Are current ocean observation networks adequate? A model for cooperative observation programs as the basis for ecosystem-based management, ocean climate research and assessment of ecosystem change

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Why are ocean time series so important?

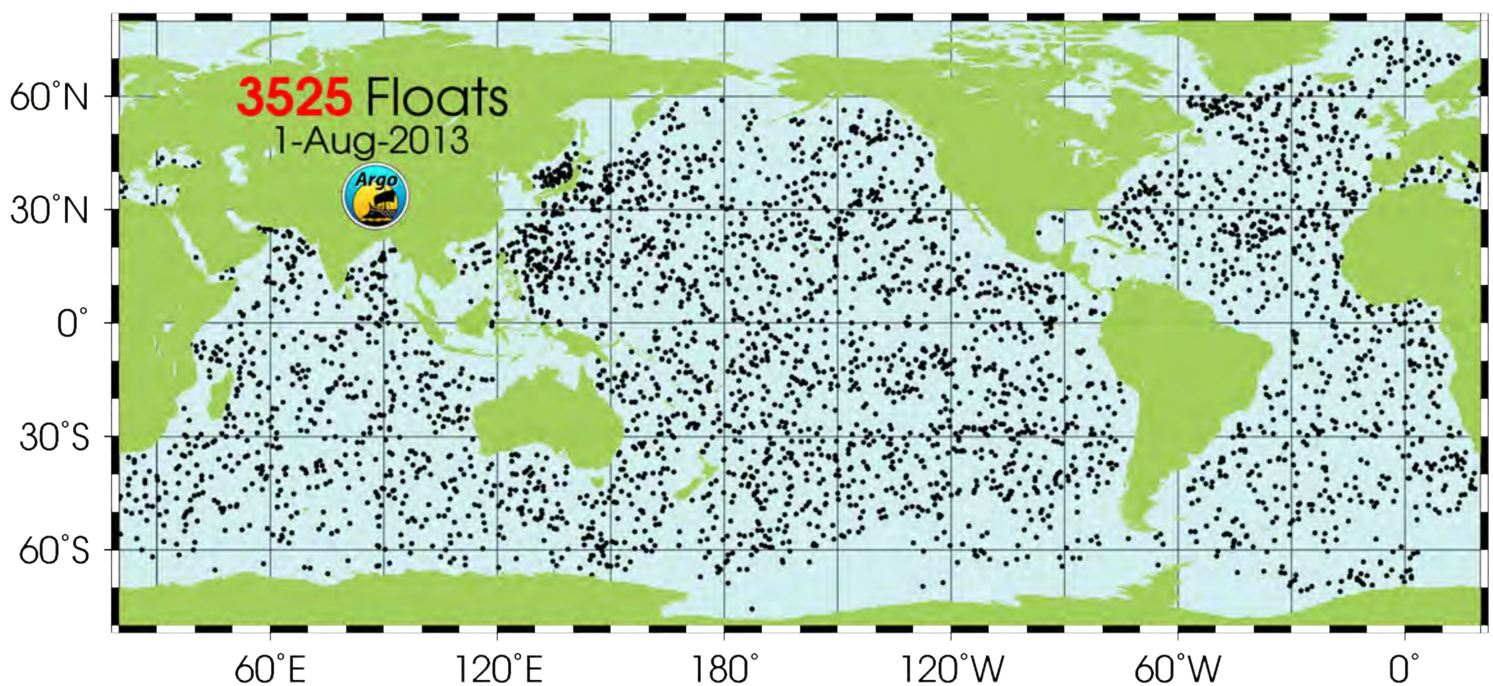
- The oceans today are subject to a host of anthropogenic stressors:
  - impacts of (over)fishing, energy and mineral extraction, nutrient runoff —> eutrophication & coastal dead zones, invasive species, pollutants, warming, acidification, deoxygenation….
- The oceans are also subject to natural variability on various time-space scales:
  - ENSO cycle, PDO, NPGO
- To distinguish secular change from natural variability requires multi-decadal time series. For ecology, species-level resolution required for core groups
- The UN's 1st World Ocean Assessment (WOA) due to be completed in 2014

How are we doing?

- Meta-analysis conducted of Pacific Ocean observation programs:
  - What is measured, how, & for how long?

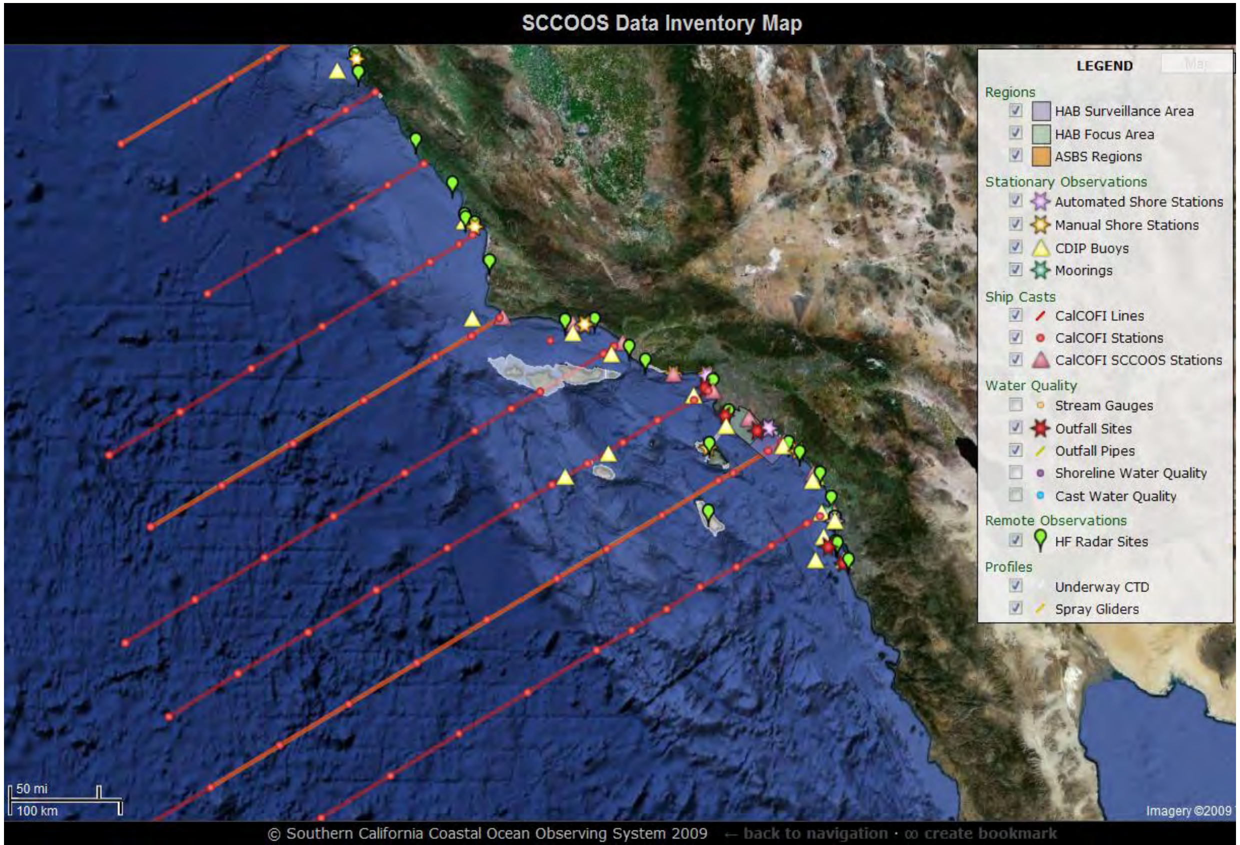
Global GOOS

GOOS established in 1990s
Notable successes in global programs that measure readily quantified variables (e.g. T, S, chl), with satellites, Argo



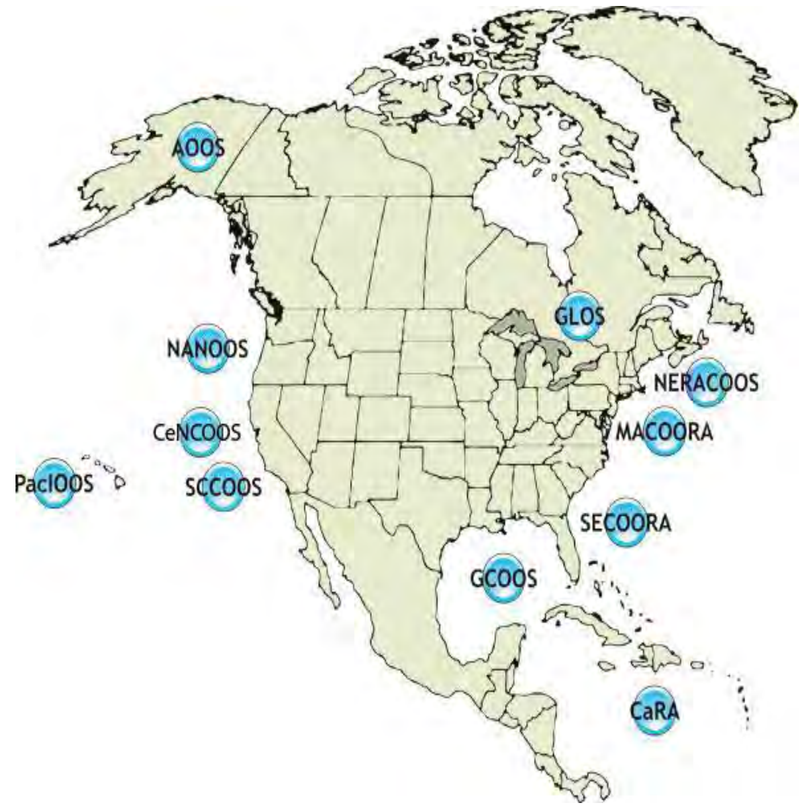
Coastal observations, including GOOS

- Fishery time series
- Nearshore stations: primarily measure T, S, nutrients, O_2, HABs
- Variables related to coastal hazards: winds, waves, sea level



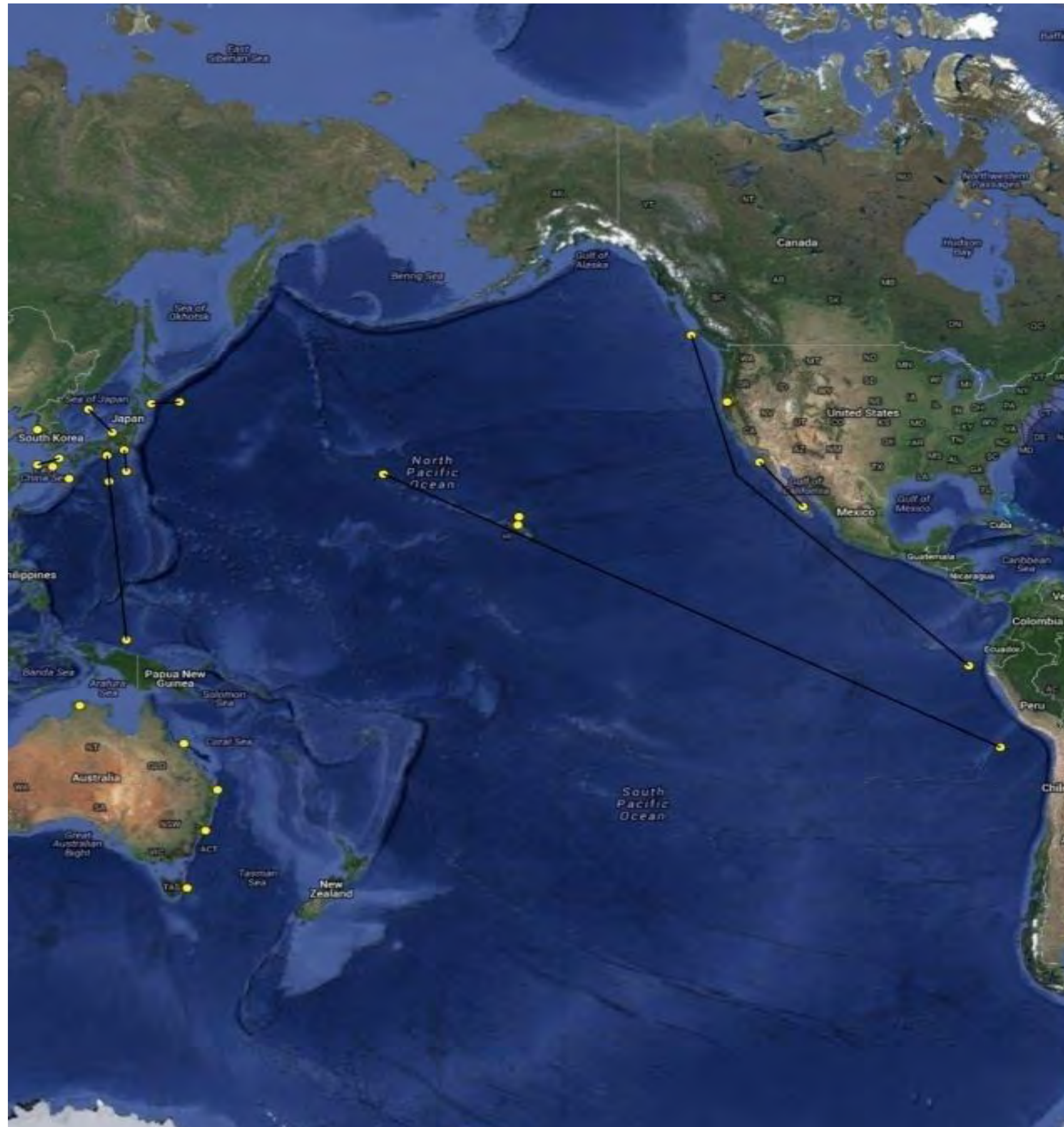
GOOS: the promise still unfulfilled

- Ecological measurements: an embarrassing “gap” (K. Alverson, former GOOS Director)
- Coastal GOOS fragmented, unsystematic
  - US GOOS divided into 11 regional associations
  - Variables monitored differ among RAs, methods not consistent, no overarching plan or synthesis
  - Focus on the “low hanging fruit”
    - Physical, chemical variables: T, S, chl, nutrients, O_2
    - Marine hazards: winds, waves, sea level



The current status of ecological monitoring in the Pacific: Key ecological groups: zooplankton

All zooplankton observation programs, including bulk biomass

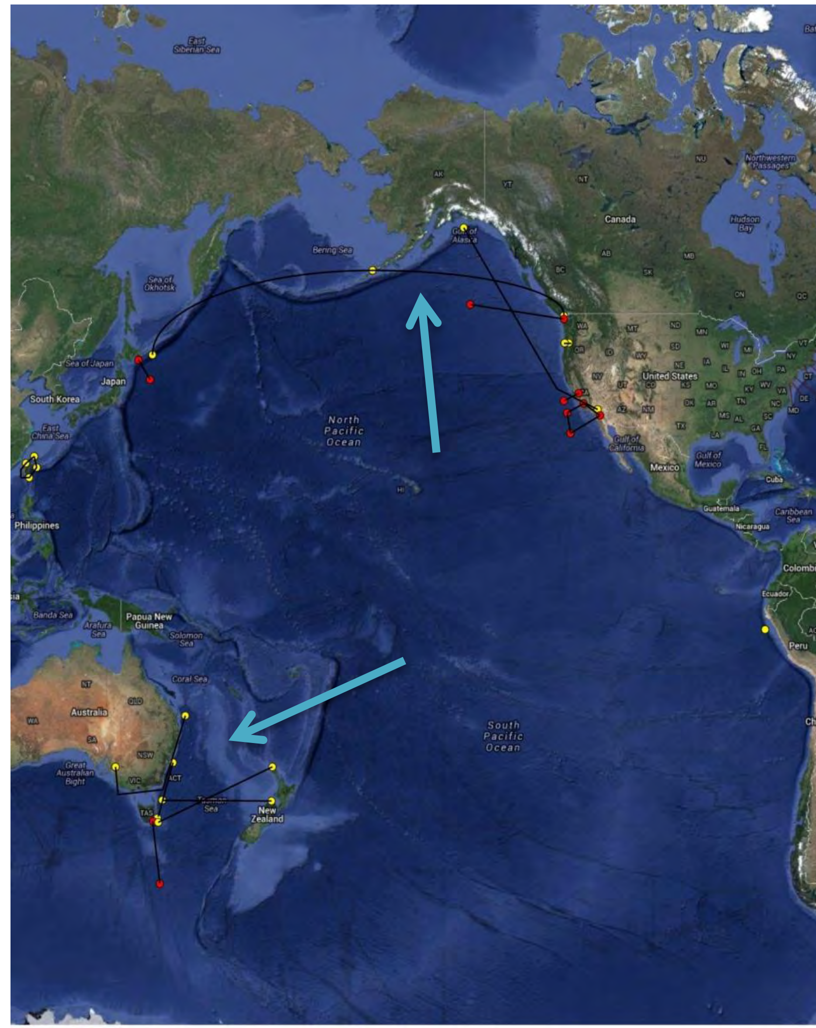


But bulk biomass is not very informative.
Species-level data required to assess changes in abundance & distribution

Zooplankton Time Series with Species-Resolution

- >20+ yr–long time series

- <20 yr-long time series



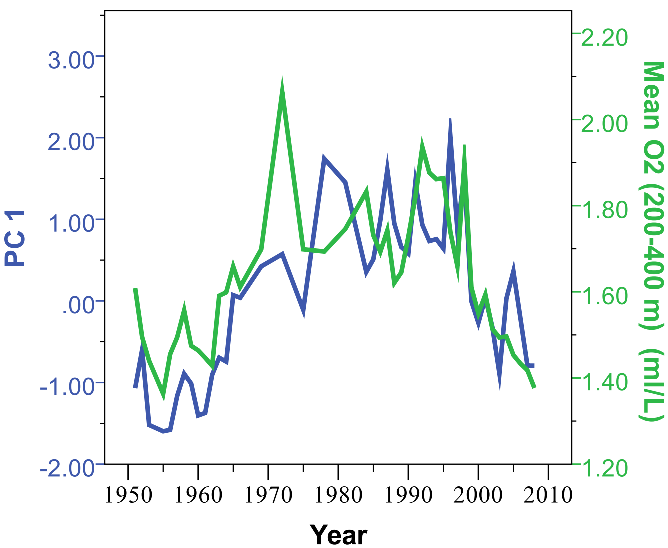
Micronekton Time Series

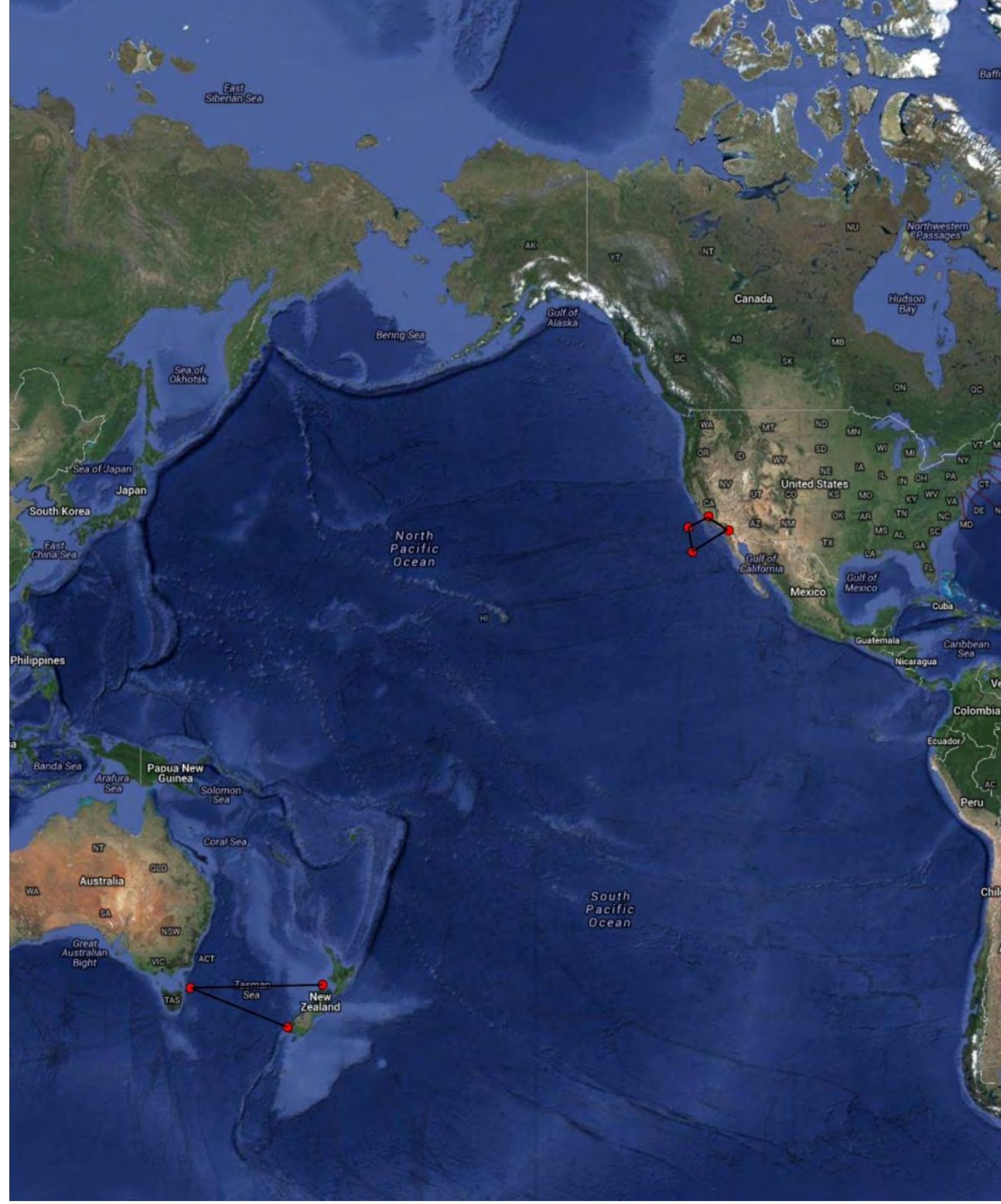
CalCOFI

(Ichthyoplankton, 1951-present)

1. Tasman Sea

(Acoustics/midwater trawl) since ~2000)





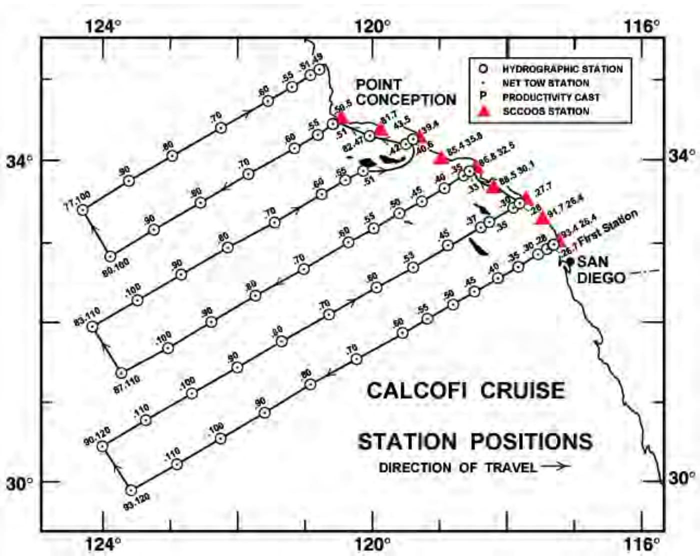
Impact of expanding OMZ?

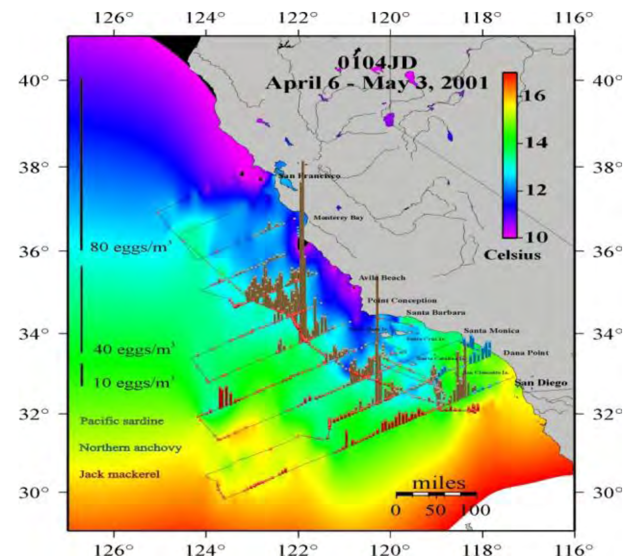
Similar patterns elsewhere in ETP & N Pacific with declining O_2 in OMZ?

How can we do better?

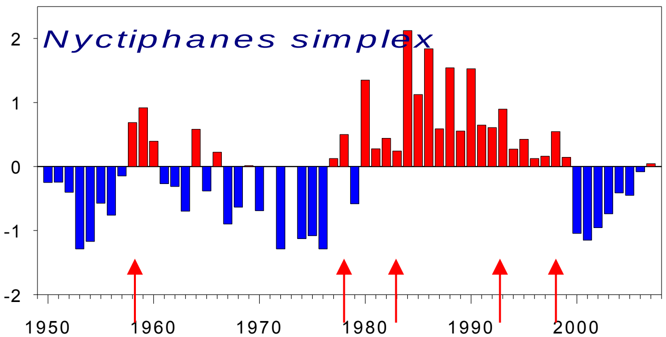
CalCOFI as a model

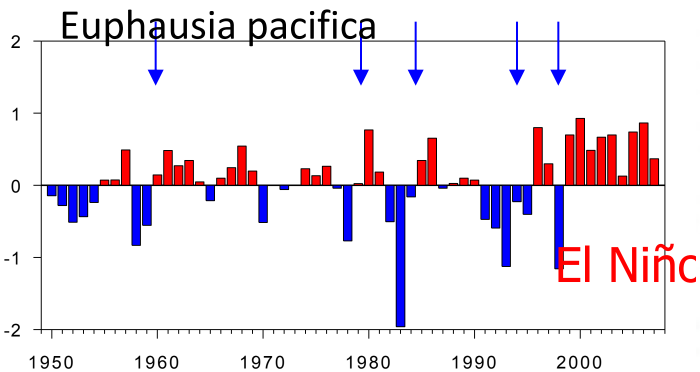
- Partnership of federal (NOAA), state (Cal Fish & Game) fishery/ management agencies + academic (SIO)
  - Govt agencies: stock assessments for key regional fisheries (sardine, anchovy, hake) based on egg production and/or acoustic/trawl surveys
  - Academic focus on physical/biological ocean environment
  - – Fishery + oceanographic sampling at each station builds fishery& oceanographic scientific infrastructure, interdisciplinary science
  - – Foundation for ecosystem-based management

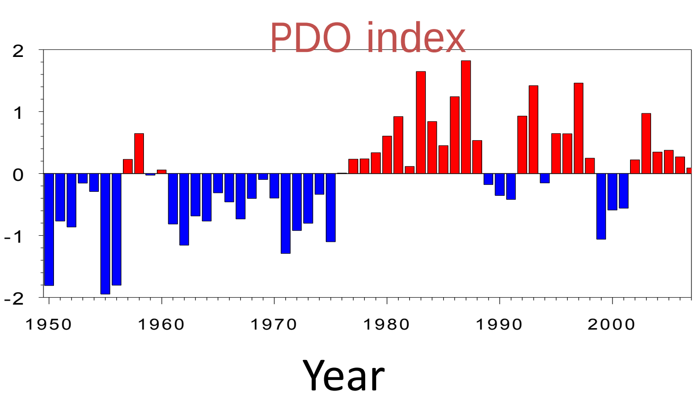


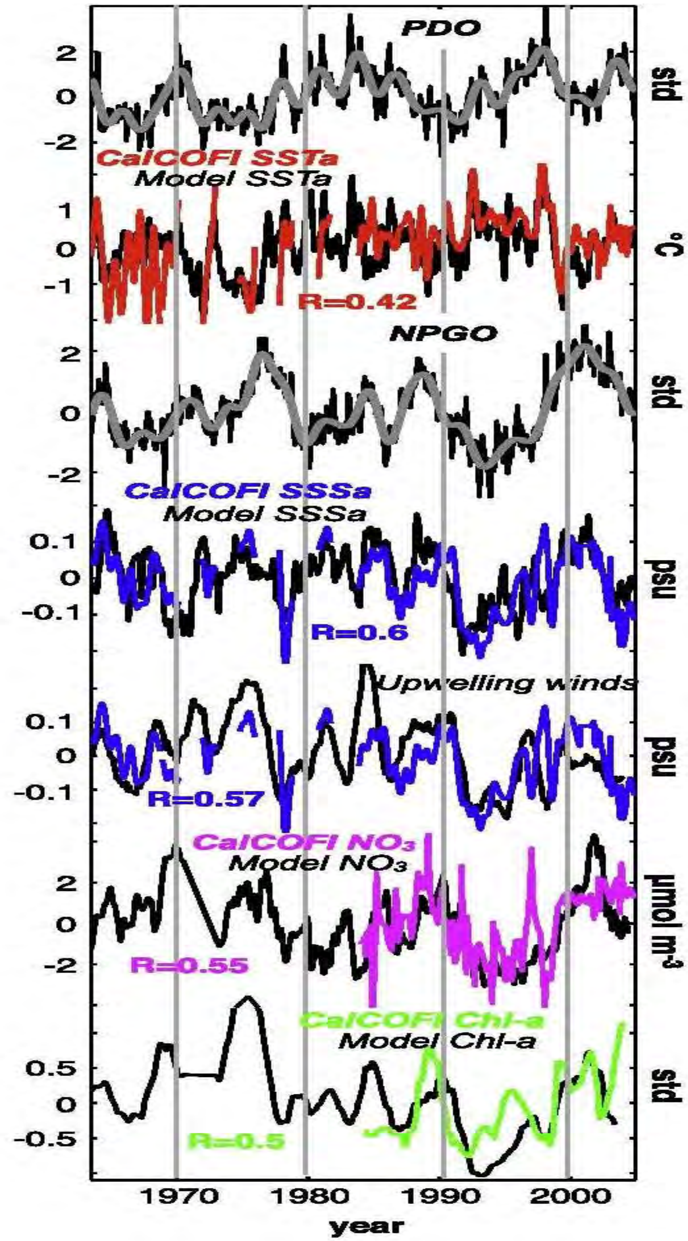


CalCOFI as a model









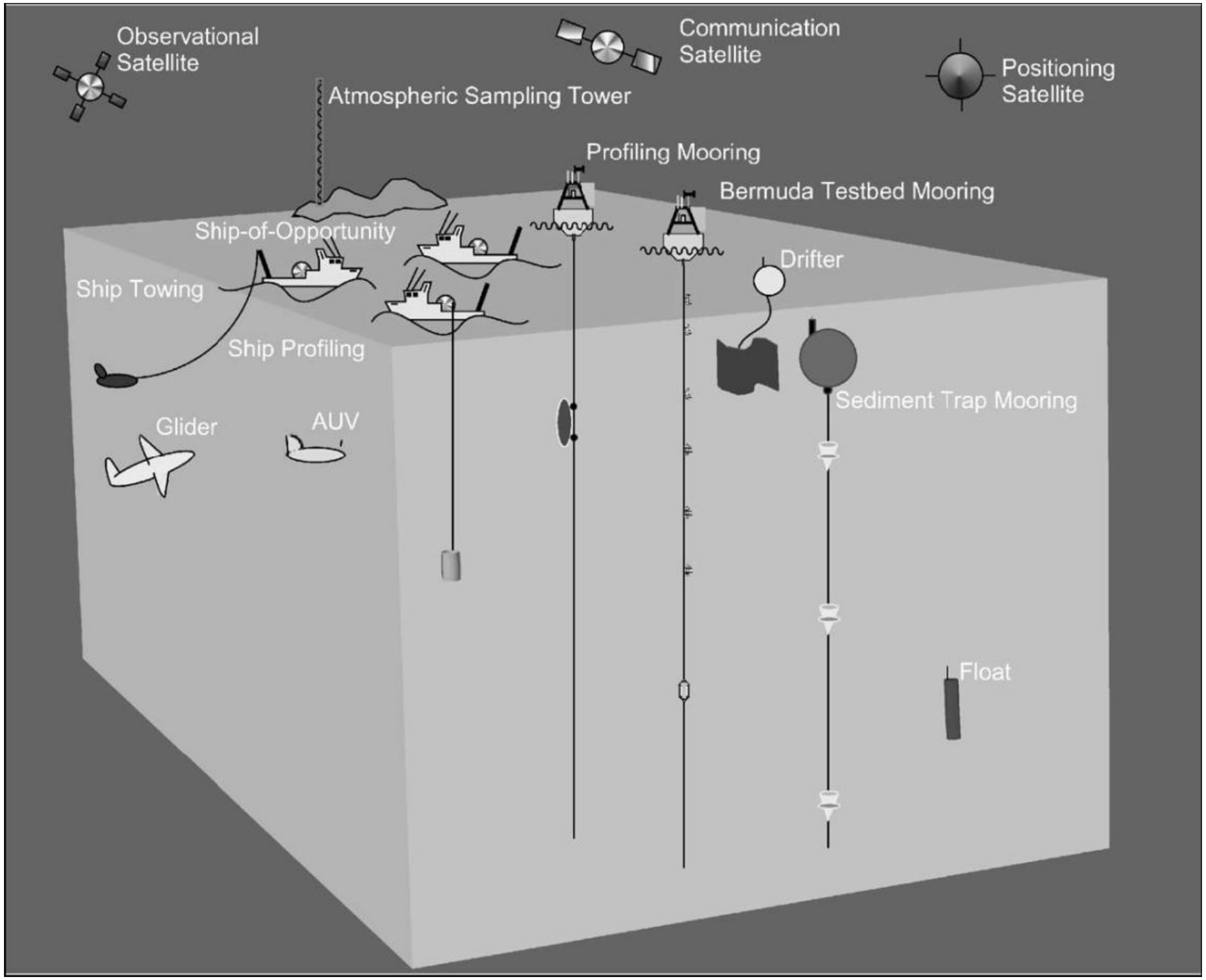
- CalCOFI climate/ocean/ ecological/fish time series underlie understanding of interannual (ENSO) to interdecadal (PDO, NPGO) variability in the California Current System

CalCOFI as a model

- Leverages additional programs, providing end-to-end observations

Temperature, salinity Chlorophyll *a*, irradiance	CalCOFI	CTD, fluorometer, PAR
Oxygen	CalCOFI	CTD, auto-Winkler
Nutrients (N, P, Si) – NH_4	CalCOFI	Auto analyzer
Primary production	CalCOFI	14C-uptake - POC, DOC
Sea surface pCO2 (select stn)	CalCOFI	IR absorbance
ICHTHYOPLANKTON + Zooplankton	CalCOFI	Bongo net (oblique), Calvet (vertical), manta (surface) tows
Other bio-optical properties	CCE LTER	cDOM,beam c vs. l
Particulate & dissolved C&N	CCE LTER	dry combustion
Upper ocean currents	Chereskin/CCE LTER	ADCP, data analyses
Taxon-specific pigments	CCE LTER	HPLC
Bacteria & picoautotrophs	CCE LTER	Flow cytometry
Nano- & microplankton	CCE LTER	Microscopy, FlowCAM
Mesozooplankton, size classes, species, species groups	CCE LTER	OPC, LOPC, Microscopy, ZOOSCAN
Seabirds Marine mammals	Farallon/PRBO, Hildebrand	Observers, Passive acoustics
Krill, micronekton, small pelagics	Koslow, NMFS	Acoustics, pelagic trawl

Modern ocean observation system

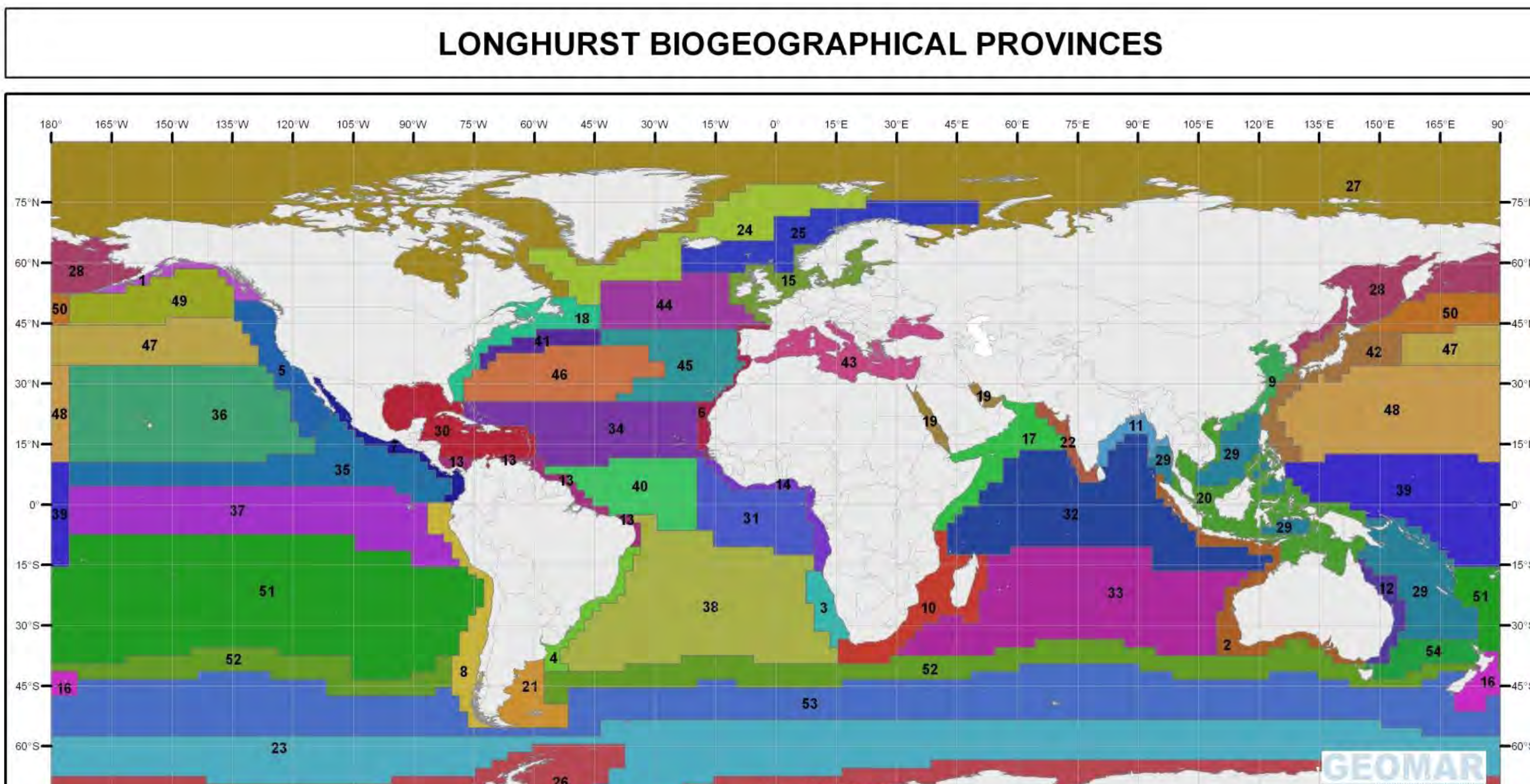


Monitor and assimilate ocean data on temporal and spatial scales unimaginable circa 1950

CalCOFI has evolved throughout its history, and will continue to evolve with new instrumentation, sampling protocols and partners

Are ship-based, species-level observations too difficult & costly?

- CalCOFI's cost: ~$5 million pa
- Longhurst: ~56 biogeographic provinces in the world's oceans
- Total cost for global ocean obs: ~$280 million
  - + savings from existing fishery & other ocean monitoring activities



Are ship-based, species-level observations too difficult & costly?

Cost of the US Ocean Observatories Initiative:

- $386 million for infrastructure, $55 million pa
- Very high tech but little species specific data. Time series???
- The cost for CalCOFI-like programs in each of the US 5-6 LMEs: $25-$30 million, ~ half of OOI budget

Cost of US NASA space exploration:

- ~$18 billion
- Cost for global ocean ship-based species-level obs: 1.5% of NASA budget

The fault lies not in the cost, but in our priorities!

Summary

- A representative global system of species-level time series are required for world ocean assessments and ecosystem-based fisheries management
- This can be achieved through development of consistent, systematic ocean observation programs in representative LMEs throughout the world's oceans (CalCOFI model)
- These observations complement existing ocean obs, e.g. moorings, satellites, gliders, coastal sampling, etc
- The cost is modest and the spinoffs are substantial:
  – Development of interdisciplinary marine science infrastructure
  – Understanding of impacts of anthropogenic stressors in relation to climate variability & climate change across spatial & temporal scales

Koslow, J.A., J. Couture (2013) *Nature 502: 163-164.*

COMMENT

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JAMES WILKINSON/SIO-CALCOFI

An instrument of the California Cooperative Oceanic Fisheries Investigations survey profiles ocean conditions off the US west coast.

Follow the fish

A global, long-term programme of ecological monitoring is needed to track ocean health, say **J. Anthony Koslow** and **Jennifer Couture**.

Next year, the United Nations aims to complete its first World Ocean Assessment, a process akin to the regular reporting of the Intergovernmental Panel on Climate Change. The assessment is timely and crucial: the world's oceans are threatened by many anthropogenic stressors, from pollutants, nutrient runoff and overfishing to warming, deoxygenation and acidification[1]. Current ocean-observation programmes are not fit for purpose.

Variables such as temperature, salinity and chlorophyll levels are monitored globally by satellites, water-column-profiling floats and moored sensor arrays. Ecological monitoring of marine systems, by contrast, is woefully inadequate and has been too long dismissed as too hard and too costly. As a result, the phytoplankton, zooplankton and micronekton (krill and small fish) that comprise the bulk of ocean ecosystems are examined on an ad hoc basis, rather than systematically.

Most natural ocean processes vary on annual to decadal timescales. To identify shifts resulting from climate change, observations need to span 50 years or more. Neglect of ecological monitoring has left the ocean-science community effectively bereft of such long-term data. The Census of Marine Life, for example, is an international effort that aims to characterize marine biodiversity, but over only a decade. Today, there are just two ecological data sets that are sufficiently long to fit the bill — and each has limitations.

A global ocean-observation network needs to be established within the next five years to provide baselines against which ocean health can be assessed in the coming century. Alongside physical oceanographic data, such a network must track the status of species in marine ecosystems around the world.

DECADAL MONITORING

Ecological time series are the Cinderellas of ocean science: long-neglected drudges, eking out their existence at the edge of what is in fashion, they now find themselves in favour at the climate change ball.

Their dismal state was brought home last year when one of us (J.A.K.) reported[2] a 63% decline in the abundance of 24 species of mid-water (mesopelagic) fish off the coast of California, apparently in response to reduced oxygen levels at those depths ▶