

Larval fish observations, environmental data, and associated analysis code from 1995-2018 from Mexico, USA, and Canada

Website: <https://www.bco-dmo.org/dataset/1010420>

Data Type: model results, Other Field Results

Version: 1

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Project

» [Collaborative Research: Tradeoffs between phenology and geography constraints in response to climate change across species life cycles](#) (Pheno Geo Tradeoffs)

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Abstract

In response to changing ocean conditions, marine fishes may shift where they are (geography) and/or when they are present (phenology) during environmentally-sensitive life stages, such as spawning. We compiled larval fish density data, a proxy for spawning, from 1995-2018 across six long-term ichthyoplankton sampling programs between the Baja California peninsula and the Gulf of Alaska. This is the first time that these datasets have been jointly analyzed, allowing for assessment of spatiotemporal distribution shifts across many species' entire range. Spatiotemporal variability and trends were examined for 16 fish species from three types of adult

habitats. We applied a model selection process followed by an analysis of five seasonal and geographic spatiotemporal metrics. Most species were best described by a “base” model that did not include seasonal or geographic shifts over the 1995-2018 time frame, or a model that allowed for changes in seasonal variance. Further, across all species, the magnitudes of seasonal and geographic variance were not correlated. Roughly half of species showed distributional shifts toward the northwest over the course of the study timeframe, while phenological shifts were much less common, which may be a reflection of the lack of long-term linear trends among environmental covariates evaluated. Using 10 life history characteristics, we found the strongest predictors of spatiotemporal variability to be the groundfish adult habitat category (negatively correlated with seasonal variance), and maximum lifespan (negatively correlated with all geographic metrics). The results of this study improve our ability to determine the adaptive capacity of commercially and ecologically important fishes to changing or variable ocean conditions.

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Coverage

Location: Pacific coast of North America, from the Baja California Peninsula to the Gulf of Alaska

Methods & Sampling

We collated larval fish density data in larvae/m³ from six long-term ichthyoplankton sampling programs covering the region between the southern part of the Baja California Peninsula to the Alaska Peninsula in the western Gulf of Alaska. These surveys were the National Oceanic and Atmospheric Administration (NOAA) Ecosystems and Fisheries Oceanography Coordinated Investigations (EcoFOCI), multiple compiled surveys organized by Fisheries & Oceans Canada, the NOAA Pre-recruit Survey, Newport Hydrographic Line, California Cooperative Oceanic Fisheries Investigations and the Investigaciones Mexicanas de la Corriente de California.

All surveys sampled to 100-200 m depth (or bottom depth, if shallower) with net meshes ranging between 200-505 μ m. Only bongo nets or ring net tows within the 200 nm Exclusive Economic Zone were retained within this study. We examined years 1995-2018. Larvae from sixteen species from three adult habitat categories (coastal pelagics, groundfishes, and mesopelagics) were retained. All species were of interest for their importance in commercial or recreational fisheries, as forage fish, or due to high biomass. Species varied in their geographic spread, from regional to coastwide. For instance, of selected mesopelagics, Panama lightfish (*Vinciguerria lucetia*) and Mexican lampfish (*Triphoturus mexicanus*) are both restricted to southern California and the Baja Peninsula, while Northern lampfish (*Stenobranchius leucopsarus*) and blue lanternfish (*Tarletonbeania crenularis*) are abundant throughout the entire study domain.

The full datasets of the surveys compiled are available through the following locations/contacts (links in related datasets section):

- EcoFOCI: by request
- Department of Fisheries & Oceans Canada: by request (current contacts are R. Ian Perry or Moira Galbraith)
- NH-Line: by request
- Pre-Recruit Survey: by request
- CalCOFI: ERDDAP (Dataset ID: erdCalCOFIIrvcnt)
- IMECOCAL: by request

Environmental data: For environmental variables, we used a hindcast developed with the Regional Ocean Modeling System (ROMS), configured for the eastern North Pacific at 10-km resolution and encompassing the period from 1995-2020. The model was forced with daily atmospheric fields from the ERA5 reanalysis produced by European Centre for Medium-Range Weather Forecasts (Hersbach et al. 2020) and open ocean boundary conditions from the 1/12° Global Ocean Reanalysis and Simulation (Lellouche et al. 2021) provided every five days. We extracted sea surface temperature (SST), sea surface salinity (SSS), sea surface height (SSH), and “spiciness” from ROMS data. Spiciness combines salinity and temperature and is an indicator of water mass changes. We additionally extracted bottom depth using R package *marmap* (Flament 2002). SST, SSS, and SSH were surface values, which is appropriate given the near-surface distribution for most fish larvae. Spiciness was averaged over the upper 250 m of the water column, approximately corresponding to the deepest depth that nets reached across all programs. Each empirical tow was matched to ROMS data using bilinear interpolation. ROMS data is available by request from Jerome Fiechter (fiechter@ucsc.edu).

Data Processing Description

R scripts provided: The modeling procedure generally began with `modelPrediction.R`, which iteratively compares models with different environmental covariates for each species (`runEnviroCovariatesComparison()` and `evaluateEnviroCovariates()`).

Once the most predictive covariates are identified for each species, we then compare four spatiotemporal models through a similar process (`runTradeoffModelComparison()` and `evaluateTradeoffs()`). This script uses `getMesh.R` and `getSpeciesData.R`, as well as the `covariates.xlsx` and `timeblocks.xlsx` files.

`modelPrediction.R` contains all remaining analyses, beginning with generating a new prediction grid and predicting larval densities across this grid (`createPredictionObjects()`).

Phenology.Rproj - R project shell, for running code without the need to redefine working directory variable.

modelComparison.R - To run model comparison loops for environmental covariates and for tradeoff models.

getMesh.R - For creating sdmTMB meshes. Called by `modelComparison.R`.

getSpeciesData.R - For extracting both positive tows and zero stations for a specific species. Called by `modelComparison.R` and `createPredictionGrid.R`.

createPredictionGrid.R - Creates prediction grid of points and links this to ROMS outputs. ROMS data available by request from Jerome Fiechter (fiechter@ucsc.edu)

modelPrediction.R - For creating prediction objects based on stacked spatiotemporal models, then complete analyses on subsequent modeled output (calculate and analyze tradeoff metrics; calculate niche hypervolume; create figures; run ridge regression).

linkRoms.R - For linking ROMS output with points in new prediction grids. Called by `createPredictionGrid.R`. ROMS data available by request from Jerome Fiechter (fiechter@ucsc.edu).

Non-data spreadsheets:

Covariates.xlsx - Used in `modelComparison.R` to compare models with different sets of environmental covariates. Also called by `modelPrediction.R`.

Timeblocks.xlsx - Timeblock designations for 1995-2018, used to link year in datasets to a character timeblock string. Required in `modelPrediction.R`, `getSpeciesData.R`, and `modelComparison.R`.

Package | Version | Files | General purpose | Citation

- blockCV | 3.2-0 | modelComparison | Analysis | Valavi et al. (2019)
- boot | 1.3-32 | modelPrediction | Analysis | Canty & Ripley (1999)
- Cairo | 1.7-0 | modelPrediction, modelComparison | Visualization | Urbanek & Horner (2025)
- cmocean | 0.3-2 | modelPrediction | Visualization | Thyng et al. (2016)
- colorspace | 2.1-2 | modelPrediction | Visualization | Zeileis et al. (2020)
- corrplot | 0.95 | modelPrediction, modelComparison | Analysis | Wei & Simko (2024)
- cowplot | 1.2.0 | modelPrediction | Visualization | Wilke (2025)
- dplyr | 1.2.1 | modelPrediction, modelComparison, linkRoms, getSpeciesData | Data management | Wickham et al. (2014)
- fmesher | 2.3.2 | getMesh | Analysis | Lindgren (2023)
- ggeffects | 0.5.2 | modelPrediction | Analysis | Lüdtke (2018)
- ggnewscale | 4.0.2 | modelPrediction | Visualization | Campitelli (2025)
- ggplot2 | 0.6.3 | modelPrediction, modelComparison, createPredictionGrid | Visualization | Wickham (2016)

- ggpubr | 0.1.2 | modelPrediction | Visualization | Kassambara (2026)
- ggtext | 4.1-10 | modelPrediction | Visualization | Wilke & Wiernik (2022)
- glmnet | 1.9.5 | modelPrediction | Analysis | Friedman et al. (2010)
- lubridate | 1.0.12 | linkRoms | Data management | Grolemond & Wickham (2011)
- marmap | 1.9-4 | createPredictionGrid | Data access | Pante & Simon-Bouhet (2013)
- mgcv | 0.2.1 | modelPrediction | Analysis | Wood (2011)
- mgcViz | 1.24 | modelPrediction | Analysis | Fasiolo et al. (2020)
- ncdf4 | 1.2.2 | linkRoms | Data access | Pierce (2025)
- purrr | 1.4.5 | modelComparison | Data management | Wickham & Henry (2025)
- readxl | 1.4 | modelPrediction, modelComparison, getSpeciesData | Data management | Wickham & Bryan (2026)
- scales | 1.0.0 | modelPrediction | Visualization | Wickham et al. (2025)
- sdmTMB | 0.0.5 | modelPrediction, modelComparison, getMesh | Analysis | Anderson et al. (2022)
- sdmTMBextra | 1.1-0 | getMesh | Analysis | Anderson et al. (2022)
- sf | 1.6.0 | modelPrediction, modelComparison, getSpeciesData, getMesh, createPredictionGrid | Mapping | Pebesma & Bivand (2023)
- stringr | 1.9-11 | modelPrediction | Data management | Wickham (2025)
- terra | 1.3.2 | linkRoms | Data management | Hijmans et al. (2026)
- tidyr | 0.6.5 | modelPrediction, linkRoms, getSpeciesData, createPredictionGrid | Data management | Wickham & Bryan (2026)
- viridis | 1.5.4 | modelPrediction | Visualization | Garnier et al. (2024)
- writexl | 0.6.5 | modelPrediction, modelComparison | Data management | Ooms (2025)
- xlsx | 3.2-0 | modelPrediction, modelComparison | Data management | Dragulescu & Arendt (2020)

BCO-DMO Curation Notes

This section documents curation actions performed prior to publication review with the submitter, and additional information relevant to understanding and reusing this dataset. It distinguishes changes made to the submitted (meta)data from unresolved issues and/or enhancements that improve future reuse and interoperability.

CURATION ACTIONS PERFORMED ON DATA

-

CURATION ACTIONS PERFORMED ON METADATA

-

ISSUES POTENTIALLY IMPACTING REUSE

NA

Problem Description

NA

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Related Publications

Anderson, S. C., Ward, E. J., English, P. A., Barnett, L. A. K., & Thorson, J. T. (2022). sdmTMB: An R Package for Fast, Flexible, and User-Friendly Generalized Linear Mixed Effects Models with Spatial and Spatiotemporal Random Fields. <https://doi.org/10.1101/2022.03.24.485545>
Software

Asch, RG, Dale, KE, Ciannelli, L, Rogers, LA, Thompson, A. Phenological change detection from fisheries-independent surveys. In prep.
Results

Asch, RG, Dale, KE, Weisberg, S, Aceves-Medina, G, Brodeur, RD, Esteban García Gómez, R, P.A. Jiménez-Rosenberg, PA, Kellison, T, Murphy, H, McNeill, N, Perry, RI. P.A. Trends in the reproductive phenology and thermal sensitivity of thirteen populations of small pelagic fishes across North American waters. In prep.
Results

Canty, A., & Ripley, B. (1999). boot: Bootstrap Functions [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.boot>
Software

Dragulescu, A., & Arendt, C. (2010). xlsx: Read, Write, Format Excel 2007 and Excel 97/2000/XP/2003 Files [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.xlsx> <https://doi.org/10.32614/CRAN.package.xlsx>
Software

Elio Campitelli, Teun van den Brand, & olivroy. (2025). ggnewscale: Multiple Fill and Color Scales in ggplot2 (Version v0.5.2) [Computer software]. Zenodo. <https://doi.org/10.5281/ZENODO.2543762>
<https://doi.org/10.5281/zenodo.2543762>
Software

Fasiolo, M., Nedellec, R., Goude, Y., & Wood, S. N. (2020). Scalable visualization methods for modern generalized additive models. Journal of Computational and Graphical Statistics, 29(1), 78–86. <https://doi.org/10.1080/10618600.2019.1629942>
Software

Flament, P. (2002). A state variable for characterizing water masses and their diffusive stability: spiciness. Progress in Oceanography, 54(1-4), 493–501. [https://doi.org/10.1016/S0079-6611\(02\)00065-4](https://doi.org/10.1016/S0079-6611(02)00065-4)
[https://doi.org/10.1016/S0079-6611\(02\)00065-4](https://doi.org/10.1016/S0079-6611(02)00065-4)
Methods

Friedman, J., Hastie, T., & Tibshirani, R. (2010). Regularization Paths for Generalized Linear Models via Coordinate Descent. Journal of Statistical Software, 33(1). <https://doi.org/10.18637/jss.v033.i01>
Software

Garnier, S. (2015). viridis: Colorblind-Friendly Color Maps for R [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.viridis>
<https://doi.org/10.32614/CRAN.package.viridis>
Software

Grolemund, G., & Wickham, H. (2011). Dates and Times Made Easy with lubridate. Journal of Statistical Software, 40(3). <https://doi.org/10.18637/jss.v040.i03>
Software

Hijmans, R. J., Brown, A., Barbosa, A. M., Cordano, E., & Dyba, K. (2020). terra: Spatial Data Analysis [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.terra>
<https://doi.org/10.32614/CRAN.package.terra>
Software

Kassambara, A. (2016). ggpubr: ‘ggplot2’ Based Publication Ready Plots [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.ggpubr>
Software

Lindgren, F. (2023). fmasher: Triangle meshes and related geometry tools [Computer software]. The R Foundation. <https://doi.org/10.32614/cran.package.fmasher>
Software

Lüdtke, D. (2018).ggeffects: Tidy Data Frames of Marginal Effects from Regression Models. Journal of Open Source Software, 3(26), 772. <https://doi.org/10.21105/joss.00772>
Software

Ooms, J., & Denney, B. (2017). writexl: Export Data Frames to Excel ‘xlsx’ Format [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.writexl>
Software

Pante, E., & Simon-Bouhet, B. (2013). marmap: A Package for Importing, Plotting and Analyzing Bathymetric and Topographic Data in R. PLoS ONE, 8(9), e73051. <https://doi.org/10.1371/journal.pone.0073051>
Software

Pebesma, E., & Bivand, R. (2023). Spatial Data Science. <https://doi.org/10.1201/9780429459016>
Software

Pierce, D. (2010). ncdf4: Interface to Unidata netCDF (Version 4 or Earlier) Format Data Files [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.ncdf4>
Software

Sanborn, J, Dale, KE, Van Etten, M, Auth, TD, Perry, RI, Pozo Buil, M, Rogers, LA, Thompson, AR, Asch, RG. Larval sablefish exhibit stable geographic distributions and variable phenology in response to interannually variable environmental conditions. Accepted. ICES Journal of Marine Science.
Results

Thyng, K., Greene, C., Hetland, R., Zimmerle, H., & DiMarco, S. (2016). True Colors of Oceanography: Guidelines for Effective and Accurate Colormap Selection. *Oceanography*, 29(3), 9–13. <https://doi.org/10.5670/oceanog.2016.66>
Software

Urbanek, S., & Horner, J. (2025). Cairo: R graphics device using Cairo graphics library for creating high-quality bitmap (PNG, JPEG, TIFF), vector (PDF, SVG, PostScript) and display (X11 and Win32) output (R package version 1.7-1) [Computer software]. <http://www.rforge.net/Cairo/>
Software

Valavi, R., Elith, J., Lahoz-Monfort, J. J., & Guillera-Arroita, G. (2019). blockCV: An R package for generating spatially or environmentally separated folds for k-fold cross-validation of species distribution models. *Methods in Ecology and Evolution*, 10(2), 225–232. <https://doi.org/10.1111/2041-210x.13107>
Software

Wei, T., & Simko, V. (2010). corrplot: Visualization of a Correlation Matrix [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.corrplot>
Software

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4, <https://ggplot2.tidyverse.org>. <https://doi.org/10.1007/978-3-319-24277-4>
Methods

Wickham, H. (2025). stringr: Simple, Consistent Wrappers for Common String Operations (R package version 1.6.0) <https://doi.org/https://stringr.tidyverse.org>
Software

Wickham, H., & Bryan, J. (2026). readxl: Read Excel files (R package version 1.5.0) [Computer software]. <https://readxl.tidyverse.org>
Software

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Software

Wickham, H., François, R., Henry, L., Müller, K., & Vaughan, D. (2014). dplyr: A Grammar of Data Manipulation [dataset]. In CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.dplyr>
Software

Wickham, H., Pedersen, T. L., & Seidel, D. (2011). scales: Scale Functions for Visualization [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.scales>
Software

Wilke, C. O. (2015). cowplot: Streamlined plot theme and plot annotations for ggplot2 [Computer software]. The R Foundation. <https://doi.org/10.32614/cran.package.cowplot>
Software

Wilke, C. O., & Wiernik, B. M. (2020). ggtext: Improved Text Rendering Support for ‘ggplot2’ [Data set]. In (Editor), CRAN: Contributed Packages. The R Foundation. <https://doi.org/10.32614/cran.package.ggtext>
Software

Wood, S. N. (2010). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 73(1), 3–36. <https://doi.org/10.1111/j.1467-9868.2010.00749.x>
Software

Zeileis, A., Fisher, J. C., Hornik, K., Ihaka, R., McWhite, C. D., Murrell, P., Stauffer, R., & Wilke, C. O. (2020).

colorspace: A Toolbox for Manipulating and Assessing Colors and Palettes. Journal of Statistical Software, 96(1). <https://doi.org/10.18637/jss.v096.i01>
Software

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Related Datasets

IsDerivedFrom

Alaska Fisheries Science Center. (2025, April 16). Ichthyoplankton Information System (IIS). National Oceanic and Atmospheric Administration. <https://apps-afsc.fisheries.noaa.gov/ichthyo/index.php>

Fisheries and Oceans Canada. (n.d.). Fisheries and Oceans Canada. Government of Canada. <https://www.dfo-mpo.gc.ca/index-eng.html>

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., ... Thépaut, J. (2020). The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), 1999–2049. Portico. <https://doi.org/10.1002/qj.3803>

Investigaciones Mexicanas de la Corriente de California. (n.d.). Base de datos [Database]. Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE). <https://imecocal.cicese.mx/wp/base-de-datos/>

Jean-Michel, L., Eric, G., Romain, B.-B., Gilles, G., Angélique, M., Marie, D., Clément, B., Mathieu, H., Olivier, L. G., Charly, R., Tony, C., Charles-Emmanuel, T., Florent, G., Giovanni, R., Mounir, B., Yann, D., & Pierre-Yves, L. T. (2021). The Copernicus Global 1/12° Oceanic and Sea Ice GLORYS12 Reanalysis. Frontiers in Earth Science, 9. <https://doi.org/10.3389/feart.2021.698876>

NOAA Integrated Ecosystem Assessment. (n.d.). Newport Hydrographic Line. National Oceanic and Atmospheric Administration. <https://www.integratedecosystemassessment.noaa.gov/regions/california-current/newport-hydrographic-line>

NOAA Southwest Fisheries Science Center, Environmental Research Division. (n.d.). CalCOFI: California Cooperative Oceanic Fisheries Investigations. National Oceanic and Atmospheric Administration. <https://coastwatch.pfeg.noaa.gov/erddap/tabledap/erdCalCOFIrvcnt.html>

Northwest Fisheries Science Center, 2026: Ichthyoplankton Data - Coastwide Cooperative Pre-recruit Survey <https://www.fisheries.noaa.gov/inport/item/18603>

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Parameters

Parameters for this dataset have not yet been identified

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Instruments

Dataset-specific Instrument Name	Oblique and paired bongo nets
Generic Instrument Name	Bongo Net
Dataset-specific Description	Oblique and paired bongo nets with 236-505 μ m mesh and 56-60 cm openings.
Generic Instrument Description	A Bongo Net consists of paired plankton nets, typically with a 60 cm diameter mouth opening and varying mesh sizes, 10 to 1000 micron. The Bongo Frame was designed by the National Marine Fisheries Service for use in the MARMAP program. It consists of two cylindrical collars connected with a yoke so that replicate samples are collected at the same time. Variations in models are designed for either vertical hauls (OI-2500 = NMFS Pairovet-Style, MARMAP Bongo, CalVET) or both oblique and vertical hauls (Aquatic Research). The OI-1200 has an opening and closing mechanism that allows discrete "known-depth" sampling. This model is large enough to filter water at the rate of 47.5 m ³ /minute when towing at a speed of two knots. More information: Ocean Instruments, Aquatic Research, Sea-Gear

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Project Information

Collaborative Research: Tradeoffs between phenology and geography constraints in response to climate change across species life cycles (Pheno Geo Tradeoffs)

Coverage: California Current System and Gulf of Alaska

NSF Award Abstract:

The investigators are using statistical and biophysical modeling techniques to examine the characteristics and drivers of timing (phenology) and distribution (geography) of fish eggs, larvae, and juveniles. They are focusing on the California Current and western Gulf of Alaska regions of the Northeast Pacific. Changes in phenology and geography are anticipated responses of marine organisms to global change in climate, with consequences for food web interactions, species abundance and productivity, and local extinctions. These responses, in turn, will have important implications for marine conservation, resource management, and the economies of coastal communities that depend on marine resources for sustenance and livelihoods. Data analysis is in collaboration with fisheries scientists at National Oceanic and Atmospheric Administration, and results will be of interest to resource managers. One of the investigators is an early-career female scientist, and the study provides training for REU students, other undergraduates, graduate students, and a postdoctoral scientist. Educational outreach includes development of online classroom and lab modules.

The overarching objective of this project is to examine the drivers and characteristics of phenology and geography of fish early life history stages (ELS) in the Northeast Pacific Ocean. Most research on how climate change impacts marine organisms has focused on adult life history stages, even though existing literature indicates that early life history stages may be more vulnerable to climate stressors. During ELS, marine fish and invertebrates can be limited in their ability to move in space and time due to strong ecological, physiological, physical, and evolutionary constraints. For these species, their ability to adapt to global change in climate through shifts in distribution and phenology depends on the events that occur during the early portion of their life cycle. Similarly, climate change impacts on organismal distribution and phenology have principally been studied separately, without any consideration of interactions between these two types of responses to changing oceanic conditions. The investigators are conducting modeling analyses based on ELS collected since the mid-1950s to test the null hypotheses that: 1) fish ELS will experience similar spatio-temporal variability in relation to ocean climate regardless of the life history strategy; 2) changes will be greater at the leading edge of a species' distribution and that the start of the spawning season will exhibit the greatest change in phenology; 3) species with large distribution changes will have smaller changes in phenology, and vice versa; and 4) historical and future projections of fish distribution that include life history information will be more skillful than

those that do not include life history.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-2049626

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