Maximum depths of the visual luminoxyscape for four species of marine invertebrate larvae from CalCOFI stations between La Jolla, California to Point Conception between 1984-2019

Website: https://www.bco-dmo.org/dataset/859867
Data Type: Cruise Results
Version: 1
Version Date: 2021-09-24

Project
» Vision-mediated influence of low oxygen on the physiology and ecology of marine larvae (Vision under hypoxia)

Contributors	Affiliation	Role
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Abstract
In this dataset, the maximum depths of the visual luminoxyscape for four species of marine invertebrate larvae were recorded. Data in this study are from CalCOFI stations restricted to an area from La Jolla, California to Point Conception and 215 kilometers maximum offshore (Station 60). We analyzed daytime casts (09:00-16:00) of both discrete bottle data and continuous CTD casts to represent the date range of 1984-2019 and used the oxygen and irradiance measurements to determine the visual luminoxyscape for each of the larval species. This range was bounded by the oxygen (partial pressure) where the pO2 would permit 50% minimum retinal function (V50; 13, 7.2, 10.2, and 6.8 kPa for larvae of 'Doryteuthis opalescens', 'Octopus bimaculatus', 'Metacarcinus gracilis', and 'Pleuroncodes planipes', respectively), and where there is sufficient irradiance for a visual response (0.0311 µmol photons m-2 s-1) for each species. Additionally, oxygen limits for metabolism were used to determine the depth of occurrence of the Pcrit (the oxygen below which the animal cannot maintain a constant metabolic rate). The depths of occurrence for metabolic limits were determined for larvae of 'D. opalescens' and 'O. bimaculatus'.

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Coverage

Spatial Extent: **N**:34.4655 **E**:-117.286666 **S**:31.99666 **W**:-120.823333
Temporal Extent: 1984-01-05 - 2019-07-25

Methods & Sampling

This dataset is a subset of data from the "Luminoxyscape environmental" dataset (BCO-DMO dataset 860397). In this "Luminoxyscape maximum depth" dataset, we provide the rows of information for the maximum depths only. The "Depth" column refers to the maximum depth of either oxygen limitation for vision (V50), oxygen limitation for metabolism (Pcrit), or irradiance limitation (Light_Lim). All species and limits are presented in one, combined data frame.

All corresponding environmental hydrographic cast data were collected by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) long-term monitoring system. All information regarding the sampling program can be found on

https://calcofi.org/about/. Briefly, CalCOFI and the Southern California Coastal Ocean Observing System (SCCOOS) samples a random array within a gridded station map during quarterly cruises and conducts vertical hydrographic casts to ~500-meters (m) depth (or 10 m above bottom where bottom depth < 500 m). More information can be found at: https://calcofi.org/index.php. All data used can be found in their original form at: https://calcofi.org/data/oceanographic-data/ctd-cast-files/.

In this analysis, we used data from CalCOFI stations restricted to an area from La Jolla, California to Point Conception (Line 80.0- Line 93.3; 32.95-34.46 °N at shoreline) and 215 kilometers maximum offshore (Station 60; 119.57-121.150 °W). We analyzed daytime casts (09:00-16:00) of both discrete bottle data and continuous CTD casts. This dataset has combined bottle and CTD casts to represent the date range 1984-2019. We used the oxygen and irradiance measurements to determine the visual luminoxyscape for each of the larval species. This range was bounded by the oxygen (partial pressure) where the pO2 would permit 50% minimum retinal function (V50; 13, 7.2, 10.2, and 6.8 kPa for larvae of *Doryteuthis opalescens, Octopus bimaculatus, Metacarcinus gracilis, and Pleuroncodes planipes*, respectively), and where there is sufficient irradiance for a visual response (0.0311 µmol photons m-2 s-1) for each species.

The "limits" are calculating depths where those oxygen and irradiance requirements would no longer be met. This would be the 'visual luminoxyscape depth' (VLD); these depths are the maximum depths presented in this metadata file. Oxygen values for oxygen limits for visual physiology were taken from McCormick et al., 2019.

Additionally, oxygen limits for metabolism were used to determine the depth of occurrence of the Pcrit (the oxygen below which the animal cannot maintain a constant metabolic rate). This was calculated in McCormick, 2019. The depths of occurrence for metabolic limits were determined for larvae of *D. opalescens* and *O. bimaculatus*.

Instruments:
Full details of the instrumentation on the CalCOFI CTD can be found here: https://calcofi.org/sampling-info/methods/bottle-sampling-methods/. Wherever possible, we used the cruise-corrected data in the "final" cast files provided by CalCOFI, indicating the files already QC by CalCOFI data managers.

For this analysis, we primarily used data from oxygen optodes [SBE 13 (1998-2003) and SBE 43 (2003-2019); SeaBird Scientific] and PAR irradiance sensors [QSP-200L (1998-2010); QSP-2300 (2003-2019); Biospherical Instruments, Inc.].

Code:
There are 3 R files associated with this dataset: Luminox_May21_Part1_ann.R, Luminox_May21_Part2_ann.R, and Luminox_May21_Part3_ann.R. These are further described in the attached file "Luminoxyscape_Code_Description_of_Files.txt". In general:
The code (separated into 3 parts for simplicity and organization) is the entire code dataset from the Luminoxyscape project. The code covers everything including the quality-control for data downloaded directly from CalCOFI (https://calcofi.org/data/oceanographic-data/ctd-cast-files/) in Part 1, the analysis of maximum depths in Part 2 (associated with data "Luminoxyscape maximum depth", and the final analysis for the paper (McCormick et al., Limnology and Oceanography Letters, accepted) including code for all statistics in the analysis and graphs used in the figures. The code is clean and works, but is designed to show the process of the analysis for the project, rather than direct reproducibility. Contact information is included for those who wish to ask questions. All code was run using R (v3.6.3) run through RStudio (v. 2021.09.0).

Data Processing Description

Data Processing:
Full details on the CTD processing procedure can be found here: https://calcofi.org/sampling-info/methods/bottle-sampling-methods/

Programs used to analyze data include SeaBird SBEDataProcessing version 7.26.7

BCO-DMO Processing:
- Converted dates to ISO8601 format in a new column;
- Adjusted field/parameter names to comply with BCO-DMO naming conventions;
- Missing data identifier ‘NA’ replaced with 'nd' (BCO-DMO's default missing data identifier);
- Added a conventional header with dataset name, PI names, version date;
- In the ENSO_Cat column, replaced "La Ni√±a" with "La Nina" and "El Ni√±o" with "El Nino".

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Data Files

File	
Luminoxyscape_Code_Description_of_Files.txt	(Octet Stream, 2.77 KB) MD5:bdd74fcdbfb3ba12e7be87d5707bde0a
Text file describing the three R files associated with the Luminoxyscape datasets: "Luminoxyscape maximum depth": doi 10.26008/1912/bco-dmo.859867.1 "Luminoxyscape environmental": doi 10.26008/1912/bco-dmo.860397.1	
luminoxyscape_max_depth.csv	(Comma Separated Values (.csv), 1.17 MB) MD5:a7725ca211166fab7ed618dec4c2a249
Primary data file for dataset ID 859867	
Luminox_May21_Part1_ann.R	(Octet Stream, 85.09 KB) MD5:4f7e3ae38a46156b3377b5280b9524a1
An annotated file showing the processing and quality control of the downloaded oceanographic data from CalCOFI (https://calcofi.org/data/). This includes loading the data files, the data frame set up, oxygen conversions, and calculating maximum depth of the casts for both early data (discrete bottle samples only) and cast data (using a CTD). Additional details about CalCOFI data can be found on their site. Details about the structure of the datasets can be found in the description for "Luminoxyscape environmental", doi: 10.26008/1912/bco-dmo.860397.1	
Luminox_May21_Part2_ann.R	(Octet Stream, 66.88 KB) MD5:b145062773a02e86f4299231dc8d196a
An annotated file showing the main analysis for the maximum depth of the visual luminoxyscape (additional details in the "Luminoxyscape maximum depth" file description, doi 10.26008/1912/bco-dmo.859867.1). This includes combining quality-controlled data frames for oceanographic data, narrowing the dataset to the stations of interest, adding in El-Nino Southern Oscillation data, and calculating the maximum depths of the luminoxyscape.	
Luminox_May21_Part3_ann.R	(Octet Stream, 61.48 KB) MD5:bf2fe7f12ff19d133770d5dfc5df643f
An annotated file showing the statistical analyses and code for publication figures for this study. This includes calculating the average/standard deviation/standard error of the maximum depths of the luminoxyscape (see "Luminoxyscape maximum depth" file description, doi 10.26008/1912/bco-dmo.859867.1), conducting the statistics, and making the figures for publication.	

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Related Publications

McCormick, L. R. (2019). Oxygen dependence of visual physiology and behavior in marine invertebrate larvae and its ecological implications. UC San Diego. ProQuest ID: McCormick_ucsd_0033D_18804. Merritt ID: ark:/13030/m5r54xrg. Retrieved from https://escholarship.org/uc/item/4670p0fb
Methods

McCormick, L. R., Gangrade, S., Garwood, J. C., Oesch, N. W., & Levin, L. A. (2022). Oxygen and irradiance constraints on visual habitat in a changing ocean: The luminoxyscape. Limnology and Oceanography Letters, 8(2), 220–228. Portico. https://doi.org/10.1002/lol2.10296
Results

McCormick, L. R., Levin, L. A., & Oesch, N. W. (2019). Vision is highly sensitive to oxygen availability in marine invertebrate larvae. The Journal of Experimental Biology, 222(10), jeb200899. doi:10.1242/jeb.200899
Methods

McCormick, L. R., Levin, L. A., & Oesch, N. W. (2022). Reduced Oxygen Impairs Photobehavior in Marine Invertebrate Larvae. The Biological Bulletin, 000–000. https://doi.org/10.1086/717565
Methods

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Related Datasets

IsRelatedTo

McCormick, L. R., Oesch, N., Levin, L. A. (2022) **Organized and quality-controlled CalCOFI data for CTD casts and bottle measurements from CalCOFI stations between La Jolla, California to Point Conception between 1984-2019.** Biological and Chemical Oceanography Data Management Office (BCO-DMO). (Version 1) Version Date 2021-09-24 doi:10.26008/1912/bco-dmo.860397.1 [view at BCO-DMO]

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Parameters

Parameter	Description	Units
Cast_ID	Unique cast identification given for each individual hydrographic cast performed by CalCOFI. Character string.	unitless
Line	CalCOFI sampling grid lines are north/south on a latitudinal grid. See CalCOFI website for details and map. Numeric format.	unitless
Station	Station. CalCOFI sampling grid stations are east/west on a longitudinal grid. See CalCOFI website for details and map. Numeric format.	unitless
ISO_DateTime_UTC	Date/time (in UTC) in ISO8601 format: YYYY-MM-DDThh:mm:ssZ	unitless
dt_PST	Date/time in Pacific Standard Time (PST). Format: YYYY-MM-DD hh:mm:ss	unitless
Hour	Hour of the day in PST. Format is numeric 1-23.	unitless
Month	Month of the year. Numeric, 1-12.	unitless
Year	Year of the data. Numeric.	unitless
Depth	Depth of data (CTD cast or bottle measurement) Numeric.	meters
Temperature	Temperature. Numeric.	degrees Celsius
Salinity	Salinity in PSU. Numeric.	PSU
SigTheta	Sigma theta is the density of seawater calculated with in situ salinity, potential temperature, and pressure =0 minus 1000 kg m-3.	1000 kg m-3
PAR	Photosynthetically Active Radiation. A measure of irradiance between ~400-700 nm.	µmol photons m-2 s-1
PARCorr	PAR weighted to the animal's spectral sensitivity. In this case, all PAR was multiplied by 0.34, as the percentage of PAR each species could detect. See McCormick et al., 2019 for additional details.	µmol photons m-2 s-1
Comb	A combined Line/Station code used for sorting data.	unitless
Latitude	Latitude of the cast. Numeric format.	decimal degrees North
Longitude	Longitude of the cast. Numeric format.	decimal degrees East (West is negative)

O2_mL_L	Oxygen concentration. Numeric format.	milliliters per liter
O2_uM	Oxygen content	µmol photons per kiligram
O2_matm	Oxygen content. Numeric	milliatmospheres
O2_kPa	Oxygen content. Numeric.	partial pressure units (kPa)
Season	Season for data. Winter (December, January, February); Spring (March, April, May); Summer (June, July, August); and Fall (September, October, November)	unitless
Dist_land	Distance from land, calculated as the spherical distance from the station to the corresponding shore station, or distance from the nearest island, for stations close to the Channel Islands.	kilometers
Light_Lim	Whether the larvae of all 4 species would have sufficient irradiance for >5% visual function at that specific cast depth bin. TRUE: Animals would have irradiance for >5% visual function; FALSE: Animals would have irradiance for <5% visual function. Based on McCormick et al., 2019. Character format (TRUE/FALSE).	unitless
Do_50	Whether larvae of Doryteuthis opalescens would have oxygen sufficient for >50% visual function at the specific cast depth bin. Character format, TRUE/FALSE. TRUE: Larvae would have oxygen for >50% visual function. FALSE: Larvae would have oxygen for <50% visual function.	unitless
Ob_50	Whether larvae of Octopus bimaculatus would have oxygen sufficient for >50% visual function at the specific cast depth bin. Character format, TRUE/FALSE. TRUE: Larvae would have oxygen for >50% visual function. FALSE: Larvae would have oxygen for <50% visual function.	unitless
Cg_50	Whether larvae of Metacarcinus gracilis would have oxygen sufficient for >50% visual function at the specific cast depth bin. Character format, TRUE/FALSE. TRUE: Larvae would have oxygen for >50% visual function. FALSE: Larvae would have oxygen for <50% visual function.	unitless
Pp_50	Whether larvae of Pleuroncodes planipes would have oxygen sufficient for >50% visual function at the specific cast depth bin. Character format, TRUE/FALSE. TRUE: Larvae would have oxygen for >50% visual function. FALSE: Larvae would have oxygen for <50% visual function.	unitless
Do_met	Whether larvae of D. opalescens would have oxygen sufficient for maintaining a stable metabolic rate (oxygen > Pcrit) at the specific cast depth bin. Character format, TRUE/FALSE. TRUE: Larvae would have oxygen >Pcrit. FALSE: Larvae would have oxygen for <Pcrit.	unitless
Ob_met	Whether larvae of O. bimaculatus would have oxygen sufficient for maintaining a stable metabolic rate (oxygen > Pcrit) at the specific cast depth bin. Character format, TRUE/FALSE. TRUE: Larvae would have oxygen >Pcrit. FALSE: Larvae would have oxygen for <Pcrit.	unitless

Loc	Categorical location of the station; whether the station was considered nearshore (“NS”; <30 km from shore) or offshore (“OS”; 30-215 km from shore). Character.	unitless
ONI	Oceanic Niño Index from the NOAA Climate Prediction Center. The Index measures the temperature anomaly in the 3.4 region in the equatorial Pacific. Numeric; positive values indicate warming, negative values indicate cooling. Data taken from: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php	unitless
ENSO_Cat	Categorical description of El Niño-Southern Oscillation phase. Categories were determined using the ONI. Winter/Spring ONI values of >=1 were considered “El Nino” years, values <= -1 were considered “La Nina” years; all other years were considered “non-ENSO” years.	unitless
Species	The species for which the maximum depth of the visual luminoxyscape was calculated. Categories are: “D. opalescens”= Doryteuthis opalescens, “O. bimaculatus”= Octopus bimaculatus, “M. gracilis”= Metacarcinus gracilis, “P. planipes”= Pleuroncodes planipes. and “All” refers to the limit being suitable for all 4 species.	unitless
MD_Limit	Oxygen limit for the maximum depth of the visual luminoxyscape. Categories are: “V50”= the oxygen level at which there would be 50% retinal function for the respective species, “Pcrit”= the oxygen limit for metabolism, below which the larvae cannot maintain a stable metabolic rate, or “Light.Lim”= the minimum irradiance level that would facilitate >5% retinal function for the larvae.	unitless

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Instruments

Dataset-specific Instrument Name	CalCOFI CTD
Generic Instrument Name	CTD Sea-Bird SBE 911plus
Dataset-specific Description	CalCOFI's primary hydrographic instrument is a Seabird 911+ CTD equipped with dual temperature, conductivity and oxygen sensors mounted on a 24-10L bottle rosette. Additional CTD sensors mounted on the rosette frame include a fluorometer, transmissometer, nitrate sensor, PAR, pH and altimeter.
Generic Instrument Description	The Sea-Bird SBE 911 plus is a type of CTD instrument package for continuous measurement of conductivity, temperature and pressure. The SBE 911 plus includes the SBE 9plus Underwater Unit and the SBE 11plus Deck Unit (for real-time readout using conductive wire) for deployment from a vessel. The combination of the SBE 9 plus and SBE 11 plus is called a SBE 911 plus. The SBE 9 plus uses Sea-Bird's standard modular temperature and conductivity sensors (SBE 3 plus and SBE 4). The SBE 9 plus CTD can be configured with up to eight auxiliary sensors to measure other parameters including dissolved oxygen, pH, turbidity, fluorescence, light (PAR), light transmission, etc.). more information from Sea-Bird Electronics

Dataset-specific Instrument Name	PAR irrandiance sensor QSP-200L
Generic Instrument Name	Photosynthetically Available Radiation Sensor
Dataset-specific Description	PAR irradiance sensor QSP-200L from Biospherical Instruments, Inc. (http://www.biospherical.com/)
Generic Instrument Description	A PAR sensor measures photosynthetically available (or active) radiation. The sensor measures photon flux density (photons per second per square meter) within the visible wavelength range (typically 400 to 700 nanometers). PAR gives an indication of the total energy available to plants for photosynthesis. This instrument name is used when specific type, make and model are not known.

Dataset-specific Instrument Name	PAR irrandiance sensor QSP-2300
Generic Instrument Name	Photosynthetically Available Radiation Sensor
Dataset-specific Description	PAR irradiance sensor QSP-2300 from Biospherical Instruments, Inc. (http://www.biospherical.com/).
Generic Instrument Description	A PAR sensor measures photosynthetically available (or active) radiation. The sensor measures photon flux density (photons per second per square meter) within the visible wavelength range (typically 400 to 700 nanometers). PAR gives an indication of the total energy available to plants for photosynthesis. This instrument name is used when specific type, make and model are not known.

Dataset-specific Instrument Name	
Generic Instrument Name	Sea-Bird SBE 13 Dissolved Oxygen Sensor
Generic Instrument Description	Dissolved oxygen sensor with either a Beckmann (SBE 13B) or YSI polarographic element (SBE 13Y limited to 2000m depth). Designed to interface with the SBE 9 and 9plus CTD underwater units. An optional plenum to connect into the pumped plumbing system was available but usage with the membrane exposed was possible. Replaced by the SBE 43 in 2001.

Dataset-specific Instrument Name	
Generic Instrument Name	Sea-Bird SBE 43 Dissolved Oxygen Sensor
Generic Instrument Description	The Sea-Bird SBE 43 dissolved oxygen sensor is a redesign of the Clark polarographic membrane type of dissolved oxygen sensors. more information from Sea-Bird Electronics

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Project Information

Vision-mediated influence of low oxygen on the physiology and ecology of marine larvae (Vision under hypoxia)

Coverage: Southern California Bight, Northeast Pacific Ocean

NSF abstract:
Oxygen is being lost in the ocean worldwide as a result of ocean warming and the input of nutrients from land. Vision requires a large amount of oxygen, and may be less effective or require more light when oxygen is in short supply. This is especially true for active marine animals with complex eyes and visual capabilities, including active arthropods (crabs), cephalopods (squid), and fish. The California coastal waters exhibit a sharp drop in oxygen and light with increasing water depth. This project examines how visual physiology and ecology in young (larval) highly visual marine animals respond to oxygen loss, with a focus on key fisheries and aquaculture species. Experiments and observations will test the hypothesis that oxygen stress will change the light required for these organisms to see effectively, influencing the water depths where they can live and survive. The project will provide interdisciplinary experiences to students and an early career scientist and inform both the public (through outreach at the Birch Aquarium at Scripps Institution of Oceanography) and policy makers about the effects of oxygen decline in the ocean.

Negative effects of oxygen loss on vision have been described for humans and other terrestrial organisms, but never in the marine environment, despite the large changes in oxygen that can occur with depth and over time in the ocean, and the high metabolic demand of visual systems. This project will test the effects of low oxygen on vision in 3 combinations of eye design and photo-transduction mechanisms: compound eye with rhabdomeric photoreceptors (arthropods), simple eye with rhabdomeric photoreceptors (cephalopods), and simple eye with ciliary photoreceptors (fish). A series of oxygen- and light-controlled laboratory experiments will be conducted on representative taxa of each group including the tuna crab, Pleuroncodes planipes; the market squid, Doryteuthis opalescens, and the white sea bass, Atractoscion nobilis. In vivo electrophysiology and behavioral phototaxis experiments will identify new oxygen metrics for visual physiology and function, and will be compared to metabolic thresholds determined in respiration experiments. Hydrographic data collected over 3 decades by the CalCOFI program in the Southern California Bight will be evaluated with respect to visual and metabolic limits to determine the consequences of oxygen variation on the critical luminoxyscape (range of oxygen and light conditions required for visual physiology and function in target species) boundary in each species. Findings for the three vision-based functional groups may test whether oxygen-limited visual responses offer an additional explanation for the shoaling of species distributions among highly visual pelagic taxa in low oxygen, and will help to focus future research efforts and better understand the stressors contributing to habitat compression with expanding oxygen loss in the ocean.

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-1829623

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