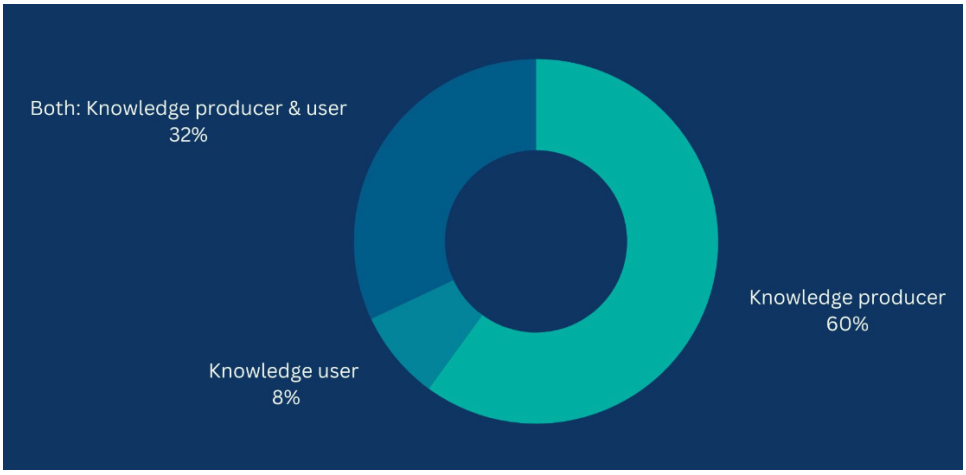
The conference consisted of keynotes, panels, workshops, and contributed talks and posters related to innovation in the collection, analysis, use, and communication of time series data and understanding the State of the California Current Ecosystem. Additionally, there were networking receptions following each day of the conference.

Registrants were from a diversity of sectors including: government (48%), academic (43%), private industry (7%), and civil society (2%).

Registrants worked from local (city/county) to international scales, with most working along the U.S. West Coast. There were registrants from nearly all continents including North America, South America, Europe, Africa, Asia, and Australia/Oceania.

Map displaying location of where participants were from who attended the CalCOFI Conference 2022

Almost two thirds (60%) of conference registrants were knowledge producers (e.g., researchers), 8% knowledge users (e.g., policy-maker, manager, decision-maker, practitioner), and a third (32%) considered themselves to be both knowledge producers and users.



Breakdown of participants that are knowledge producers or users involved in the CalCOFI Conference 2022

Nearly half (47%) of the registrants considered themselves early career professionals, so within 8 years of completing professional training, which suggests that the CalCOFI program is reaching the next

generation of ocean leaders through its annual meeting. Nearly half (42%) indicated that this was their first CalCOFI conference, which suggests that this year's conference brought in many new members to the CalCOFI community, while retaining participation from past members.

Welcome Ceremony & Opening of the Conference

Conference Welcome

Noelle Bowlin, NOAA SWFSC & Brice Semmens, Scripps Institution of Oceanography, UCSD

The conference was opened by Noelle Bowlin (NOAA SWFSC) and Brice Semmens from Scripps Institution of Oceanography and this year's conference host. They provided an overview of the venue, goals of the conference, theme, conference agenda, and attendee information. They highlighted that the CalCOFI program and this conference could not have been possible without its many contributors and supporters.

Opening Keynote Remarks

Margaret Leinen, Scripps Institution of Oceanography, UCSD

Following the welcome remarks, Margaret Leinen, the Director of Scripps Institution of Oceanography, gave the opening keynote. Leinen described the importance of biological observations coupled with physical and chemical observations. **She highlighted that CalCOFI is a globally unique time series of biological observations with a reputation for innovation (e.g., biomolecular).** She went on to discuss how CalCOFI has recently applied to be a part of a novel ocean biomolecular network known as the Ocean Biomolecular Observing Network (OBON) with the Partnership for Observation of the Global Ocean (POGO). She also noted that the legacy samples from CalCOFI are also a resource that continues to be useful as a lens into the past using novel methods (e.g., genomics, DDT).

Margaret Leinen, SIO, giving the keynote remarks for the CalCOFI Conference 2022

State of the California Current Ecosystem Report

Andrew Thompson, NOAA SWFSC & Rasmus Swalethorp, Scripps Institution of Oceanography, UCSD

In the annual State of the California Current Ecosystem (CCE) presentation, Rasmus Swalethorp (SIO) and Andrew Thompson (NOAA SWFSC), described the patterns and trends of the physical, chemical, and biological conditions in the California Current from 2021-2022. **Marine heatwaves were abundant in the California Current Ecosystem in 2022.**

The physical oceanography over the past years indicates that there was a persistent warm state between 2014-2020, but in 2020 the conditions switched to La Nina (negative PDO) conditions. The ONI and PDO have been negative since 2020 and the NPGO is still negative (since 2014), which is unusual during La Nina. The California Current Ecosystem is currently in a La Nina state (since early 2020), and this is the longest continuous La Nina since 2010-2014. Generally, La Nina has been characterized by low sea surface temperature (SST), high upwelling, high primary productivity, high abundances of northern lipid rich zooplankton, and high salmon survival. **Yet, this La Nina is different from those previously observed. As such, many typical La Nina characteristics were not met in the California Current Ecosystem in 2022.**

For example, contrary to what would be expected the sea surface temperature (SST) has been high in the North Pacific since 2014. Specifically, temperatures near the surface have been well above average and cooling at depth (CalCOFI glider line 90 & CalCOFI CTD data). Generally, the chlorophyll was low (Newport Hydrographic Line) or above average in the fall (Trinidad Head) and harmful algal blooms (HABs) were generally low in 2022.

Rasmus Swalethorp, CalCOFI/SIO, presenting on the State of the California Current

The northern copepod species, which tend to be lipid rich, were highly abundant in winter, average during spring and fall and southern copepod species were found in low abundances (Newport Hydrographic Line).

Based on the Juvenile Salmon Ocean and Ecosystem Survey (surface trawl) in 2022 the outgoing chinook and coho yearling numbers were about average. Additionally, the market squid abundances were high and the Pacific pompano (warmer water species) were above average in 2022, indicative of the intrusion of warm water. Anchovy eggs have had high abundances since 2017, and sardine and jack mackerel eggs have had very low abundances, based on the California Continuous Fish Egg Sampler (CUFES). In Oregon, the abundance of southern offshore taxa decreased, dropping to below average; rockfish abundance was above average, anchovy abundance was low, and myctophids were average.

To the south, the California Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) found average abundances of YOY rockfish, YOY hake and YOY sanddabs. In addition, the adult anchovy in the southern region had average abundances and high abundances in the central region. The

YOY anchovy had high abundances in the southern region and average in the central region. The adult and YOY sardine abundances were low overall.

Even more south, the CalCOFI Bongo tows for ichthyoplankton found high abundances of anchovy and very low abundances of sardine. The anchovy were found in high abundances offshore, which is unusual because anchovy are typically considered more of a shelf species. Additionally, there were increased abundances of market squid, high abundances of southern mesopelagic species and low abundances of northern species, increased abundances of rockfish, cowcod, and flatfish.

Seabirds experienced total reproductive failure of Common Murre and Pelagic Cormorant at Yaquina Head, but had average to above average reproductive success at the Southeast Farallon and Pt Reyes. Sea Lions experienced the highest body weights in 2022.

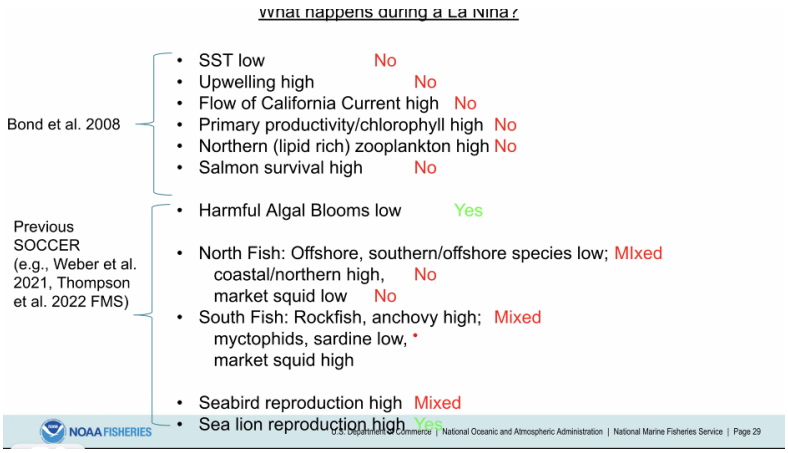


Figure from the State of the California Current Report synthesizing what happens during a La Nina

State of the Fisheries Report

Julia Coates, California Department of Fish and Wildlife (CDFW)

Julia Coates (California Department of Fish and Wildlife CalCOFI Program Lead) described trends in fishery landings for 2022 throughout California. **The port bringing in the most catch by weight was Santa Barbara and the highest value was Los Angeles.** Commercial landings from southern CA (including and south of Santa Barbara) made up 75% of total landings and 59% of total value in 2022. Combined central & southern CA (south of San Francisco) commercial landings made up 88% of total landings and 73% of total value in 2022. The top commercial fishery species in 2022 was market squid (by pounds & value; ~90 million lbs; ~$55 million). Dungeness crab (~$21 million) and Chinook salmon (~$16 million) were the other two most valuable fisheries.

Julia Coates, CDFW, presenting the State of the Fisheries Report

The top recreational fisheries kept by anglers in private/rental boat mode in 2022 (# of fish) included Pacific sanddab (~120,000), Black rockfish (~100,000), and Brown rockfish (~50,000). The top recreational fish species kept by anglers in CPFV mode in 2022 (# of fish) included California scorpionfish (~220,000), Ocean whitefish (~120,000), and Bocaccio (~80,000). Interestingly, the Canary rockfish limit has increased since 2015, which has led to a dramatic uptick in recreational landings.

Notably, recreational dorado catches were very high in 2022. Among other migratory, warm water associated species, catches of albacore and bluefin tuna were relatively high but Pacific barracuda, skipjack tuna, white seabass, and yellowfin tuna were low.

Recent marine ecosystem/fishery events in 2022 and the management responses:

- Domoic acid events - Worked with partner agencies and fleets on fishery closures
- Whale distributions and Dungeness fishery interactions - Creation of whale safe fisheries program and conducting risk assessments
- New species landed - New experimental fishery permit programs (EFPs) for box and king crab
- North coast kelp collapse - Closure of the red abalone recreational fishery led to kelp and abalone recovery planning and purple urchin mitigation
- Changing market squid dynamics - Market squid changes led to the development of a squid fishery advisory council
- Habitat loss and poor conditions for salmon - Drought and poor ocean conditions led to drought mitigation and restoration

Ocean Observations from the Field: Panel & Discussion

Joe Cacciola, Captain Sea Star, Oceanside, CA
Abreanna Gomes, Environmental Specialist II, Kashia Band of Pomo Indians
Renae Logston, CalCOFI Technician, Scripps Institution of Oceanography, UCSD
Shane Volberding, owner of Shane's Seafood & Mackerel Fisherman
Rasmus Swalethorp, Scripps Institution of Oceanography, UCSD (moderator)

This session was structured as a panel discussion with the goal of hearing the trends and changes experienced by ocean professionals who are regularly on the water. The panelists provided introductions and opening remarks followed by a question and answer session.

Joe Cacciola (left), Shane Volderding, Renae Logston, and Abreanna Gomes (right) speaking on the Ocean Observations from the Field Panel

Abreanna Gomes shared many of the long term observations that the Kashia Band of Pomo Indians have conducted along the north coast. The Kashia Band of Pomo Indians have conducted monthly beach watch surveys of a 1.5 mile long stretch of beach since 2021. The surveys include beach profile and waterway photos, species observations, human use activities (shore and ocean) since 2021. Species that were frequently observed/sighted along the Sonoma County coast included gulls, cormorants, harbor

seals, and brown pelicans (according to beach watch surveys conducted by the Kashia Band of Pomo Indians)

In addition, the Kashia Band of Pomo Indians conduct monthly mussel and phytoplankton sampling to test for domoic acid, paralytic shellfish poisoning, and HAGs. They also conduct tide surveys in partnership with other tribes, kelp surveys with the Greater Farallones Association, and tribal member interviews which provide opportunity for tribal members to share knowledge, experiences, and observations along the coast. The Kashia Band of Pomo Indians Tribal Member Surveys revealed that 2022 had an abundance of sea urchin but low levels of abalone and seaweed.

Renae Logston shared that there have been many weather-related issues to sea-going observations this year. Shane Volberding has fished weekly for mackerel species for several years. Mackerel often occur at 30-50 fathoms (180-300 ft) depth and associate with schools of fish of similar size (e.g., large mackerel in schools with small bonito). The largest Pacific mackerel schools tend to be in 'clean' water (clearer, blue water) whereas Spanish mackerel tend to be deeper, feed on krill, and are harder to catch. Schools of younger, smaller fish seem to occur in spring and early fall. He also has observed higher numbers of squid in recent years and fewer anchovy.

Joe Cacciola shared a 50 year perspective from fishing in southern CA. This year he saw huge schools of anchovy up to 150' deep and offshore. In addition, it was a record year for Dorado landings which were mainly inshore because of warm water, abundant bait. Dorado are not often found this far north except in El Nino years. There also was an apparent lack of other pelagic sport species such as yellowtail or skipjack tuna, and there were some yellowfin but they were not as abundant as in the past.

He also noted that there was turbid green water ('dirty' water) close to shore (in 30-40 ft deep water) and that phytoplankton blooms have occurred nearshore year-round.

Joe also mentioned that the inshore kelp forests have been diminishing in size and quality over the last 10 years which has likely led to a loss of habitat for associated species. He also has observed a decline in migratory predatory fish nearshore, such as bonito and sandbass aggregations (none in last 12 years). Bluefin tuna have been more abundant. Migration routes of yellowtail and black seabass have appeared to shift north. Blue sharks have not been around as much, but great white sharks have been spotted more near the beach. Finally, humpback whales tend to be present year-round (possibly feeding on the abundant krill), whereas they were historically scarce.

A few key observations from the panelist included:

- *Intense weather*. Many weather-related issues have impacted sea-going operations
- *Nearshore phytoplankton blooms*. Phytoplankton blooms have occurred nearshore year-round
- *Abundant gulls, cormorants, harbor seals, and brown pelicans*. Species that were frequently observed/sighted along the Sonoma County coast included gulls, cormorants, harbor seals, and brown pelicans
- *Abundant mackerel, squid, sea urchin, Dorado*
    - Abundant Pacific and Spanish mackerel in southern CA
    - Abundant sea urchin along the north coast
    - Higher numbers of squid in recent years and fewer anchovy. Huge schools of anchovy up to 150' deep and offshore.
    - High Dorado landings but lack of other pelagic sport species such as yellowtail and skipjack tuna
- *Declining abalone, kelp, and migratory predatory fish nearshore (e.g., Bonito).*

    - Small or scarce abalone
    - Seaweed has been less abundant
    - Sandbass aggregations have been virtually nonexistent in the past 12 years.
- *Northward migration of yellowtail & black seabass*. Migration routes of yellowtail and black seabass have appeared to shift north.
- *Concerns about declines of nearshore fisheries & declining fishers*. Some large concerns for local communities include decline of nearshore fisheries and fewer resident fishers

Contributed Talks: Part I & II

The Use of Fisheries and Biological Data for Siting Offshore Wind Infrastructure: A Review of Available West Coast Data and Lessons Learned from the East Coast and Europe was presented by Deanna Pinkard-Meier (Tetra Tech). A main point of this presentation was that there is a need to explore available fisheries and biological data and data needs for offshore wind siting, permitting and monitoring on the West Coast, with lessons learned from the East Coast and Europe.

Evaluating the utility of pre-recruit indices of year class in stock assessments was presented by John Field (NOAA Southwest Fisheries Science Center). A key finding was that indices of pre-recruit abundance can provide managers with useful insights into future population trajectories for commercially important marine fishes.

12 years of acoustic backscatter observations shed light on the dynamics of mid-trophic level organisms in the California Current Ecosystem was presented by Jerome Guiet (UCLA). A main finding was that by merging EK60 acoustic transects, a new dataset was developed that gives a novel perspective on the dynamics of mid-trophic levels in the California Current. It especially sheds light on acoustic variability from the epi- to the mesopelagic ocean.

The school trap hypothesis predicts the distribution patterns and environmental preferences of Pacific Sardine in the California Current following the 2010s collapse was presented by Juan Zwolinski (NOAA Southwest Fisheries Science Center). This presentation showed that the school trap hypothesis predicts virtually every distributional pattern observed from the currently depleted stock of Pacific Sardine, including interrupted migrations and shifts in their environmental preferences.

Drivers of diatom abundances and diversity in a coastal upwelling biome was presented by Robert Lampe (Scripps Institution of Oceanography). A main point was that DNA sequencing of diatom communities over seven years in the region reveals the extent and seasonal nature of their abundance and diversity as well as the environmental conditions associated with specific diatom taxa.

Inter- and intraspecific variation in forage quality within Central and Southern California was presented by Stephanie Nehasil (UC San Diego). A key finding was that top predators in the California Current Ecosystem have access to a range of low- to high-energy forage over space and time that most likely depends on CPS life history traits and species-specific energy storage strategies.

Momma's Larva: maternal oceanographic experience and larval size influence early survival of rockfish was presented by Will Fennie (NOAA Southwest Fisheries Science Center & UCSC). A main point was that the oceanographic conditions female rockfish experience during gestation are related to the quality of larvae produced which affects their early growth and survival.

Juvenile Albacore Tuna (Thunnus alalunga) diet variability and resilience in the northern California Current Large Marine Ecosystem was presented by Catherine Nickels (National Research Council). A key finding was that Albacore diets have changed over time whether characterized by

number, weight, or energy content but diets have similar energetic values despite differences in prey composition.

Diet and Feeding Niche in Larval Rockfishes (Sebastes spp.) of the Southern California Bight: Implications for Recruitment Success was presented by Kamran Walsh (Scripps Institution of Oceanography, UCSD). A main point was that larval rockfishes selectively feed on Calanoid nauplii and copepodites, and this selection towards Calanoids increases with ontogeny. Maternal investment may increase the likelihood of survival in late stage larvae by improving feeding capability at age.

Validation of Pacific Sardine annuli in a captive growth experiment was presented by Kelsey James (NOAA Southwest Fisheries Science Center). From this presentation, the assumption that annuli in otoliths are deposited annually in young Pacific Sardine is validated.

Combining scat analyses and fisheries–independent survey to unravel feeding preferences of California sea lions in the Southern California Bight and support ecosystem-based fisheries management was presented by Pierre-Yves Hernvann (NOAA Northwest Fisheries Science Center & University of California Santa Cruz). The multispecies functional response framework presented assesses the differential affinities of sea lions for their prey in the California Current, highlights preference for high-energy content species, and predicts the response of sea lion consumption to changes in key forage species abundance.

California sea lions as samplers of market squid dynamics in the Southern California Bight was presented by K. Alexandra Curtis (NOAA Southwest Fisheries Science Center).

CalCOFI Tribute

Sam McClatchie, FishOcean Enterprises Ltd

Sam McClatchie described the contributions of Ralf Goericke to the CalCOFI program in a short presentation to honor Ralf's retirement. Sam shared Ralf's connections to family, the outdoors, and the CalCOFI program. Ralf may have spent years of his career at sea, advocating for CalCOFI, and collaborating with many different colleagues. He contributed substantially to the State of the California Current Report and developed interesting subsurface plots of anomalies like ocean temperature and mixed layer depth.

Ralf Goericke (center) gives a speech in response to Sam McClatchie's (not pictured) presentation honoring Ralf's contributions to the CalCOFI program

Keynotes: Innovations in Fisheries Management

Leveraging ecological indicators improve fisheries recruitment forecasts

Eric Ward, NOAA Northwest Fisheries Science Center

Key message: Using stock assessment models from 30 species on the west coast, we tested whether larval fish survey indices or environmental variables are useful at short term forecasts of recruitment; there are a number of species where this approach improves forecast skill.

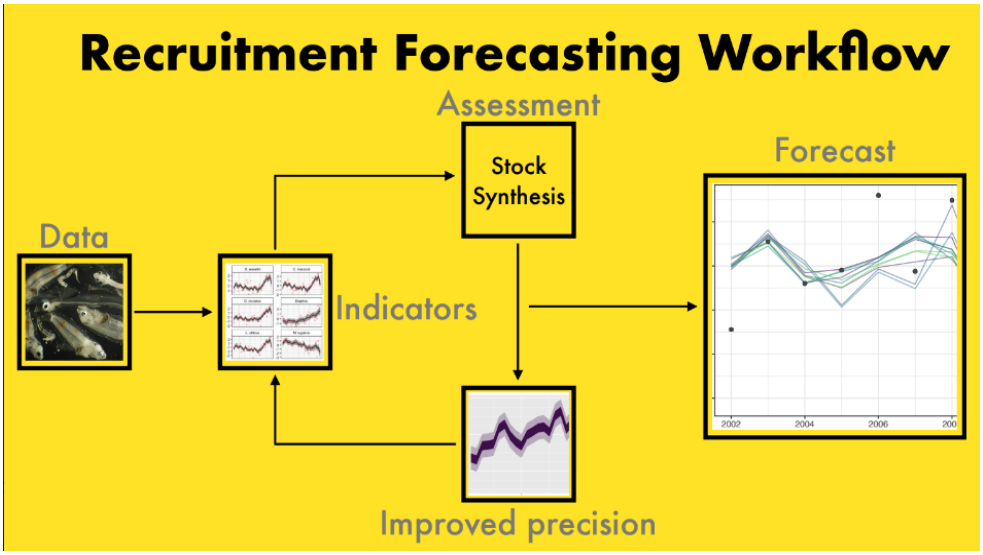
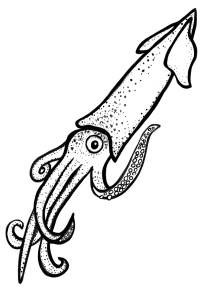


Figure from the presentation by Eric Ward, NOAA NWFSC, displaying recruitment forecasting workflow

Interest in ecological forecasting has rapidly increased over the last decade, with both data and methodologies evolving to meet the complex challenges of making predictions in a non-stationary world. Predicting future fish productivity or recruitment has been a focus of forecasting efforts in fisheries for the last century; this remains inherently difficult because recruitment time series are often short, they are produced from model estimates that are subject to error, mechanistic understanding of drivers is often limited. We assembled a dataset of 30 U.S. west coast groundfish stock assessments, and performed a short term (1–2 year) forecasting comparison across statistical models (parametric, non-parametric) and predictor variables to predict future recruitment deviations. Predictor variables included larval fish indices from CalCOFI and the Rockfish Recruitment and Ecosystem Assessment Survey, ROMS oceanographic model outputs, and derived ecosystem state indices (via dynamic factor analysis). Including a wide range of assessed species allows us to identify populations with skillful recruitment forecasts. Similarly, comparing statistical models or predictor variables is useful for identifying the most robust approaches for performing forecasts. Our results show that for 10 populations in our analysis, recruitment deviations can be forecast with some degree of skill ($R2 > 0.7$). We find that for the majority of these populations, larval fish indices from the CalCOFI survey offer the best predictive skill (lowest RMSE) – and in all cases, multivariate linear models outperformed more complicated approaches. Finally, we discuss caveats of this overall approach, as well as future research to better link these approaches with assessment tools.



Applications of time series data to explore California market squid fishery and environmental dynamics using empirical dynamic modeling

Katie Grady & Julia Coates, California Department of Fish and Wildlife

Key message: Market squid fishery is routinely the largest and most valuable fishery in California. Novel assessment techniques, untapped time series data, and stakeholder engagement are being utilized to inform management of this complex short-lived stock.

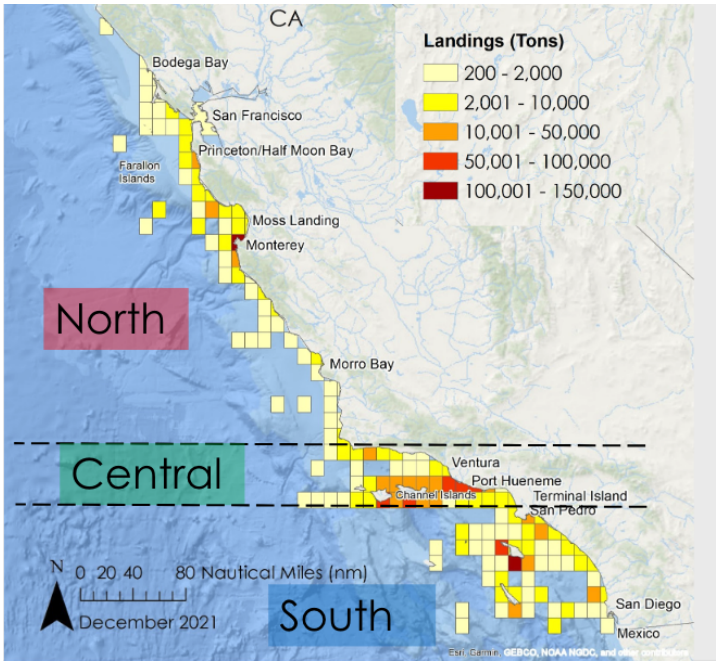


Figure from the presentation by Katie Grady & Julia Coates, CDFW, showcasing the landings of the market squid fishery

The market squid fishery is routinely the largest commercial fishery in California in terms of both landed volume and value. Market squid are terminal spawners, and like many short-lived species, exhibit rapid growth and population turnover, thus have highly variable abundance driven largely by environmental conditions. Empirical dynamic modeling (EDM) is a data-driven approach that is ideal for analysis of stocks like squid. EDM does not require model specification, assumptions, or prior knowledge of system dynamics. Instead, it is used to make predictions based on patterns in time series data. This allows for the full system complexity to emerge, unbiased by predetermined model equations.

Fortunately, the California market squid fishery is relatively data rich with available information including landings, logbook effort data with high spatial specificity, detailed biological information from dockside sampling, and larval abundance surveys. In efforts to inform market squid fishery management and stakeholder deliberations, this presentation explored preliminary investigations using EDM including: (1) forecasts of landings informed by fishing effort and larval abundance at relevant temporal and geographic scales, (2) temperature data to evaluate climate impacts on squid, and (3) fishery effort scaling to compare the performance of management control rules. Findings suggest good prediction accuracy, particularly when using data post-2005 with the R2 of leave-one-out analyses yielding 0.60, 0.61, and 0.53 for northern, central, and southern fishery regions, respectively. In addition, CalCOFI larval abundance data can improve accuracy. The results presented suggest that the current amount of fishing effort maximizes yield, particularly in the northern Channel Islands region. Temperature impacts yield and the effort level at which it is maximized. This indicates the ability of EDM to tease out complex spatial and temporal dynamics and highlight long-term survey information of greatest value.

Keynotes: Innovations in Water Quality & Ocean Observing

The road to eDNA method adoption for marine biomonitoring

Susanna Theroux, Southern California Coastal Water Research Project (SCCWRP)

Key message: eDNA method adoption requires coordinated optimization and harmonization across monitoring programs.

The use of environmental DNA (eDNA) for marine biological surveys has accelerated rapidly in the past decade. However, the adoption of eDNA methods for informing environmental management decision-making has lagged these scientific advances. Environmental managers are faced with adapting novel eDNA technologies to pre-existing monitoring programs, and in the process can encounter obstacles related to lack of DNA method standardization, lack of data reporting standards, and lack of lab accreditation procedures.

In an effort to accelerate the adoption of eDNA methods for routine biomonitoring and bioassessment, workgroups such as the California Molecular Methods Workgroup, Better Biomolecular Ocean Practices (BeBOP) programme, and the Southern California Ocean Biomolecular Observing Network (SoCal-OBON) are working to harmonize eDNA sampling and analytical protocols and data reporting standards. This presentation described the efforts of these workgroups to bring together a diverse community of researchers and managers to enhance coordination across monitoring programs, perform intercalibration and optimization studies, and identify best practices and standardized protocols. In addition, the 2022 National Marine eDNA Workshop emphasized the need for a national strategy to eDNA method adoption and current efforts to scale international collaboration on eDNA method standardization.

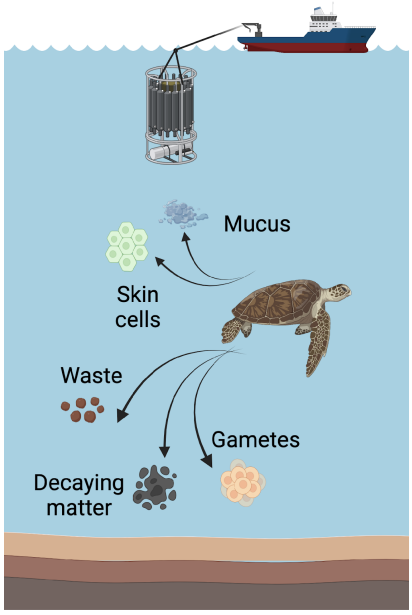


Figure from the presentation by Susanna Theroux, SCCWRP, showcasing the ways that eDNA gets into the environment

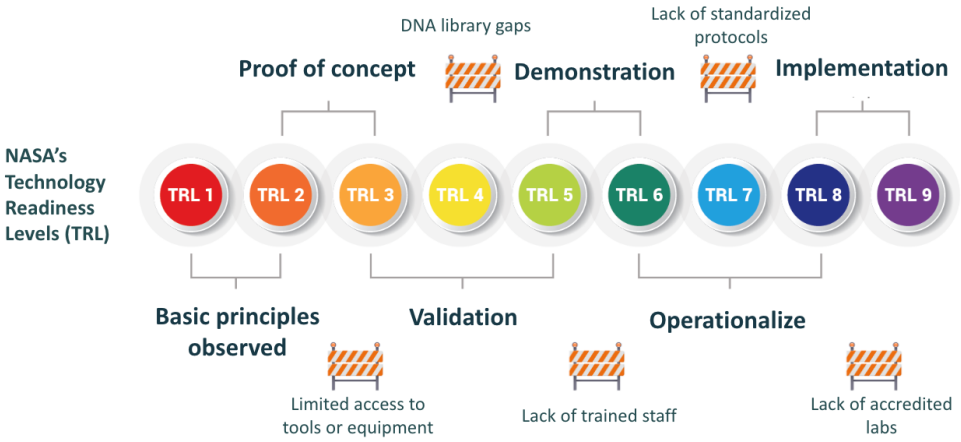


Figure from the presentation Susanna Theroux, SCCWRP, showcasing the roadblocks to the adoption of eDNA methods for informing environmental management

How the Southern California Coastal Ocean Observing System Envisions Building An End-to-End Ecosystem Observing System

Megan Medina, SCCOOS

California's coastal ocean is undergoing drastic changes due to climate variation and change. In the past decade, marine heatwaves have become more persistent and extreme. Luckily, upwelling and mixing have attenuated some warm temperatures nearshore. The near-fully realized glider network envisioned by West Coast ocean observing leadership (formerly PacOOS) provides high-quality time series data needed to track anomalous conditions and to deliver information in near-real time. Moorings provide continuous, fixed-point observations required for model validation and to track change over time. Models, particularly assimilative and with a biogeochemical and ecosystem component, enable responsive decision-making.

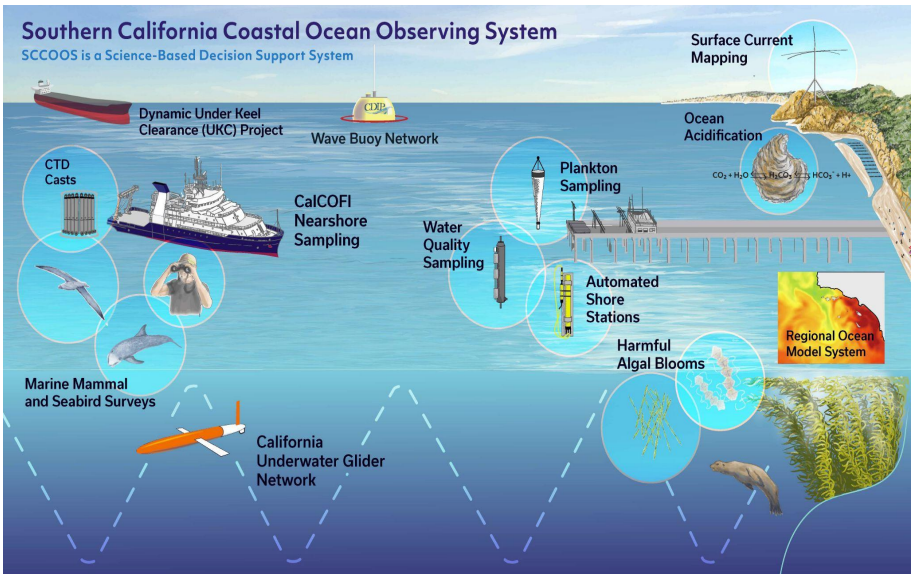


Figure from the presentation by Megan Medina, SCCOOS, showcasing the assets of the Southern California Coastal Ocean Observing Systems (SCCOOS)

Contributed Talks: Part III & IV

New lenses may provide novel insights on fish recruitment was presented by Andrew Thompson NOAA/SWFSC. A main point of this presentation was that we are getting closer to finally understanding the drivers of small pelagic fish population dynamics.

Integrating and harmonizing molecular observations in support of sustainable marine management through the proposed Southern California Ocean Biomolecular Observing Network (SoCal-OBON) was presented by Zachary Gold (CalCOFI/SCCWRP). The Southern California Ocean Biomolecular Observing Network's (SoCal-OBON) primary objective is to provide an unprecedented resolution of key ecological indicators across space, time, and trophic levels relevant to marine management.

Zooglider across the California Current Ecosystem: insights from in situ imaging of zooplankton integrated with active and passive bioacoustics was presented by Mark Ohman (Scripps Institution of Oceanography). A main message of this presentation was that in situ

Zachary Gold, CalCOFI/SCCWRP, presents on the Southern California Ocean Biomolecular Observing Network (SoCal-OBON)

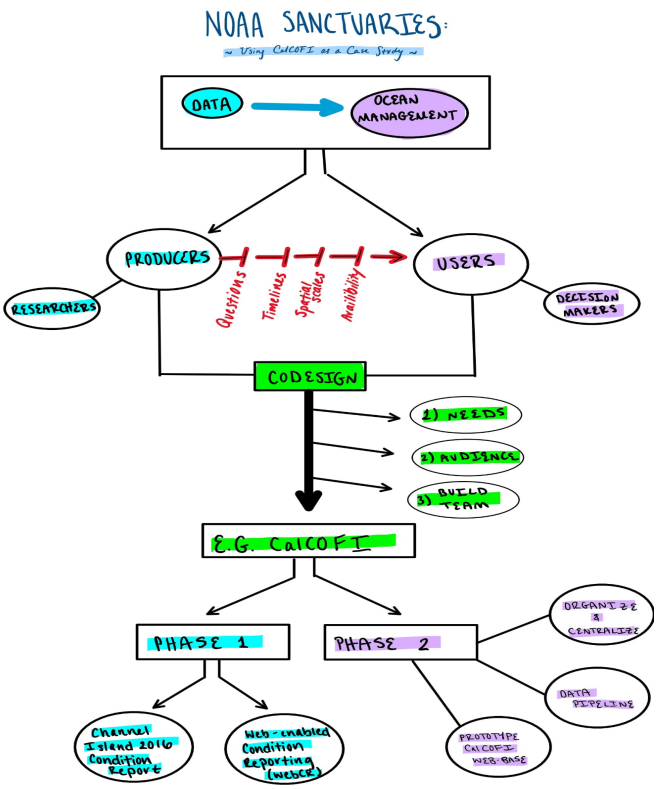
imaging and bioacoustic sensing with the autonomous Zooglider provides measurements on the scale of interaction of zooplankton with their predators and prey.

Spatiotemporal patterns of growth potential explain interannual recruitment variability for an ecologically important fish species of the central California Current System was presented by Mark Morales (University of California Santa Cruz). For this work, a coupled biophysical individual-based model was used to simulate somatic growth of an ecologically important marine fish species. Spatial climatological growth patterns are related to the distribution of spawning grounds and pelagic juvenile catch rates. Spatiotemporal statistics of growth patterns significantly explain a large proportion of an empirical-based recruitment time series.

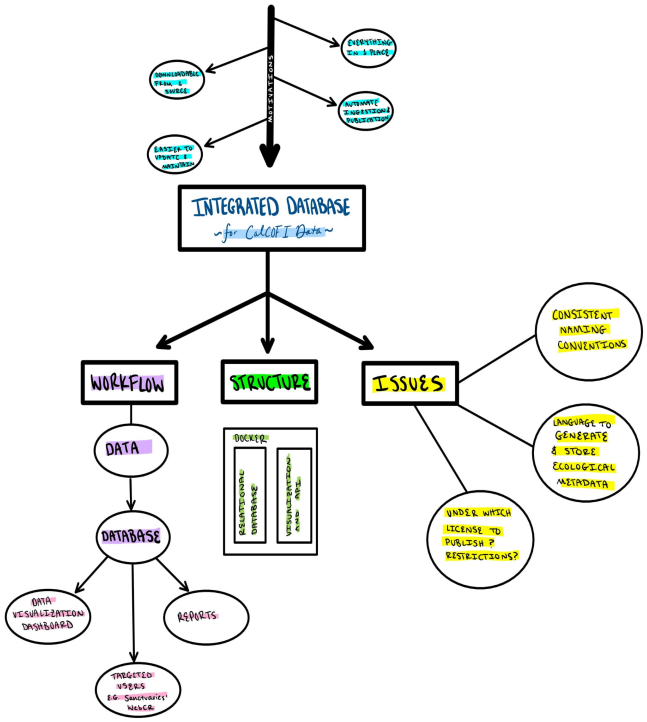
Investigating How Physiological Responses to Temperature Propagate Through Oceanic Food Webs Using Ecosystem Models was presented by Jacob Snyder (NOAA & The Pennsylvania State University). A key finding was that the indirect effects of temperature within a food web setting were greater on high trophic level predators than direct effects of temperature on species individually. Some species exhibited increased productivity under increasing temperatures, necessitating investigation of how competitive advantages may change.

Expanding CalCOFI: Meeting Multiple Mandates for Resource Management was presented by Ryan Freedman (NOAA Office of National Marine Sanctuaries - Channel Islands). A main point of this work was that expanding CalCOFI sampling can address additional government resource management needs.

CalCOFI data products for tracking and reporting change in sanctuary ecosystems was presented by Jennifer Brown (Channel Islands National Marine Sanctuary). A main point of this work was that data can be packaged and visualized in different ways depending on the audience, especially related to users technical expertise and needs.

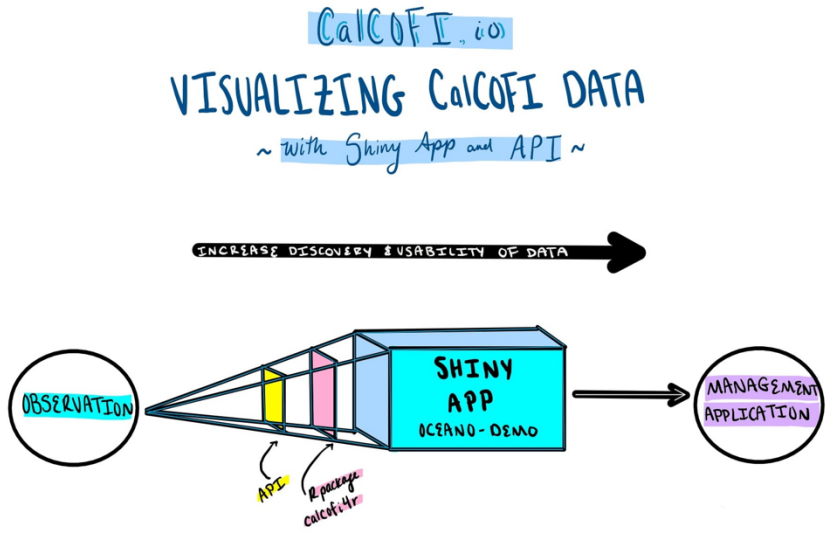


An artistic overview drawn by Jacob Schmidt of Jennifer Brown's, CINMS, presentation on CalCOFI data products for tracking and reporting change in sanctuary ecosystems



An artistic overview drawn by Jacob Schmidt of Marina Frants', CalCOFI/CCE-LTER, presentation on developing a central, integrated database for CalCOFI data

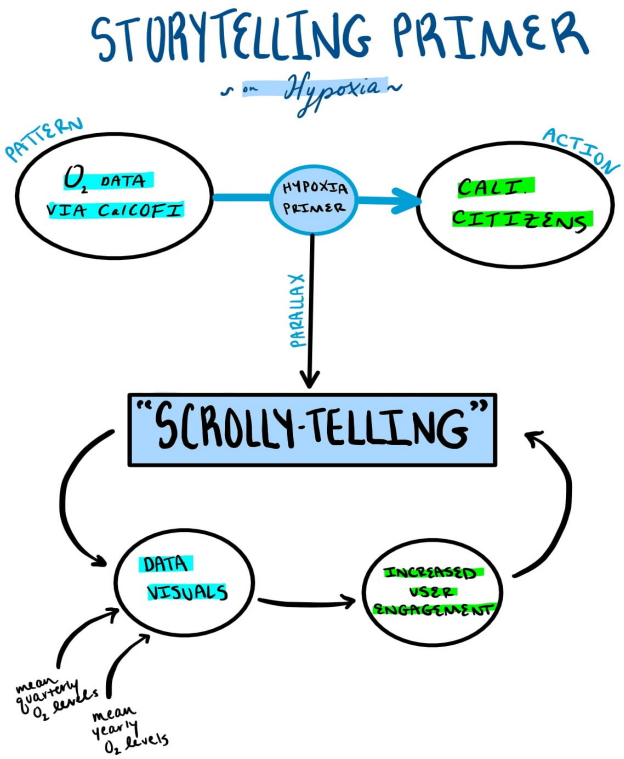
Developing a central, integrated database for CalCOFI data was presented by Marina Frants (Scripps Institution of Oceanography). Overall, a centralized Postgres SQL database is being developed to host data collected on the CalCOFI platform.



An artistic overview drawn by Jacob Schmidt of Benjamin Best's, EcoQuants, presentation on fetching and visualizing CalCOFI with the new Shiny App, R package, & API

Fetching and Visualizing CalCOFI Data with the new Shiny App, R package and API was presented by Benjamin Best (EcoQuants). CalCOFI data can be fetched and visualized with the new Shiny app, R package and API which are available at CalCOFI.io.

A scrollytelling primer on hypoxia: Developing a data storytelling tool to communicate ocean observing data to California citizens was co-presented by Mallika Gupta & Annie Adams (CalCOFI & California Sea Grant, Scripps Institution of Oceanography, UCSD). A main point of this presentation was that scrollytelling data products are engaging educational tools that can contextualize the stakes around an environmental issue, demonstrate the value of previous research, and encapsulate the necessity of future calls to action.

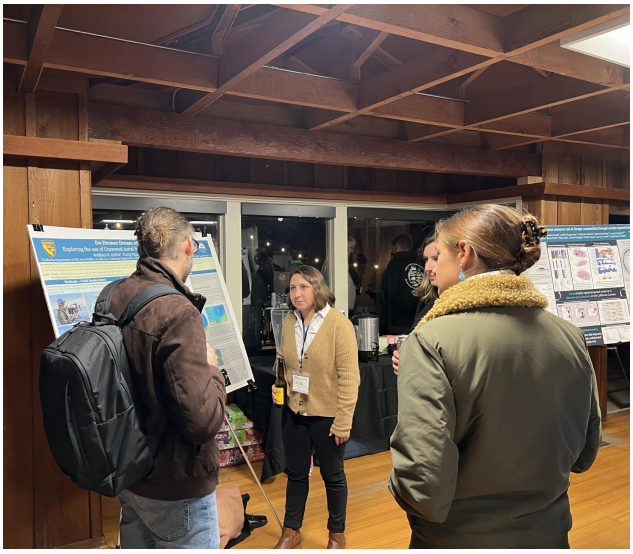


An artistic overview drawn by Jacob Schmidt of Mallika Gupta & Annie Adams, CalCOFI, presentation on a scrollytelling primer on hypoxia using CalCOFI data




Poster & interactive sessions

Nearly 20 participants presented their work through a poster or interactive exhibit during the even



Workshops

The CalCOFI Conference workshops provided a valuable, interactive opportunity to bring together the conference participants around shared interests, goals, and priority topics, build partnerships, and gather input. The workshops were forward-looking and provided a space to discuss, interact, share, and explore together. The workshops consisted of three concurrent sessions related to eDNA, pollutants, and fisheries described below.

Southern CA Ocean Biomolecular Observing Network Workshop: Coordination & Integration Strategy

This workshop was co-led by Zachary Gold (NOAA Pacific Marine Environmental Laboratory), Susanna Theroux (Southern California Coastal Watershed Research Project), and Andrew Thompson (SWFSC, NOAA).

Key to the success of harmonizing ocean monitoring across ocean observing platforms is the standardization of molecular sampling efforts. The Southern California Ocean Biomolecular Observing Network's (SoCal-OBON) objective is to provide an unprecedented resolution of key ecological

indicators across space, time, and biodiversity relevant to marine management. To achieve this, the Network will integrate the suite of existing ocean observing platforms bridging nearshore and offshore biomonitoring efforts and apply standardized molecular approaches to best characterize biological communities and their response to environmental change across the Southern California Bight. This leveraged effort will combine physical and chemical measurements, advanced ocean imaging technologies, and molecular biomonitoring approaches to provide the ecological resolution needed to 1) understand the interplay of water quality and climate driven ocean acidification/hypoxia impacts on biological communities, 2) allow for the identification and forecasting of HABs, 3) better inform fisheries management through the identification of trophic and oceanographic drivers of assemblage dynamics, and 4) map spatio-temporal distributions of protected species.

This was the third of a series of scoping meetings to identify priority objectives that will leverage regularly occurring conferences that have strong stakeholder buy-in and attendance. This workshop builds off of the 2nd National Marine eDNA Workshop and Bight '23 workshops to bring together key SoCal-OBON stakeholders to address the operational and scientific challenges of multi-platform interoperability.

The goals of the workshop were to convene representatives from local, state, and federal management agencies; industry representatives; and academics to 1) identify operational, methodological gaps between current monitoring efforts, 2) identify key management questions of concern and prioritize biodiversity targets to address them, 3) coordinate the design and validation of molecular assays for priority targets, and 4) plan and coordinate leveraged studies to compare current sampling practices and identify key sources of platform specific sampling methodology disagreement.

The workshop brought together representatives from Bight program (SCCWRP and partner agencies), CCE LTER, SCCOOS, SCB-MBON, CalCOFI and NCOG, Scripps Ecological Observatory, SWFSC Juvenile Rockfish Survey, NOAA AOML, and NOAA PMEL. The workshop participants coalesced on two main priority projects as a group:

1) Characterizing the impacts of warming, ocean acidification, and hypoxia on Southern California Current marine ecosystems and

2) Development of comprehensive reference databases for key taxa of interest.

In addition, the workshop participants highlighted the value of harmonizing sample collection and processing methods as well as the conduction of an inter-calibration exercise on the enhanced CalCOFI cruise that occurred in September 2022. Both exercises will allow for the development of SoCal-OBON standard operating procedures and integration of data sets.

Key immediate deliverables and objectives were related to:

a) processing and analysis intercalibration efforts to inform standard operating procedure and harmonization efforts,

b) sequencing of zooplankton taxa from archived CalCOFI bongo net tows to determine their value,

c) identifying and applying for sources of funding to support SoCal OBON efforts, and

d) begin discussions and efforts to integrate already generated datasets

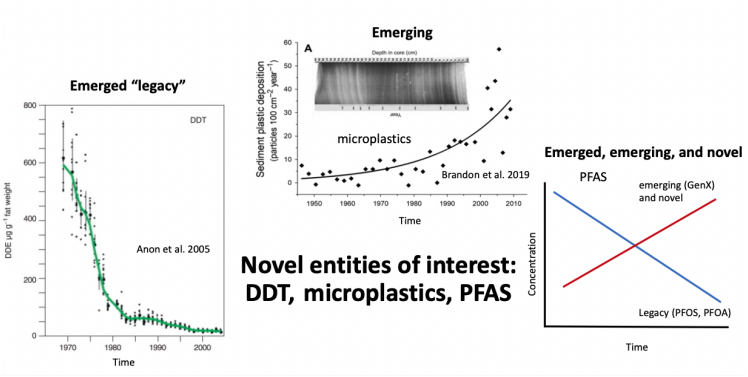
Ultimately, the direct comparisons of molecular methodologies spawned from this meeting will provide the baseline intercalibration data needed to identify current operational gaps between observing platforms and help inform best practices needed for successful integration of molecular biomonitoring efforts. The results and outcomes of integration efforts will directly inform the national NOAA Strategic Molecular Strategy and CA Ocean Protection Council Ocean Monitoring Plan, serving as a template for strategic integration of molecular ocean observing worldwide.

Incorporating & coordinating pollutant time series into a California pollutant monitoring program

This workshop was led by Matthew Savoca (Stanford University) and co-led by Erin Satterthwaite (CalCOFI), Karen McLaughlin (SCCWRP), and Amalia Almada (USC Sea Grant). The environment is contaminated by hundreds of thousands of legacy, emerging, and novel synthetic compounds that are persistent in the environment on scales of decades to centuries. Long-term datasets are essential to uncover patterns over time as synthetic chemicals are introduced, regulated, and phased out of production. At the same time there are numerous compounds of unknown origin, use, effects, and fates that have permeated marine systems. Long term monitoring datasets, such as CalCOFI, SCCWRP Bight Monitoring Program, and SWAMP, provide unparalleled temporal resolution of planktonic organisms in the Southern California Bight to delve into questions related to the chronology of contaminants in this ecosystem. The purpose of this roundtable is to explore current efforts to understand pollutant monitoring in CA (e.g., DDT+, PFAS, microplastics), understand what samples exist for contaminant analyses, understand opportunities for longer term/consistent sample collection, and how to develop a collaborative, statewide sampling paradigm moving forward that leverages existing pollutant monitoring efforts and incorporates pollutants into existing time series programs. We will also allot time to discuss possible mechanisms to fund this work, exploring the potential for a future proposal. The goals of the workshop were:

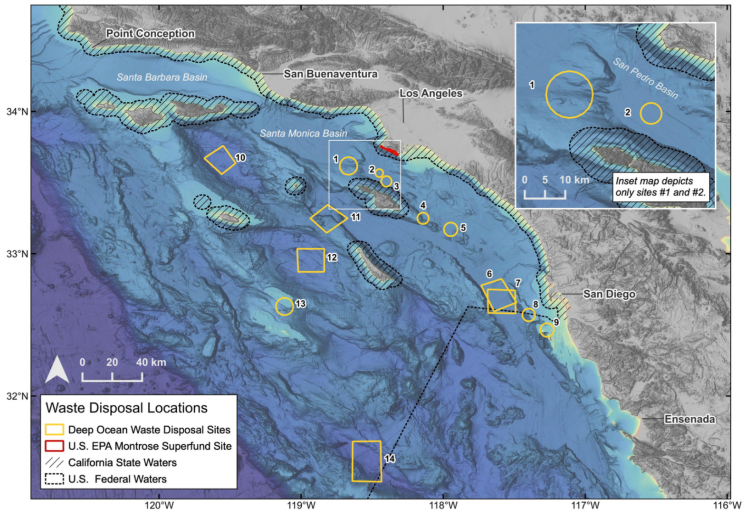
- Explore the legislative drivers for pollutant monitoring related to the case studies below in CA Review what pollutant studies and more long-term efforts have been conducted from existing pollutant monitoring/observing systems in CA
- Discuss what capabilities exist within our networks & existing programs to provide and process samples for which pollutants
- Consider pollutant studies that could be conducted using archived CalCOFI samples
- Propose sample collection framework for future CalCOFI cruises to use for pollutant studies
- Brainstorm ways to fund this work which includes analysis as well as coordination of living database/platform of available samples and/or interested community of practice

The workshop started with Matt Savoca giving an overview presentation of the morning ahead. The main points he raised were: 1. There are numerous crises facing the environment in the Anthropocene, and tracking the flow and effects of anthropogenic chemicals in the environment is worth more scientific and public attention than it receives (i.e., elevating this issue to the level of climate change and biodiversity loss). 2. This workshop provides a unique opportunity to link those studying pollution to those who have knowledge and access to long-term monitoring/observing programs. 3. Combining this with recent legislative drivers (and funding) to understand and ameliorate chemical pollution at state and federal levels is a powerful and rare opportunity.

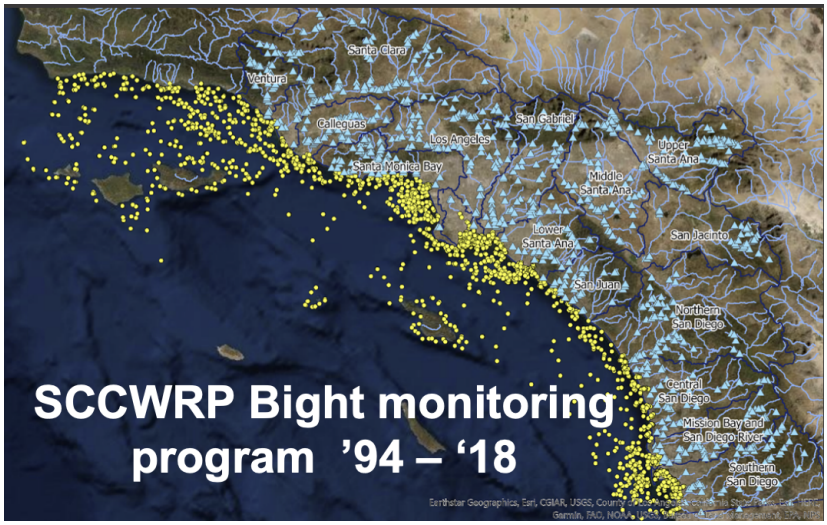


Following the opening, Scott Coffin gave a presentation focused on recent state bills related to pollutants, specifically SB 1263, 1422, and 54. He mentioned that it took a lot of effort to define terms of reference when discussing what microplastics even are. The definition they landed on was, "solid polymeric materials to which chemical additives or other substances may have been added, which are particles which have at least three dimensions that are greater than 1 nanometer and less than 5,000 micrometers. Polymers that are derived in nature that have not been chemically modified (other than by hydrolysis) are excluded." He also reviewed what's on the horizon for the state for PFAS as well. The most common PFAS is Teflon in things like Gortex, cooking utensils, fire fighting foam etc. The State Water Board is using many methods for PFAS monitoring, including both targeted and non-targeted analysis. Scott also discussed his web-based applications to improve plastic pollution research: Tomex (https://microplastics.sccwrp.org) a living R Shiny microplastic risk assessment database and Plastiverse.org which includes plastic literature and more. The State is working with SCCWRP to develop and certify labs around the state for microplastic analysis as required by recent state bills. The State wants better monitoring data, see the OPC Statewide microplastics strategy. The Microplastics Monitoring Subcommittee meetings may be of interest and they are open to all and meet quarterly.

Next, Lian Guo and Amalia Almada presented on their recent DDT stakeholder work. In addition to the known DDT dumping off the Palos Verdes Peninsula, there were recently rediscovered deep barrel dumping sites between the Palos Verdes Peninsula and Santa Catalina Island. Between 2022-2025 there is $11M in federal funding allocated to determine the impact of this dumping and mitigate its effects. Lian and Amalia led a Research Needs Assessment for the community via engaging with local stakeholders and the general public. The major findings of their community engagement scoping report was related to the need for: California Deep Ocean DDT+ Community of Practice, data needs assessment (to follow the research needs assessment), living catalog of archived samples and DDT+ research programs, and data quality assurance, quality control and standardization.



Karen McLaughlin presented on the SCCWRP Bight Program, which is an integrated, coordinated monitoring program started in 1994 to answer basic questions about environmental status and trends not captured any other way. For some the Bight Program is a regulatory mandate, so they have to participate which helps provide leverage for other non-mandated participants. SCCWRP Bight Program is a national model, and it's the people's program, answering questions that the people in the program need answered. The Bight Program provides consensus assessment, since no single agency can alone which is very powerful. One of the greatest values of the program is the standardization and extensive intercalibration. Nearly 200 participants from all sectors test for: sediment quality, HABs, microplastics, microbial pathogens, submerged aquatic vegetation (SAV), water quality (OAH), sport fish tissue pollutants (Safe to Eat collaborative working group).



Finally, Noelle Bowlin gave an excellent talk on the history of CalCOFI and how the cruises work, including: when sampling occurs, how the CalCOFI sampling grid has changed in space and time, what exists in the stored collections to be sampled, how these samples are stored, and what might be possible for CalCOFI cruises to sample in the future, regarding pollutants, and showed the amount of

effort it takes to go from the retrieval of a net at sea to the cataloging of a sample in the CalCOFI collection. She also shared an essential paper showing many standardized oceanographic/ecological surveys that we may draw data from, beyond just CalCOFI.

The workshop concluded with the observation that the group is well positioned to mobilize quickly if and when relevant potential funding calls are announced and to keep the community developed during this workshop going forward.

Integrating ecosystem observations and recruitment forecasting into fisheries assessment and management

This workshop was co-led by Eric Ward (NOAA NWFSC) and Brice Semmens (CalCOFI/SIO) and was focused on methods and ideas around recruitment forecasting methodology and links to fisheries management. Understanding the environmental drivers of fish recruitment has been a major area of research for more than a century. In an era of non-stationary ocean conditions, quantifying these relationships is essential for robust management of fish populations. At the same time, new modes of observation, combined with robust long-term monitoring programs, continue to generate increasingly complex fisheries and ecosystem data streams. Recently, a number of studies have demonstrated that fish recruitment can be forecasted over short periods of time using covariates related to larval densities, data from similar species, and/or raw or derived environmental time-series. A variety of emerging computational methods have also been used to improve forecasts and assess their skill, including linear, non-linear and non-parametric approaches. While the forecasting skill of these methods can be surprisingly high, the path towards using these forecasts within traditional fisheries stock assessments remains unclear. Challenges include dealing with large numbers of possible environmental drivers, non-stationary relationships, complex estimation models that already integrate many data sources, incorporating non-parametric methods into stock assessment's likelihood-based framework, and the sometimes weak relationships between single drivers and recruitment.

Following recent workshops and reviews, including the 2019 CAPAM workshop on best practices for modeling recruitment in fisheries, there is a clear need to better understand and link environmental drivers and external information to recruitment in fisheries assessment models (Sharma et al. 2019). Recruitment is perhaps the most obvious case where these data may be informative (Haltuch et

North American West Coast monitoring programs

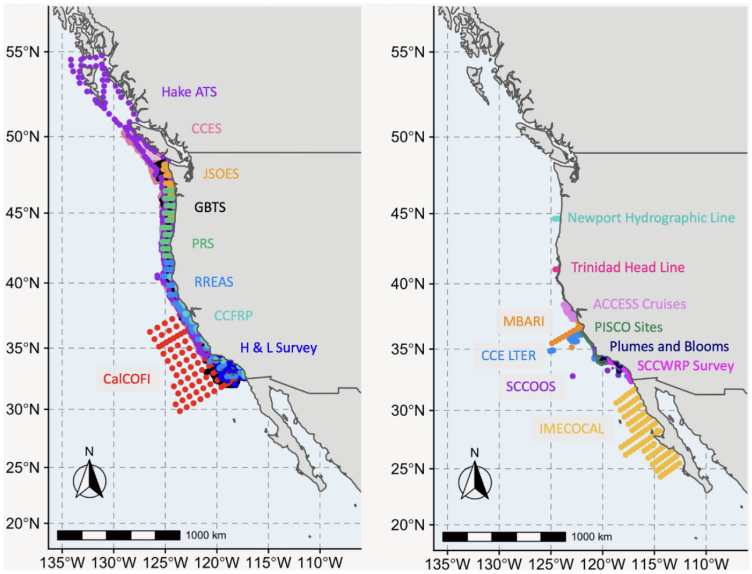


Figure from: Gallo et al. *Front Mar Sci* 2022

al. 2019). Further, this type of modeling may be also useful at elucidating mechanisms between climate and population processes (because of the lack of time lags that allow for other processes, such as movement, to be confounded). On the west coast of the US, a number of assessments have used larval (CalCOFI) or juvenile (RREAS) indices of abundance as recruitment time series (with associated standard errors); examples include boccaccio, chilipepper rockfish, shortbelly rockfish, cowcod, canary rockfish, blue/deacon rockfish, widow rockfish, and black rockfish assessments. At least one assessment has included an environmental variable– a SSH indicator was included as a recruitment indicator in the most recent sablefish stock assessment (ROMS variables will be explored for petrale sole in 2023).

The goals of this workshop were to discuss emerging recruitment prediction tools and brainstorm methods for incorporating prediction into fisheries management workflows, including but not limited assessment methods. The workshop was structured as a 3 hour meeting, divided into 3 topic areas, including: 1. Modeling background, 2. Integrating recruitment predictions into assessment models, and 3. Management onramps with Fisheries Management Council decision making. This was followed by a discussion around conclusions and recommendations for next steps. The findings are detailed below.

Modeling background

Overview. Quantifying recruitment for many fish populations is difficult, and in the absence of independent datasets, many approaches have relied on treating the recruitment deviations from assessments as response variables. There are a number of challenges of this approach that have been pointed out by Brooks & Deroba (2015) and Giron-Nava et al. (2020), among others. Importantly, all quantities derived from stock assessment models are imperfect, limited both by data and model assumptions. On the west coast of the US, assessments are generally implemented with the Stock Synthesis framework, where recruitment is assumed to be stationary (and usually) stochastic under a Beverton-Holt relationship. The assumptions of Beverton-Holt recruitment are necessitated by the need for a density dependent relationship, which is in turn required to estimate reference points associated with maximum sustainable yield (MSY). Assumptions about stationarity may be relaxed in the future (but requires additional model / code development and is several years away from being implemented). The ability to estimate recruitment deviations is largely dependent on data (specifically age / size composition data) – without these data, recruitment is largely driven by estimates of spawning stock biomass (Stock Synthesis allows recruitment deviations to be not estimated, in which case recruitment is derived solely from the stock-recruit relationship). In cases where direct measures of recruitment exist, but don't agree with compositional data, the compositional data always will dominate within the stock assessment framework (Kiva Oken's presentation highlighted an example with Pacific hake, where recruitment deviations are dominated by compositional data, and recruitment deviations are very overdispersed).

Tension between mechanisms and prediction. A consistent theme through several workshops discussions was a tension between the need to understand mechanisms driving recruitment versus the need to make predictions about the future for management decisions (acknowledging both mechanistic and correlative studies can be useful for management). One participant highlighted a report from Lasker (1985) making the point that a large number of processes may be limiting focal species (here, clupeoids), and that rather than trying to understand all drivers, focal questions should include "what limits clupeoids mostly?" and "when in the life cycle does limitation occur?". Understanding mechanisms behind environmental - recruitment relationships is also necessary when these drivers are included in assessments or ecosystem models (several participants gave examples of STAR panels reviewing assessments, or the PFMC process receiving information on ecosystem indicators). Knowledge about mechanisms is useful

for monitoring programs, and helpful in identifying the type of information that these programs should be collecting.

While fully understanding mechanisms can be important, there is also a need to provide reliable forecasts to managers and decision makers. Several of the workshop participants highlighted the role of non-stationary dynamics in the California Current – many of these being driven by climate change (as a caveat, non-stationary linear relationships and stationary non-linear relationships may appear similar). A limitation of recruitment process studies is that any data - driven effort will be several years behind current management efforts; as relationships change through time, relying on historical data may be unreliable in making future predictions (examples highlighted included responding to immediate shocks, such as the 2014-2015 warm blob). In rapidly changing environments, agencies may not have the time or personnel resources to understand mechanistic relationships for a large number of fish species. A second challenge of data-driven approaches is that some processes may be incomplete (or key linkages may be missing) – in these cases, time lags (EDM) or covariate proxies may be sufficient to generate reasonable predictions. For either case, part of the challenge in adopting new methodologies is recognizing the cultural component of the scientific and management processes – and requires socialization and time to change.

Throughout the workshop, several comparisons were made between statistical forecasting models in the technology sector, versus approaches more common in ecology. As a field, ecology is more data limited (our time series being relatively short, e.g. 25-30 years) and affected by relatively large observation errors – because we often lack of data to validate predictions, there is a continued need to rely on mechanistic understanding to refine lists of potential covariates. Several additional ways that participants suggested covariate candidates may be pared down included (1) narrow down time series, such as ROMS, based on uncertainty of model predictions for each variable, (2) focus on time series, including ROMS, that we have good forecast skill for. One challenge of working with ROMS variables is that because they are available at very fine resolution (specific locations, depths, times, and days), species-specific conceptual life history models need to be constructed to identify what time periods, depths, and spatial areas to extract from ROMS model outputs (as in Haltuch et al. 2019, Tolimieri et al. 2018).

Integrating recruitment predictions into assessment models

Overview. There are two general approaches for bringing external data into fisheries assessments: (1) larval / juvenile indices / ROMS variables may be brought in as indices in a likelihood framework (with associated uncertainties), and (2) covariates can drive parameters of the stock-recruit relationship (Maunder and Thorson 2019). For data reasons (no missing values are allowed) , PFMC assessments have exclusively considered the first approach (assessments on other regions relying on other software tools may allow for missing data). However, the new Fisheries Integrated Modeling System that is being developed to replace Stock Synthesis will permit estimation of random effects via laplace approximation, and should make the model-based approach more feasible for assessments in the 2025 or 2027 cycles.

For recruitment indices to be useful in forecasting, they need to be very good predictors of recruitment (several weak predictors will not be useful). Kiva Oken's presentation included an example of the sablefish assessment – while ROMS variables (sea surface height) are included in the final assessment model, recruitment deviations are largely unchanged when ROMS variables are not included in the model. Beyond whether a particular indicator is included or not in assessments (this may partially be driven by personal preferences and / or political reasons), a broader challenge is how best to quantify the

contribution of external factors (quantifying the relative contributions of data sources may be output from Stock Synthesis; another approach is to compare the relative improvement in forecasting ability).

A broad question identified in considering multiple predictors within an assessment model is how multiple predictors or models may be considered. As a first approach, a brute force method was suggested (running many - 1000s of stock assessment models and comparing predictive performance). This approach might be computationally prohibitive (assessment team is small, and may be unable to add more work to their plate). Second, multiple covariates may be done within the existing assessment model frameworks. Ongoing efforts by several workshop organizers are examining the feasibility of these approaches, initially with simulated datasets.

What other kinds of data might be informative? As noted above, recruitment indices from the larval (CalCOFI) and juvenile (RREAS) indices have been used as recruitment indicators within west coast assessments. These indicators have been developed from standardized indices of density data. In addition to densities, there is an opportunity for other information from the larval and juvenile surveys to provide indices of recruitment – examples include recently developed genomics data (eDNA samples collected by CalCOFI starting in 2015), indices representing recruitment quality (other researchers are working prediction of hake recruitment based on size distributions of larvae; Hinchliffe et al. 2021), and exploring spatial relationships (NOAA staff from SWFSC partnering with IMECOCAL to explore these spatial distribution issues in Mexican waters).

What species / assessments are recruitment indices most likely to impact? The impact of a new recruitment index on any assessment is going to be affected by a number of factors, including the existing data already feeding into the assessment model. Species / stocks that are difficult to age (thornyheads being an example on the west coast), and those lacking compositional data might be particularly good candidates for including recruitment indices. In selecting recruitment indices, time series with more precision (higher quality) will have more weight than indices with high uncertainty. However, for stock assessments with limited age composition data that don't have well-informed recruitment deviations, it's unclear how to test the skill of new potential recruitment indices. Beyond the groundfishes explored in the 2022 CalCOFI workshop, there is additional interest in exploring these methods with CPS / HMS stocks.

Management onramps with Fisheries Management Council decision making

A limitation of existing west coast stock assessment procedures is that at best, stock assessments are updated every 2 – 4 years (with some full assessments occurring at 8 – 10 year intervals). Recruitment forecasting work may provide a more intermediate picture of ecosystem responses to climate change. We discussed three potential avenues for recruitment forecasting to inform tactical (short-term) fisheries management decisions: ecosystem status reporting, stock assessment prioritization, and catch advice.

The California Current Ecosystem Status Report (ESR) has historically been focused on species other than groundfish, and recruitment forecasts (numeric ones, or qualitative ones based on terciles) would be useful in filling out the groundfish section of the report. Limitations of the approaches Eric described are that they would ideally be applied to a larger number of stocks, and be automated to allow for annual updates. The emerging FEP initiative may lead to new products co-developed by NMFS and the Council focusing on species-specific or FMP-specific indicators. This may be a promising pathway for developing groundfish recruitment indicators in addition to, or in lieu of reporting them in the ESR.

The number and frequency of groundfish stock assessments on the west coast continues to be limited by capacity (6 – 8 assessments being done every 2 year cycle). NMFS has developed and presented a prioritization framework to the Council for the past four cycles that ranks groundfish species

according to many factors, including fishery importance, biomass trends, and ecosystem importance, among others. Predictions of recent recruitment (qualitative or quantitative) could potentially be incorporated into the prioritization framework, for example, to give more weight to assessing species where there is evidence of ongoing poor recent recruitment. When published, the climate vulnerability assessment could also be incorporated into the assessment prioritization to give more weight to assessing species that are more vulnerable to climate variability and long-term change.

Recruitment forecasts could also be used to directly inform the harvest specifications process. Forecasts could inform harvest levels set through the harvest control rules (e.g., sardine). Forecasts could also inform the magnitude of scientific uncertainty of an assessment (e.g., this uncertainty increases with the age of PFMC assessments) or the Council's risk tolerance for exceeding the overfishing limit. A risk table approach similar to the NPFMC (Dorn & Zador 2020) may be a useful framework to translate recruitment forecasts to levels of uncertainty or risk.

Ecosystem information, including the recruitment forecasts, may be useful at providing advice directly to industry. Examples highlighted by participants included (1) phytoplankton size used to predict bigeye tuna catches in Hawaii, and (2) shortbelly rockfish recruitment being used to understand the relative cohort strength on the west coast of the USA, when shortbelly rockfish was being encountered as bycatch in the hake fishery. Risk tables, as referenced above, may also help to better anticipate these kinds of interactions.

What are the potential best next steps?

This workshop identified two main ways in which recruitment predictions or ecosystem indicators of recruitment may be better linked to fisheries management. The first approach (and lowest hanging fruit) seems to be providing forecasts of recruitment deviations external to stock assessment model development efforts. The benefits of this approach are that recruitment forecasts may be able to provide partial information about population status between assessment cycles (particularly when the environment is changing rapidly and/or when age and composition data are sparse). Challenges of this approach include (1) ground truthing mechanisms that are responsible for correlations identified between indicators and recruitment, and (2) examining a broader suite of environmental drivers (e.g. more ROMS predictors) for the stocks that are not well explained by existing predictors (e.g. in Eric Ward's presentation, only 8-10 sets of recruitment deviations of the 29 assessments used result in forecasts with high skill). Future work will also examine the utility of empirical dynamic modeling (EDM) to forecast recruitment deviations, using time lags in lieu of covariates. For process-based recruitment studies, future work will aim to utilize existing datasets to develop better measures of recruitment (Andrew Thompson's work examining young of the year anchovy, hake, and sardine time series from the RREAS survey, or size - frequency data for anchovy, sardine, and hake from CalCOFI larvae).

A perhaps more challenging link to fisheries management involves incorporating additional recruitment indicators into fisheries assessment models. Recent simulation approaches (Kiva Oken referenced these in her presentation) have suggested that in data rich cases, additional recruitment indicators may not change assessment outputs in a meaningful way, but they can still be useful in reducing uncertainty in recruitment in the most recent few years of an assessment and potentially in the forecast period, depending on the life history of the species and selectivity-at-age in the survey and fishery. Additional simulations are needed however – specific examples include (1) simulating a large number of scenarios varying the data type and quality, and (2) evaluating new estimation approaches, particularly for incorporating multiple drivers into an assessment.

Future directions

Following the 2022 CalCOFI workshop, a symposium on recruitment forecasting will be organized at the 2023 PICES meeting (October 2023, in Seattle). This meeting will draw expertise from a broader geographic area, incorporating researchers with diverse perspectives and using different datasets and methodologies beyond the west coast of the US.

Pier & Collections tours

Each day during lunch, Kevin Walsh and Linsey Sala took conference participants on tours of the pier and Pelagic Invertebrate Collections.

Receptions & networking

Each evening of the conference there was a reception with food, music, and networking. Additionally, there was an opportunity to send a postcard from the CalCOFI conference.

Acknowledgments

We are grateful to all conference participants, the invited speakers, contributed talks & poster presenters, panelists, and workshop leads, for making this a successful conference. We are especially grateful to our amazing volunteers who helped with all aspects of the conference.

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Report Preparation & Materials

This report was prepared by the CalCOFI Coordinator (Dr. Erin Satterthwaite) with input and feedback from the CalCOFI Committee (Drs. Brice Semmens, Noelle Bowlin, Julia Coates, Rasmus Swalethorp, Andrew Thompson, and Briana Brady) and from conference speakers and moderators.

To find all materials, including abstracts, associated with the 2022 CalCOFI Conference, please visit the CalCOFI website (https://calcofi.org/conference/conference-2022/).

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