Supplemental Information: Data sources and raw data

Data Sources

Landings Data

Description

A dataset containing the landings (in metric tons) of oil sardines in Kerala State 1956-2015. The data are collected and processed into a total landings estimate based on a stratified sampling of landing sites along the SW coast of India throughout the year. The program is run by the Central Marine Fisheries Research Institute (CMFRI) in Cochin, India. The data were obtained from reports published by CMFRI; see references.

References

CMFRI reports were downloaded from the CMFRI Publication repository http://www.cmfri.org.in.

1956-1968 Antony Raja BT (1969). "Indian oil sardine." CMFRI Bulletin, 16, 1-142.

1968-1978 Pillai VN (1982). Physical characteristics of the coastal waters off the south-west coast of India with an attempt to study the possible relationship with sardine, mackerel and anchovy fisheries. Thesis, University of Cochin.

1975-1984 Kerala Jacob T, Rajendran V, Pillai PKM, Andrews J, Satyavan UK (1987). "An appraisal of the marine fisheries in Kerala." Central Marine Fisheries Research Institute. Report.

1975-1984 Kernataka Kurup KN, Nair GKK, Annam VP, Kant A, Beena MR, Kambadkar L (1987). "An appraisal of the marine fisheries of Karnataka and Goa." Central Marine Fisheries Research Institute. Report.

1985-2015 Provided by CMFRI directly via a data request.

SST Data

Description

The SST satellite data (units degree Celcius) were downloaded from the NOAA ERDDAP server using R Mendelssohn's **rerddapXtracto** R package which uses the ropensci **rerddap** R package.

Details

For 1981 to 2003, We used the Pathfinder Version 5.2 (L3C) monthly day and night product on a 0.0417 degree grid. These SST data use the Advanced Very-High Resolution Radiometer (AVHRR) instrument on the Pathfinder satellites. These data were provided by the Group for High Resolution Sea Surface Temperature (GHRSST) and the US National Oceanographic Data Center. This project was supported in part by a grant from the NOAA Climate Data Record (CDR) Program for satellites.

For 2004 to 2016, we used the NOAA CoastWatch sea surface temperature (SST) products derived from NOAA's Polar Operational Environmental Satellites (POES). The SST estimates use the Advanced Very-High Resolution Radiometer (AVHRR) instruments on the POES satellites and are on a 0.1 degree grid.

Both SST data sets were downloaded from the NOAA ERDDAP server:

https://coastwatch.pfeg.noaa.gov/erddap/info/erdAGsstamday/index.html

https://coastwatch.pfeg.noaa.gov/erddap/info/erdPH2sstamday/index.html.

The SST values were averaged across thirteen 1 degree by 1 degree boxes which parallel the bathymetry (Figure 1 in main text).

References

These data were provided by GHRSST and the US National Oceanographic Data Center. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environmental Research Division.

Casey KS, Brandon TB, Cornillon P, Evans R (2010). "The past, present, and future of the AVHRR Pathfinder SST program." In Oceanography from space, 273–287. Springer.

Simons RA. 2019. ERDDAP. https://coastwatch.pfeg.noaa.gov/erddap . Monterey, CA: NOAA/NMFS/SWFSC/ERD.

Walton C, Pichel W, Sapper J, May D (1998). "The development and operational application of nonlinear algorithms for the measurement of sea surface temperatures with the NOAA polar-orbiting environmental satellites." Journal of Geophysical Research: Oceans, 103(C12), 27999–28012.

Upwelling Data

Description

Three upwelling indices were used: a SST nearshore offshore differential (degree Celcius), a wind-based index (m s^{-1}) and the Bakun mass transport indices (kg m^{-1} s^{-1}). The upwelling indices and SST data were downloaded from the NOAA ERDDAP server using R Mendelssohn's **rerddapXtracto** R package which uses the ropensci **rerddap** R package. See the SST data description for package references.

Details

The Wind-based monthly upwelling indices (m s^{-1}) were downloaded from the NOAA ERDDAP server. The first is 1999-2009 on a 0.125 degree grid. The second is 2009 to present on a 0.25 degree grid. Download urls with information: https://coastwatch.pfeg.noaa.gov/erddap/info/erdQSstressmday/index.html and https://coastwatch.pfeg.noaa.gov/erddap/info/erdQAstressmday/index.html.

The SST differential upwelling indices (degree Celcius) were computed from SST data downloaded from the NOAA ERDDAP server. The first is 1981-2012 on a 0.0417 degree grid. The second is 2003-2016 on a 0.1 degree grid. Both are AVHRR so accurate for close to the coast. https://coastwatch.pfeg.noaa.gov/erddap/info/erdPH2sstamday/index.html and

https://coastwatch.pfeg.noaa.gov/erddap/info/erdAGsstamday/index.html. The SST-based UPW index is the difference between the coast box (1 to 5) and a box 3 degrees longitude offshore at the same latitude.

The Bakun index (Bakun 1973) is calculated based upon Ekman's theory of mass transport due to wind stress. The index is computed from the ektrx and ektry, which are the x- and y- components of Ekman Transport (kg m^-1 s^-1) obtained from the ERDDAP link below, and coast_angle is 158 degrees for the India west coast near Kochi (74.5E 11.5N). The ekrtrx and ektry data were downloaded for (74.5E 11.5N) from

https://coastwatch.pfeg.noaa.gov/erddap/info/erdlasFnWPr/index.html.

The function to compute the Bakun index is from https://oceanview.pfeg.noaa.gov/products/upwelling/bakun.

References

SST data: These data were provided by GHRSST and the US National Oceanographic Data Center. This project was supported in part by a grant from the NOAA Climate Data Record (CDR) Program for satellites.

The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environmental Research Division.

Wind-based UPW index: NOAA's CoastWatch Program distributes wind velocity measurements derived from the Seawinds instrument aboard NASA's QuikSCAT satellite. The Seawinds instrument is a dual-beam microwave scatterometer designed to measure wind magnitude and direction over the global oceans. CoastWatch further processes these wind velocity measurements to wind stress and wind stress curl.

Bakun index: The Environmental Research Division (ERD), within NOAA Fisheries, has long been a leader in development and calculation of upwelling and other environmental indices. ERD was originally established as the Pacific Environmental Group at the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California, to take advantage of the Navy's global oceanographic and meteorological models. FNMOC produces operational forecasts of the state of the atmosphere and the ocean several times daily. Before the advent of satellite oceanography, these forecasts provided global snapshots of ocean conditions for Navy operations, but were also invaluable for studies of fisheries climatology since they provided long time series of environmental conditions at a much higher resolution than was possible from direct measurement. The FNMOC sea-level pressure became the basis of the Bakun upwelling index calculation, and provides estimates of upwelling for the Northern Hemisphere starting in 1948 and globally since 1981.

Bakun A (1973). "Coastal upwelling indices, west coast of North America." US Department of Commerce, NOAA Technical Report NMFS SSRF-671.

Chamberlain S (2019). rerddap: General Purpose Client for 'ERDDAP' Servers. R package version 0.6.5, https://CRAN.R-project.org/package=rerddap.

Mendelssohn R (2020). rerddapXtracto: Extracts Environmental Data from 'ERDDAP' Web Services. R package version 0.4.7, https://CRAN.R-project.org/package=rerddapXtracto.

Precipitation Data

Description

We used three precipition datasets off the southwest coast of India. Two are satellite derived and one is based on land gauges.

Details

The National Climatic Data Center provides basic information on the Global Precipitation Climatology Project (GPCP) Precipitation dataset. The dataset consists of monthly precipitation estimates (average mm/day) from January 1979 to the present. The precipitation estimates merge several satellite and in situ sources into a final product. Data are provided on a 2.5 degree grid. The GPCP Precipitation data are provided by the NOAA/NCEI Global Precipitation Climatology Project and were downloaded from https://www.ncei.noaa.gov/data/global-precipitation-climatology-project-gpcp-monthly. Two boxes were defined, one off the Kerala coast and one off the Karnataka coast, and the average values of all grid points within these boxes were used. The boxes are Kerala Lat(8.75, 11.25), Lon(73.25, 75.75) Karnataka Lat(13.75, 16.25), Lon(71.25, 73.75)

The land gauge data are a monthly rainfall (in mm) area weighted average for each state in India starting from 1901 onwards. This data set is based on rain guages. The data are provided by the India Meteorological Department (Ministry of Earth Sciences). The 1901 to 2014 data were downloaded from the Open Government Data Platform India https://data.gov.in. The 2015 and 2016 data were extracted from the yearly Rainfall Statistics reports (see references).

NASA's Tropical Rainfall Measuring Mission (TRMM) website provides background on the TRMM precipitation data (https://pmm.nasa.gov/). 1997 to 2015 monthly precipitation estimates on a 0.25 degree grid were downloaded from the Tropical Rainfall Measuring Mission (TRMM) website. The data were averaged in the 2.5 x 2.5 degree boxes 1 to 13 used for the other satellite data.

References

Adler R, Huffman G, Chang A, Ferraro R, Xie P, Janowiak J, Rudolf B, Schneider U, Curtis S, Bolvin D, Gruber A, Susskind J, Arkin P (2003). "The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present)." Journal of Hydrometeorology, 4, 1147-1167.

Adler R, Wang J, Sapiano M, Huffman G, Chiu L, Xie PP, Ferraro R, Schneider U, Becker A, Bolvin D, Nelkin E, Gu G, Program NC (2016). "Global Precipitation Climatology Project (GPCP) Climate Data Record (CDR), Version 2.3 (Monthly)." National Centers for Environmental Information. doi: 10.7289/V56971M6.

Purohit MK, Kaur S (2016). "Rainfall Statistics of India - 2016." India Meterorological Department (Ministry of Earth Sciences). http://hydro.imd.gov.in/hydrometweb/.

Kothawale DR, Rajeevan M (2017). Monthly, seasonal and annual rainfall time series for all-India, homogeneous regions and meteorological subdivisions: 1871-2016. Report, Indian Institute of Tropical Meteorology..

NCEI (2017). Global Precipitation Climatology Project Monthly Product Version 2.3. Retrieved from National Centers for Environmental Information website:
https://www.ncei.noaa.gov/data/global-precipitation-climatology-project-gpcp-monthly/access/.

Chlorophyll Data

Description

The CHL satellite data were downloaded from the NOAA ERDDAP server using R Mendelssohn's **rerddapXtracto** R package which uses the ropensci **rerddap** R package (see citations in the SST data description).

Details

The Chlorophyll-a products are developed by the Ocean Biology Processing Group in the Ocean Ecology Laboratory at the NASA Goddard Space Flight Center.

For 1997 to 2002, we used the Chlorophyll-a 2014.0 Reprocessing (R2014.0) product from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) on the Orbview-2 satellite. These data are on a 0.1 degree grid with units of mg m^{-3}. See reference below.

For 2003 to 2017, we used the MODIS-Aqua product on a 4km grid with units of mg m^{-3}. These CHL data are taken from measurements gathered by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua Spacecraft. See reference below.

Both CHL data sets were downloaded from the NOAA ERDDAP server:

https://coastwatch.pfeg.noaa.gov/erddap/info/erdSW1chlamday/index.html

https://coastwatch.pfeg.noaa.gov/erddap/info/erdMH1chlamday/index.html.

The CHL values were averaged across thirteen 1 degree by 1 degree boxes which parallel the bathymetry (Figure 1 in main text).

References

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group; (2014): SeaWiFS Ocean Color Data; NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. https://dx.doi.org/10.5067/ORBVIEW-2/SEAWIFS_OC.2014.0

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Chlorophyll Data; 2014 Reprocessing. NASA OB.DAAC, Greenbelt, MD, USA. https://dx.doi.org/10.5067/AQUA/MODIS/L3M/CHL/2014

Hu C, Lee Z, Franz B (2012). "Chlorophyll aalgorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference." Journal of Geophysical Research: Oceans, 117(C1).

ENSO and IOD Data

Description

Oceanic Nino Index and Dipole Mode Index.

Details

The Oceanic Nino Index (ONI) is one of the primary indices used to monitor the El Nino-Southern Oscillation (ENSO). The ONI index is 3 month running mean of ERSST.v5 SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W)], based on centered 30-year base periods updated every 5 years.
The ONI was downloaded from the National Weather Service Climate Prediction Center

http://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt

The DMI is the monthly Dipole Mode Index. The DMI is defined by the SSTA (SST anomaly) difference between the western Indian Ocean (10°S–10°N, 50°E–70°E) and the southeastern Indian Ocean (10°S–0°, 90°E–110°E). The data were downloaded from

https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/dmi.long.data The original data source is the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) via the page

http://www.jamstec.go.jp/frcgc/research/d1/iod/e/iod/about_iod.html.

References

Saji NH, Yamagata T (2003). "Possible impacts of Indian Ocean Dipole mode events on global climate." Climate Research, 25(2), 151-169. doi: 10.3354/cr025151.

Climate Prediction Center. El Nino-Southern Oscillation.

https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml

Raw Data

Table S1. Landings data and environmental covariates, part 1. N=Oct-Mar Kerala landings. S=Jul-Sep Kerala landings. Values have been rounded to 2 digits. ns- = nearshore (0-80km) boxes 2 to 5 in Figure 1 (main text). r- = regional (0-160km) boxes 1 to 5 and 7 to 10.

Year	N	S	Jun-Jul o-Precip	Apr-May o-Precip	Jun-Jul l-Precip	Apr-May l-Precip	ONI	Sep-Nov DMI	2.5 yr ave DMI	Jun-Sep Bakun UPW
1956	9.76	5.19	NA	NA	611.10	251.45	-0.58	-0.31	NA	NA
1957	12.27	9.81	NA	NA	853.65	225.70	0.96	-0.12	NA	NA
1958	11.02	8.99	NA	NA	668.00	244.30	0.83	-0.63	-0.20	NA
1959	10.15	8.56	NA	NA	1014.25	248.95	0.14	-0.32	-0.30	NA
1960	12.27	10.27	NA	NA	615.60	373.30	0.07	-0.42	-0.37	NA
1961	11.58	9.26	NA	NA	1075.85	297.30	-0.02	0.77	-0.27	NA
1962	11.19	8.49	NA	NA	598.00	283.75	-0.22	0.10	0.08	NA
1963	10.66	8.18	NA	NA	556.75	126.70	0.66	0.61	0.27	NA
1964	12.33	10.42	NA	NA	566.80	89.05	-0.34	-0.42	0.18	NA
1965	11.61	10.41	NA	NA	531.40	162.15	0.90	0.20	0.00	NA
1966	12.01	10.96	NA	NA	549.05	131.30	0.38	0.15	-0.16	NA
1967	12.06	10.23	NA	NA	641.55	157.50	-0.31	0.44	0.02	361.96
1968	12.06	10.97	NA	NA	1002.65	111.65	0.14	-0.23	0.19	1001.08
1969	11.66	9.62	NA	NA	684.65	172.30	0.74	0.18	0.13	320.38
1970	12.06	10.76	NA	NA	546.70	210.90	-0.32	-0.17	0.11	248.03
1971	11.72	9.87	NA	NA	769.10	215.25	-0.94	-0.11	0.10	388.74
1972	10.97	9.37	NA	NA	558.10	261.75	0.93	0.78	0.15	378.01
1973	11.21	9.85	NA	NA	600.25	125.70	-0.62	-0.11	0.31	553.12
1974	11.40	9.63	NA	NA	635.55	174.75	-0.89	-0.34	0.29	503.45
1975	10.94	9.43	NA	NA	697.85	143.00	-1.05	-0.40	0.03	504.33
1976	11.38	9.12	NA	NA	419.15	105.15	-0.05	0.13	0.05	444.57
1977	11.26	9.75	NA	NA	676.45	204.35	0.51	0.28	0.12	435.16
1978	11.54	9.73	NA	NA	722.40	235.35	-0.10	-0.06	0.13	498.40
1979	11.25	10.15	7.13	0.64	622.55	84.85	0.25	0.06	0.03	679.70
1980	10.72	8.69	7.28	2.97	749.95	110.05	0.25	-0.26	-0.02	467.86
1981	11.80	10.29	8.01	3.16	701.10	121.10	-0.27	-0.22	-0.01	360.28
1982	11.63	10.26	7.92	2.01	561.85	104.30	0.99	0.78	-0.01	158.49
1983	11.71	8.77	5.53	0.33	453.00	44.55	0.48	0.11	0.15	420.36
1984	11.39	9.55	8.25	3.98	748.10	123.35	-0.51	-0.21	0.22	454.20
1985	10.76	9.86	6.83	4.50	608.80	160.40	-0.60	0.12	-0.04	542.46
1986	9.19	5.24	7.05	2.46	461.35	94.90	0.25	0.19	-0.08	631.25
1987	9.43	10.36	4.53	2.30	396.80	82.75	1.28	0.53	-0.01	476.04
1988	11.24	9.85	12.44	3.25	507.05	167.40	-0.81	-0.02	0.15	238.77
1989	11.46	11.22	8.56	3.53	554.10	155.45	-0.60	0.02	0.12	316.99
1990	11.50	10.97	5.94	3.29	582.00	265.15	0.32	0.13	-0.05	352.55
1991	10.42	9.49	11.92	1.49	1000.80	105.20	0.65	0.36	0.02	298.60
1992	9.88	8.80	8.99	4.07	793.55	130.70	0.63	-0.28	0.06	270.65
1993	9.80	9.69	9.30	2.97	716.60	112.75	0.31	0.17	0.03	232.04
1994	6.57	5.91	8.72	4.01	900.25	147.90	0.48	0.84	-0.01	147.73
1995	9.67	8.27	6.69	1.96	597.95	245.25	-0.16	0.06	0.31	211.98
1996	10.64	9.29	7.67	2.16	634.20	99.30	-0.46	-0.53	0.30	174.91
1997	10.57	9.61	8.29	1.97	757.35	97.10	1.17	1.30	0.02	105.08
1998	10.93	10.09	8.42	2.66	686.95	106.35	-0.06	-0.28	0.26	-10.37
1999	11.45	10.80	7.42	5.22	653.85	282.40	-1.23	0.22	0.33	69.47
2000	11.20	11.31	5.18	4.82	488.50	110.40	-0.84	0.16	0.16	195.69

Year	N	S	Jun-Jul o-Precip	Apr-May o-Precip	Jun-Jul l-Precip	Apr-May l-Precip	ONI	Sep-Nov DMI	2.5 yr ave DMI	Jun-Sep Bakun UPW
2001	11.11	10.78	9.07	7.39	648.30	238.25	-0.31	0.03	0.20	126.03
2002	11.98	11.15	5.54	4.52	404.95	228.80	0.63	0.60	0.14	134.28
2003	11.88	10.83	10.15	1.87	518.10	108.55	0.25	0.18	0.14	94.71
2004	11.90	11.04	6.97	4.65	545.80	353.60	0.45	0.25	0.16	387.97
2005	11.82	10.91	6.72	4.73	756.00	170.10	0.04	-0.07	0.13	429.31
2006	11.87	10.81	4.97	5.62	573.25	297.10	0.10	0.83	0.03	464.25
2007	12.01	11.00	11.90	3.26	866.75	173.05	-0.58	0.43	0.18	369.20
2008	11.51	11.06	8.74	2.55	493.35	91.15	-0.76	0.34	0.32	317.37
2009	11.58	11.21	8.07	4.61	680.55	129.10	0.31	0.27	0.33	405.72
2010	12.27	10.63	10.02	3.86	649.55	165.05	-0.45	-0.06	0.31	99.47
2011	12.18	11.01	6.85	4.11	664.45	143.40	-0.83	0.63	0.27	110.04
2012	12.44	11.71	5.78	1.94	402.60	140.65	-0.13	0.49	0.28	131.89
2013	11.40	9.92	8.88	3.36	936.45	84.30	-0.29	0.25	0.32	158.15
2014	11.30	10.76	5.05	3.31	566.10	173.35	0.14	0.33	0.21	216.61
2015	NA	10.20	8.32	3.62	687.95	174.65	1.49	0.70	0.14	152.07

Table S2. Landings data and environmental covariates, part 1.

Year	Apr-May r-SST	Oct-Dec ns-SST	Jun-Sep sst-diff UPW	Jun-Sep ns-SST	2.5 yr ave r-SST	Jul-Sep log CHL	Oct-Dec log CHL
1982	29.41	29.18	1.43	26.51	NA	NA	NA
1983	29.27	28.76	0.70	27.67	28.48	NA	NA
1984	29.49	28.39	1.87	25.70	28.49	NA	NA
1985	29.53	28.54	1.44	25.91	28.38	NA	NA
1986	29.46	28.23	1.26	25.86	28.22	NA	NA
1987	30.02	29.54	1.12	26.93	28.27	NA	NA
1988	29.69	28.60	0.56	27.08	28.54	NA	NA
1989	29.78	28.53	1.24	26.03	28.67	NA	NA
1990	29.43	28.92	1.22	26.06	28.35	NA	NA
1991	29.72	28.13	1.04	26.43	28.28	NA	NA
1992	29.49	28.47	0.98	26.50	28.23	NA	NA
1993	29.47	28.77	0.47	27.04	28.22	NA	NA
1994	29.36	28.56	1.48	26.11	28.25	NA	NA
1995	30.12	28.73	0.88	26.79	28.39	NA	NA
1996	29.51	28.32	0.78	26.28	28.43	NA	NA
1997	30.19	29.80	0.93	27.64	28.56	0.09	-0.90
1998	30.60	28.45	-0.10	27.79	28.87	1.46	-0.06
1999	28.86	28.16	0.74	26.72	28.91	1.45	0.07
2000	29.11	29.13	1.12	26.72	28.53	1.65	-0.56
2001	29.38	28.62	1.30	26.19	28.32	1.54	-0.08
2002	29.84	28.80	1.12	26.73	28.37	1.85	-0.32
2003	29.72	28.67	1.15	26.90	28.46	2.12	0.22
2004	29.70	29.14	1.07	26.67	28.58	2.49	-0.01
2005	30.01	28.67	0.78	27.45	28.69	1.75	0.70
2006	29.40	28.96	0.63	27.72	28.71	2.07	-0.14
2007	29.81	28.60	0.27	27.87	28.82	1.69	-0.28
2008	29.18	28.92	0.62	27.49	28.70	1.57	-0.43
2009	29.78	29.03	0.66	27.48	28.71	1.90	1.04
2010	30.31	28.57	1.01	27.51	28.82	1.92	0.38
2011	29.57	29.06	1.06	27.45	28.81	1.84	0.25
2012	29.31	29.38	0.69	27.66	28.78	1.52	-0.14
2013	29.79	28.64	1.18	26.70	28.78	1.71	0.04
2014	29.88	29.02	0.59	27.78	28.72	1.73	-0.54
2015	30.00	29.55	0.39	28.42	28.79	0.94	-0.63