Characterizing secular trends of warming and deoxygenation in the CalCOFI time series and ecological implications for fisheries species

Natalya D. Gallo ndgallo@ucsd.edu

Introduction

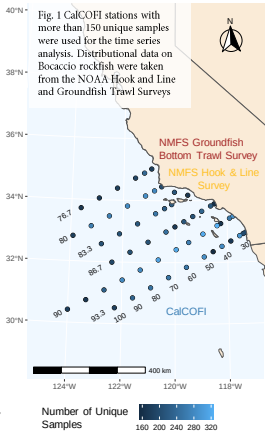


Fig. 1 CalCOFI stations with more than 150 unique samples were used for the time series analysis. Distributional data on Bocaccio rockfish were taken from the NOAA Hook and Line and Groundfish Trawl Surveys

Eastern boundary upwelling systems, like the California Current Ecosystem (CCE), are characterized by high variability of environmental conditions over interannual and multidecadal timescales. This high variability makes it difficult to distinguish secular trends, even when long time series are available, such as those collected by the CalCOFI Program (Gallo et al. 2019). While rapid oxygen losses have been observed in the CCE (Bograd et al. 2008, 2014, McClatchie et al. 2010), our confidence in distinguishing anthropogenic forcing from internal variability is still low (Long et al. 2016, IPCC SROCC). In this study, generalized additive models are used to model the different drivers of temperature and oxygen variability in the 71-year CalCOFI time series. The following questions are addressed:

1. Can significant secular warming and deoxygenation trends be detected in the CalCOFI time series?

2. If so, what are the rates of these trends, and how do they differ inshore-offshore and across depths in the water column (0-500 m)?

3. How do the rates of secular change compare to changes driven by natural climate forcing phenomena and those projected in global climate models?

4. Can we use the CalCOFI time series to calculate changes in habitat suitability for fisheries species using the Metabolic Index (Deutsch et al. 2020)?

Methods

Generalized additive models (Wood 2017) were fit to CalCOFI hydrographic data from stations sampled more than 150 times during the time series (n=56) and for all interpolated standard level depths (n=14): 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, and 500 m. Parameters meant to capture seasonal, mesoscale, interannual, multidecadal, and secular components of variability were included. For each station and depth a separate model was run to explain variability in oxygen, temperature, and Phi. Model coefficients and slopes were extracted from each model and compared across stations and depths.

$[O_2]$ Anomaly = s(Julian Day) + s(Salinity) + ONI Index + NPGO Index + PDO Index + Year

Temp Anomaly = s(Julian Day) + s(Salinity) + ONI Index + NPGO Index + PDO Index + Year

Φ Ratio = s(Julian Day) + s(Salinity) + ONI Index + NPGO Index + PDO Index + Year

Secular trends from the GAMs were compared to RCP 8.5 LENS climate model projections for the region.

$$\Phi = \frac{\text{Supply}}{\text{Demand}} = \frac{\alpha_S}{\alpha_D} B^{\varepsilon} p_{O_2} \exp\left\{\frac{E_o}{k_B}\left[\frac{1}{T} - \frac{1}{T_{ref}}\right]\right\}$$ Deutsch et al. (2020)

Lab measurements of pCrit for Bocaccio rockfish and Pacific sardine were used to estimate metabolic index parameters (hypoxia tolerance and temperature sensitivity of hypoxia tolerance). The metabolic index (Phi) was then calculated for CalCOFI samples from the SCB at relevant habitat depths.

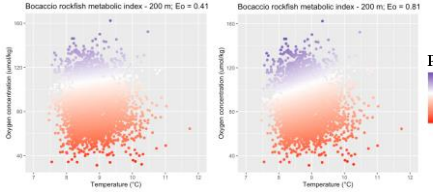


Fig. 2 Phi for Bocaccio rockfish calculated for SCB CalCOFI samples from 200 m, with two different values for temperature sensitivity (Eo = 0.41 left – less T-sensitive, and Eo = 0.81 right – more T-sensitive). Bocaccio are already exposed frequently to metabolically challenging conditions (Phi < 2) at 200 m. Phi is < 2 for 85% of samples (left) and ~80% of samples (right). Interestingly, greater temperature sensitivity (i.e. higher Eo) increases suitable habitat at 200 m, but decreases it at 100 m.

Results

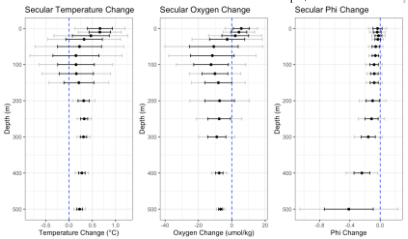
Using GAMs, we were able to examine the contributions of different drivers of temperature and oxygen variability, and examine differences in the strengths of those drivers spatially and through the water column.

Significant ($p < 0.05$) secular warming trends were detected in 469 of 718 models, with greater warming at the surface.

Significant ($p < 0.05$) secular deoxygenation trends were detected in 327 of 718 models. A significant increasing trend is observed in 101 models at shallow depths (0-30 m). Trends are stronger at nearshore stations.

Significant ($p < 0.05$) decreases in Phi were detected in 430 of 718 models. The largest decreases in Phi were at the deepest depths.

Fig. 3 Overall secular changes in temperature, oxygen, and Phi over the 71 year CalCOFI time series. The mean for all model runs is shown for each ISL depth, with +/- 1 and 2 STD



References

Bograd et al. 2008 GRL. Bograd et al. 2014 DSR-II. Deutsch et al. 2020 Science. Gallo et al. 2019 FMS. IPCC SROCC. Kay et al. 2015 BAMS. Long et al. 2016 GBC. McClatchie et al. 2010 GRL. Wood 2017 Generalized Additive Models: an introduction with R, 397 pp.

Conclusion

We were able to distinguish significant secular warming and deoxygenation trends from internal variability in the 71 year CalCOFI time series, and examine how interannual and multidecadal drivers affect temperature and oxygen dynamics for the southern CCE. This information is being used to calculate changes in habitat suitability for fisheries species such as Bocaccio rockfish and Pacific sardine using the Metabolic Index framework. Observed changes over the past 71 years will be compared to projected changes for the 21st century under an RCP 8.5 emissions scenario.

Acknowledgements: This work would not have been possible without the contributions of many collaborators, who are listed here alphabetically: Yassir Eddebbar, Lisa A. Levin, Joshua Lonthair, Stephanie Nemeth, Brice X. Semmens, Gavin L. Simpson, Andrew Thompson, Nick C. Wegner.

Funding: This research has been supported by a NOAA QUEST grant to Brice X. Semmens.

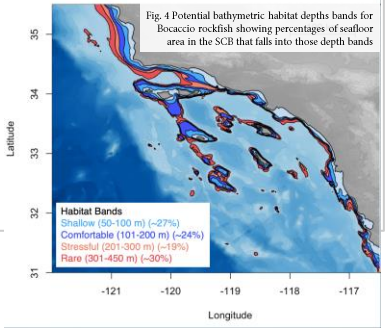


Fig. 4 Potential bathymetric habitat depths bands for Bocaccio rockfish showing percentages of seafloor area in the SCB that falls into those depth bands