Temporal trends in southern California coastal fish populations relative to 30-year trends in oceanic conditions

M. James Allen, Robert W. Smith[1], Erica T. Jarvis, Valerie Raco-Rands, Brock B. Bernstein[2] and Kevin T. Herbinson[3]

ABSTRACT - Changes in the abundance of southern California marine fish populations during the past 30-years have raised concerns that these populations are at risk. These changes have been attributed to changes in oceanic conditions, overfishing, pollution, and habitat alteration. The objective of this study was to assess the relationship of changes in southern California fish populations to trends in different environmental variables. Fish population trends were determined from long-term (20- to 30-year) fish databases (e.g., power generating station fish impingement and trawl monitoring, recreational fishing, and publicly owned treatment work (POTW) trawl monitoring). Combined, these databases provided information on 298 species of fish. A number of long-term environmental databases (e.g., CalCOFI oceanographic data, shoreline temperature, coastal runoff, and POTW effluent contaminant mass emissions) were used to identify several important independent environmental variables (e.g., Pacific Decadal Oscillation (PDO); El Niño-Southern Oscillation (ENSO); offshore temperature; upwelling in the north, Southern California Bight (SCB), and south; coastal runoff; and contaminant mass emissions). Relationships of fish population trends to these environmental trends were determined using stepwise multiple regression analysis. The analysis sequentially assessed the relative importance of temperature, upwelling, and "other" variables in describing fish population trends. Most southern California fish populations had population trends that followed trends in natural oceanic variables. The most important of these were PDO (positive and negative responses), upwelling in the SCB, offshore temperature, and ENSO. The PDO was the dominant influence for most species in these databases, with the presence or absence of upwelling in the SCB during the warm regime having an important influence on others. The reduced abundance of cold-water species during the regime shift at the end of the 1970s was compensated only in part by increased abundances of warm-water species. Trends in surface runoff and mass emissions were difficult to distinguish from positive and negative PDO trends, respectively. While many species showed positive or negative responses to the environmental variables, catch trends for several important fished species showed weak or no relationships with any of the environmental variables examined, perhaps due in part to fishing or other influences.

INTRODUCTION

Marine fish populations along the California coast have undergone considerable changes in abundance during the past century. During the past few decades, populations of many commercially and recreationally fished species, as well as unfished species, have decreased in California and southern California (Love *et al.* 1998a,b; Herbinson *et al.* 2001; Brooks *et al.* 2002). These declines in abundance have raised concerns among scientists, managers, and the public that populations of many fish species are at risk and that such changes may have serious consequences to these populations and to the ecosystem, as well as reducing the overall value of this resource for human use. Changes in California fish populations often have been attributed to anthropogenic activities, such as overfishing, habitat alteration, and pollution, as well as to natural changes in

[1]Private consultant, P.O. Box 1537, Ojai, CA 93023.
[2]Private consultant, 308 Raymond Street, Ojai, CA 93023
[3]Southern California Edison Company, P.O. Box 800, Rosemead, CA 91770

oceanic conditions (Allen 1977, Stull *et al.* 1987, Parrish and Tegner 2001, Sheehan and Tasto 2001, Thomson 2001, Allen *et al.* 2002).

This array of potential causes of change makes it difficult to assess whether any particular increase or decrease in abundance, or shift in population distribution, is due to human activity or due to natural changes in the oceanic environment. Although identification of anthropogenic influences on fish population changes is generally of concern because it is under human control, understanding the natural influence on these populations provides the necessary environmental context within which anthropogenic change must be distinguished and managed. Fish populations are known to undergo natural changes in abundance in the absence of significant human exploitation or influence. Layers (varves) of scales from the anaerobic Santa Barbara Basin show periodic cycles of pelagic fish abundance extending back 2000 years (Soutar and Isaacs 1969, 1974; Baumgartner *et al.* 1992). Natural changes include short-term and local changes resulting from storm runoff, longer term regional changes due to El Niños and La Niñas, and even longer-term changes due to interdecadal shifts in oceanic regimes (Radovich 1960, 1961; Mearns 1988; Lea and Rosenblatt 2000, Parrish and Tegner 2001). Recent studies have related temporal changes in fish populations along the West Coast at least in part to natural changes in these oceanic conditions (Hollowed *et al.* 1995, Mantua *et al.* 1997, Klyashtorin 1998, Hollowed *et al.* 2001, Brooks *et al.* 2002, Chavez *et al.* 2003). Improving our ability to separate anthropogenic from natural causes of change is therefore critically important to our ability to manage and enhance this important resource.

The goal of this study is to understand the relationship of southern California fish populations to trends in environmental variables, with emphasis on natural oceanic and atmospheric variables. The objectives of this study are to determine the following: 1) What environmental variables have the most effect on southern California fish populations? 2) What species respond to what environmental variables? 3) Do all species respond alike to an environmental variable? 4) How important are environmental variables in determining trends in fish populations? Details of this study are presented more fully in Allen *et al.* (2003).

METHODS

Database Development

Fish species and abundance databases were developed from several long-term (20-30 year) fish monitoring programs in southern California to determine environmental effects on fish species. These databases included power generating station impingement data, trawl survey data, and recreational fish catch surveys. Oceanographic data were compiled from a number of online databases. These included temperature data collected from offshore waters in the SCB and shoreline temperature data collected along southern California beaches, as well as a number of indices describing warm and cold periods in the ocean and strength of upwelling. In addition to oceanographic databases, rainfall/runoff and outfall mass emissions databases were also developed for nearshore influences.

Fish Abundance Data

Fish abundance data were obtained from the Southern California Edison Company (SCEC) for five southern California power generating stations at Ormond Beach, El Segundo, Redondo Beach, Huntington Beach, and San Onofre (Figure 1a). These coastal power generating stations use seawater to cool condensers. Seawater is pumped into the station from shallow coastal waters via an intake conduit, generally at depths of 4-9 m. Fish impinged in the plant at this time are separated from the seawater on impingement screens. Fish species collected on these screens are identified, counted, measured, and weighed at regular or irregular intervals during the year. San Onofre Nuclear Generating Station (SONGS) data were treated separately from non-SONGS generating stations (and was split into SONGS units 1 and units 2&3) due to variation in duration of data collection and catch for impingement catches from different intake conduits. Non-SONGS data ranged from 1972 to 1999, SONGS 1 from 1972 to 1993, and SONGS 2&3 from 1983 to 2000 (Table 1)

Trawl data were obtained from County Sanitation Districts of Los Angeles County (CSDLAC) for the Palos Verdes Shelf, and from MBC Applied Environmental Sciences for Huntington Beach (Figure 1a). These data were collected as part of National Pollutant Discharge Elimination System (NPDES) monitoring programs for assessing effects of the CSDLAC Joint Pollution Control Plant wastewater discharge and of the Huntington Beach

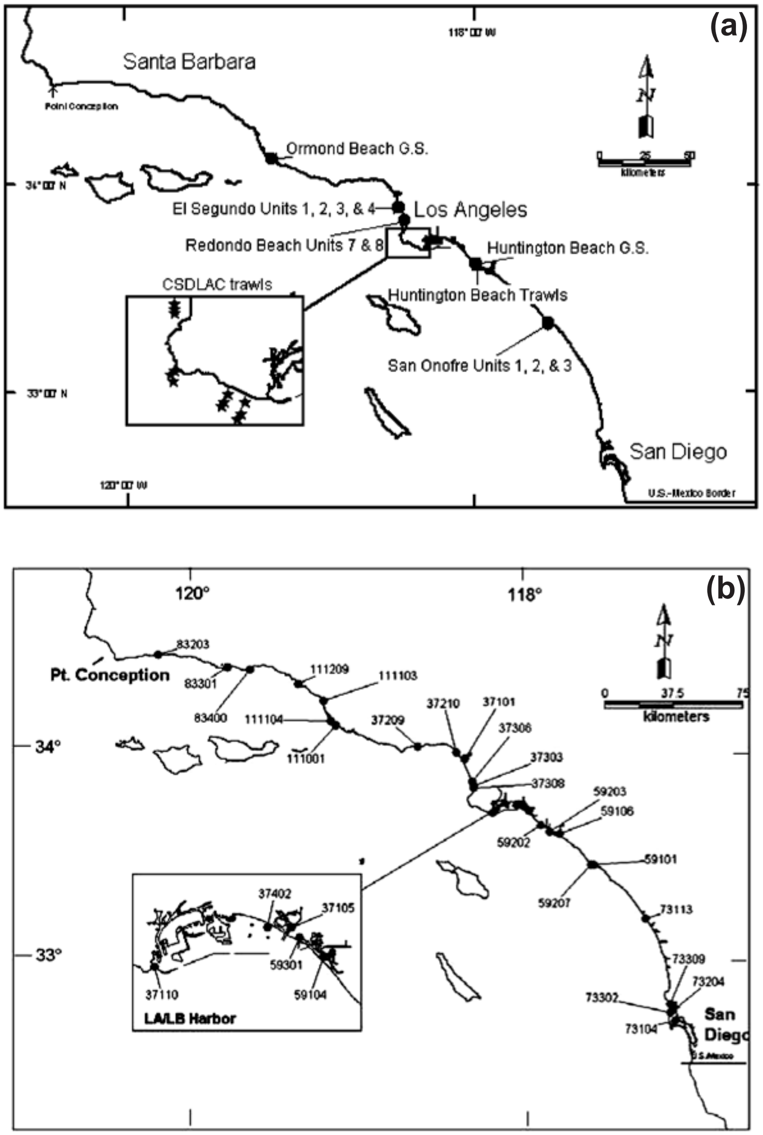


Figure 1. Maps of fish data sites: (a) Locations of power generating station impingement data and trawl data in southern California used in study; (b) Marine Recreational Statistical Survey (MRFSS) sites. CSDLAC = County Sanitation Districts of Los Angeles County; G.S.= Generating station.

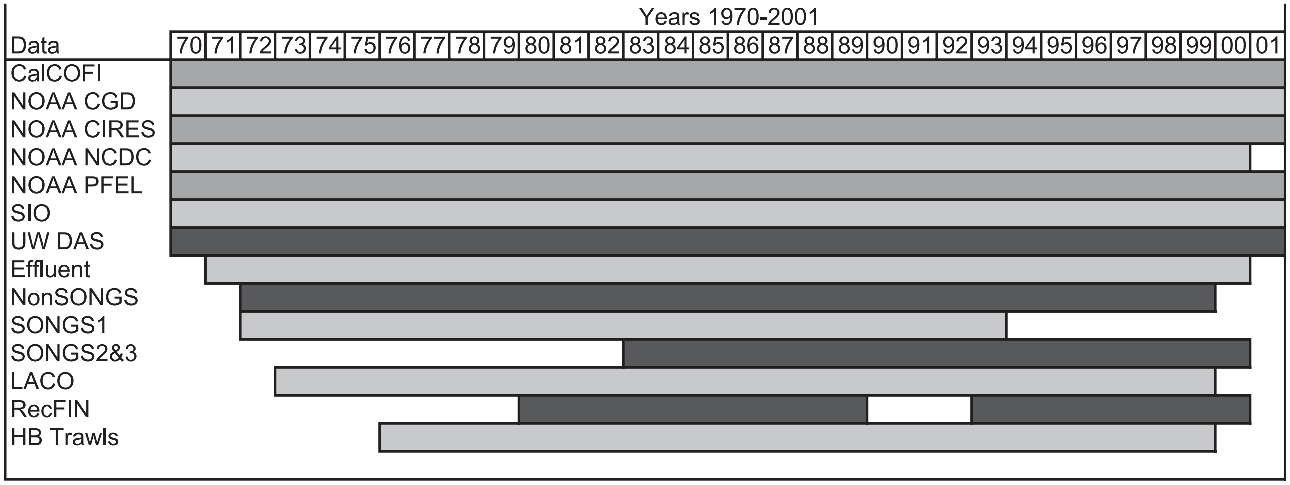
Generating Station (HBGS) cooling water discharge. Both surveys were collected with 7.6 m (headrope) otter trawls with 1.3 cm cod-end mesh, and towed at 1.0-1.25 m/sec. CSDLAC surveys trawled for 10-min along isobaths at 12 stations (3 depths and 4 transects); station depths in each transect were 23, 61, and 137 m. HBGS surveys trawled for 5 min at 12 stations (4 stations each at 3 sites) at 15 m. CSDLAC data used in this study extended from 1973 to 1999, and HBGS data from 1976 to 1999 (Table 1). Abundance, biomass, and length data were obtained for both surveys. Data from individual stations were available for all CSDLAC data but only summed survey catch per unit effort (CPUE) was available for HBGS data.

Recreational fish catch data collected by the Marine Recreational Fisheries Statistical Survey (MRFSS) were obtained from the Recreational Fisheries Information Network (RecFIN) website[4]. The National Marine Fisheries Service (NMFS), state fisheries agencies, and other fishery management groups use these data to aid in fisheries conservation and management decisions and the development of fishery management plans. On the Pacific Coast in California, the MRFSS is conducted as a project of the Pacific States Marine Fisheries Commission (PSMFC) in conjunction with California Department of Fish and Game (CDFG) and NMFS. Data samples were obtained for the years 1980 to 2000 with a hiatus from 1990 to 1992 (Table 1).

MRFSS data result from surveys of angler catch (species, number, weight, and length) and effort at fishing sites upon completion of a fishing trip by trained interviewers. Catch data were obtained for fish species caught by shore and boat (ocean within 3 miles [4.8 km] from shore), with all fishing gear types, from Point Conception, California, to the United States-Mexico International Border (Figure 1b). Shore mode fishing access sites consist of piers, docks, breakwaters, beaches, banks, bridges, and breach ways, while boat mode access sites consist of privately chartered boats, commercial passenger fishing vessels (CPFV), rental boats, and privately owned boats. Data parameters selected for analyses were the following: catch rates (number of fish per angler) and angler hours (total hours fished for a given fishing access site and fishing mode). All data parameters collected for a particular species, site, mode, and year were provided in 2-month intervals termed waves (i.e. January/February, Wave 1).

[4]Pacific States Marine Fisheries Commission. 1999. Recreational Fisheries Information Network (RecFIN) [W. Van Buskirk, ed.] http://www.psmfc.org/recfin.

Table 1. Sources of environmental and fish abundance data and years with available data.



CalCOFI = California Cooperative Oceanographic Fisheries Investigation.
Effluent = Hyperion Treatment Plant, City of Los Angeles; Joint Water Pollution Control Plant, County Sanitation Districts of Los Angeles County; Orange County Sanitation Districts.
HB Trawls = Huntington Beach Generating Station Trawls.
LACO = Los Angeles County Sanitation Districts trawls.
NOAA = National Oceanic and Atmospheric Administration.
NOAA CGD = NOAA, Climate & Global Dynamics division.
NOAA CIRES = NOAA, Cooperative Institute for Environmental Sciences.
NOAA NCDC = NOAA National Climatic Data Center.
NOAA PFEL = NOAA, Pacific Fisheries Environmental Laboratory.
NonSONGS = Impingement data from non-SONGS power generating stations: Ormond Beach, El Segundo, Redondo Units 7&8 and Huntington Beach.
RecFIN = Recreational Fisheries Information Network angler surveys.
SIO = Scripps Institution of Oceanography.
SONGS = San Onofre Nuclear Generating Station.
SONGS1 = SONGS Unit 1 impingement data.
SONGS2 & 3 = SONGS Units 2 & 3 impingement data.
UW DAS = University of Washington, Department of Atmospheric Sciences.

Several manipulations of the MRFSS data set were necessary to meet the study objective. To obtain more complete temporal and spatial coverage, data from several sites were lumped with other site data (in cases where a new name was given to an existing site, or where a site was closed to fishing and replaced with a nearby new fishing site with a different name). In addition, only sites with the longest time series of data were used for analyses (Figure 1b). Catch rates were converted to number of fish per 10,000 h and fishing pressure was represented by the total number of hours fished for any given location and time period. Missing species data for a given site and wave were estimated by multiplying the average deviation in catch rate for that "fish year" by the average catch rate of all other years for the same site and wave. To account for fishing seasonality, the "fish year" was defined as November of the previous year to the following November.

Atmospheric-Oceanic Environmental Data

Nearshore and offshore temperature data were obtained from data archives available through the CalCOFI website (www.calcofi.org). The CalCOFI program is a collaborative effort of Scripps Institution of Oceanography, the Coastal Fisheries Resources Division of the Southwest Fisheries Science Center; NMFS, of the National Oceanic and Atmospheric Administration (NOAA); and the California Department of Fish and Game (CDFG), who conduct surveys of the California Current. These cruises have monitored physical and biological changes of the California Current ecosystem since 1949. Although surveys have extended from northern California to the Gulf of California in the past, recent quarterly cruises off California have been conducted from just north of Point Conception to San Diego. This region is divided into five water

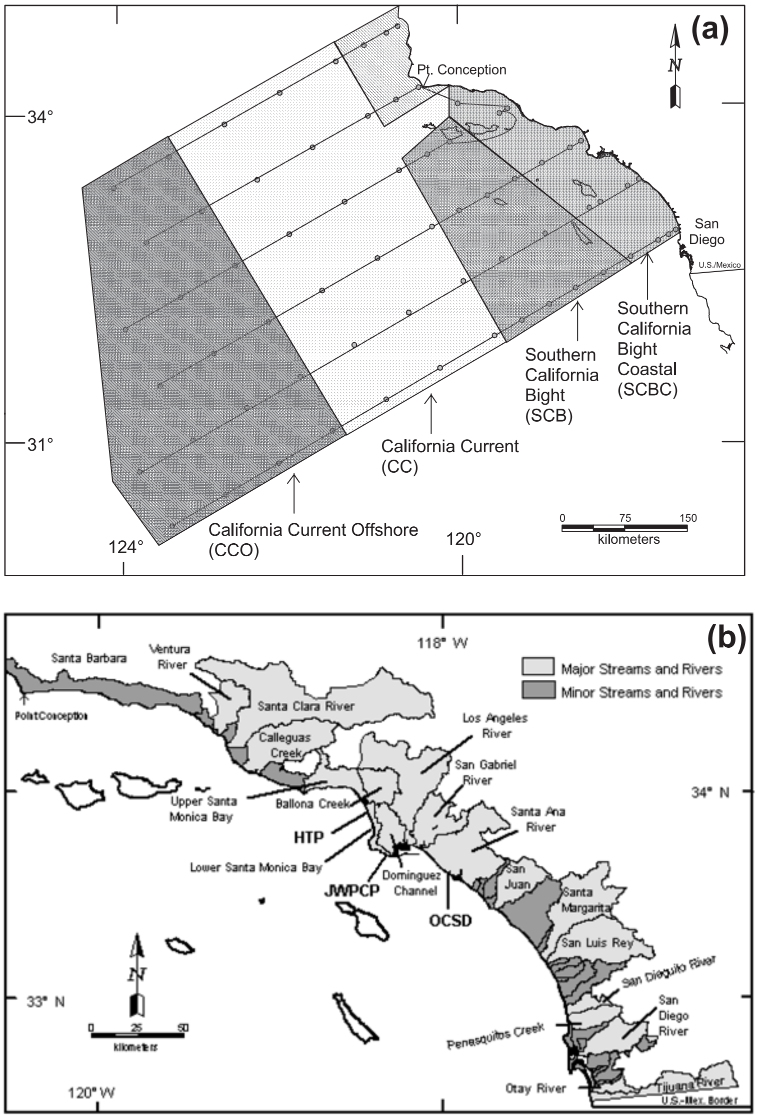


Figure 2. Physical data sites: (a) California Cooperative Fisheries Investigations (CalCOFI) cruise stations in the southern California Bight, with five distinct water mass regions (California Current Offshore, California Current, Southern California Bight [SCB], SCB Coastal, and Point Conception); (b) Watersheds used to estimate runoff volumes and POTWs (publicly owned treatment works) used for effluent mass emission data: Hyperion Treatment Plant (HTP; City of Los Angeles); Joint Water Pollution Control Plant (JWPCP; County Sanitation Districts of Los Angeles County); and Orange County Sanitation Districts (OCSD).

mass regions: California Current (CC); California Current Offshore (CCO); Point Conception (PC); Southern California Bight (SCB); and the Southern California Bight Coastal (SCBC) (Figure 2a). Yearly mean parameter values (temperature, salinity, and zooplankton volume) have been computed for each site in the survey grid. In the present study, temperature, salinity, and zooplankton volume data were obtained for the years 1970 to 2001 (Table 1). Methods used in calculating these values are given in Allen et al. (2003).

Historical shoreline sea surface temperature data were obtained via anonymous FTP at ftp://nemo.ucsd.edu/pub/shore. The FTP site is a project of the Shore Stations Program of the Marine Life Research Group at Scripps Institution of Oceanography. The Shore Stations Program is responsible for the collection, analysis, and yearly publication of daily sea surface temperature and salinity readings from various shore stations along the Pacific coast of California, Oregon, and Washington. The various stations collect temperature readings using a variety of sampling methods including tide gauges, automated systems, commercial immersion thermometers, calibrated immersion thermometers, and calibrated electronic digital thermometers. Temperature readings that are reported in degrees Fahrenheit are converted to the nearest 0.1°C. Shoreline temperature data used in this study were analyzed from Port San Luis, California, to the Scripps pier in La Jolla, California. Data used in this study ranged from 1970 to 2001 (Table 1).

Multivariate El Niño indices were obtained from the NOAA-Cooperative Institute for Environmental Sciences (CIRES) Climate Diagnostics Center web site (http://www.cdc.noaa.gov). The data are principal component analysis (PCA) scores from six ENSO-related weather and oceanographic variables that include sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Positive MEI values represent the warm (El Niño) phase and negative values represent the cold (La Niña) phase of the ENSO. The MEI values are given for 12 sliding bimonthly seasons (Dec/Jan, Jan/Feb, Feb/Mar, etc.). A high and a low MEI value was calculated for each year by averaging the three highest MEI values for the year, and the three lowest MEI values for the year. The average with the highest absolute magnitude was used for each year. Data used in this survey ranged from 1970 to 2001 (Table 1).

Several indices representing the longer-term persistent temperature regimes of the Pacific Decadal Oscillation (PDO) were obtained via from the following website: ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest. The index used is the first principal component of the extra-tropical North Pacific Ocean sea surface temperature (SST) anomalies (Mantua *et al*. 1997, Zhang *et al*. 1997, Hare and Mantua 2000). Data used in this survey ranged from 1970 to 2001 (Table 1). Indices negatively correlated with the PDO index were obtained from the Climate and Global Dynamics Division of the National Science and Atmospheric Research website (http://www.cgd.ucar.edu). Values represent area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W, or the area of the northern Pacific pressure cell known as the Aleutian Low (Trenberth and Hurrell 1994). Data used in this survey ranged from 1970 to 2001 (Table 1).

Coastal upwelling indices were obtained from the PFEL website (http://www.pfeg.noaa.gov). The index values represent wind-driven Eckman transport normal to the coastline. Positive values are, in general, the result of equatorward wind stress while negative values imply downwelling, the onshore advection of surface waters accompanied by a downward displacement of water. The index was obtained for six locations along the coast of California and Baja California (24°N, 27°N, 30°N, 33°N, 36°N, and 39°N). Data used in this survey ranged from 1970 to 2001 (Table 1).

Outfall Mass Emissions and Runoff Data

Effluent data from the three largest municipal wastewater treatment facilities: Hyperion Treatment Plant (HTP; City of Los Angeles); Joint Water Pollution Control Plant (JWPCP; CSDLAC); and Orange County Sanitation District (OCSD) (Figure 2b) in the SCB were obtained directly from each discharging agency. These facilities discharge an average of 353, 351, and 215 million gallons per day (mgd), respectively, of treated wastewater effluent. Effluent constituent monitoring is mandated under the NPDES permits issued by the U. S. Environmental Protection Agency (U.S. EPA) and the Los Angeles and Santa Ana Regions of the California Regional Water Quality Control Board (CRWQCB). Monthly data were originally obtained for 87 constituents covering the years 1971 through 2000. The methods used for calculating effluent parameter mass emissions is given in Allen *et al.* (2003).

Daily rainfall data from 1970-2000 for six rainfall gauges at airfields (Santa Barbara, Los Angeles, Long Beach, Vista, San Diego-Miramar, San Diego-Lindbergh) were obtained from the NOAA National Climatic Data Center website. Daily rainfall data were summed by month and then entered in a database for further calculation of amount of storm runoff. A total of 168 watershed delineations along the southern California coast were obtained from a data set created by the Interagency California Watershed Mapping Committee (CALWATER) (Figure 2b). The watersheds then were assigned to 75 discharge points. Runoff from these watersheds was determined using rainfall data (see Allen *et al.* 2003) and a runoff model (Ackerman and Schiff 2003).

Data Analysis

Data analysis involved the following steps: 1) selection of the most meaningful databases for each fish species; 2) selection of important environmental variable trends; 3) determine relationships of fish population trends relative to environmental variables using multiple regression analysis; 4) determination of the most influential environmental trends for each species and classification of fish species by the single environmental variable that most influenced their population trends.

Selection of Most Meaningful Database for Fish Species

As many fish species were found in different databases in this study, there was a need to select a most meaningful database for use in the analyses. The importance of fish species in each database was determined by its frequency of occurrence (number of years of occurrence) and percent total catch in the database over the period examined. The most meaningful database for a species was that in which it had its highest frequency of occurrence (i.e., occurred in the most years), and, in the case of ties with another database, its highest percent abundance. Frequency of occurrence was adjusted to a 30-year database to provide a more even weighting between 20- and 30-year databases. Thus, a maximum percent occurrence for a species occurring 100% of the time in a 20-year database would be 67%.

Identification of Most Important Environmental Variables

Initially, 25 weather/oceanographic variables were identified from the environmental databases described above. These were reduced to only those summarizing the main patterns in the weather and oceanographic indices using principal component analysis. For each set of interrelated variables, a PCA and Varimax analysis was performed (see Allen *et al.* 2003). This analysis created new variables (axis scores) that were correlated with independent subsets of the original variables. Thus, the most important of the original weather/oceanographic variables were identified as those that were most correlated with the major principal component axes. These new variables were defined as shoreline temperature, NpiPDO (North Pacific Index x PDO), offshore temperature, El Niño, a dummy PDO variable, northern upwelling, upwelling in the Bight, upwelling off Baja California, runoff, and outfall mass emissions (see Results). Data for each new variable were converted to *z* scores to standardize the data for trend comparison and multiple regression analysis. Plots of these variables then were smoothed using a LOESS multivariate smoothing technique (Grosse 1989, Venables and Ripley 2002) in an attempt to capture general patterns rather than short-term fluctuations.

Stepwise Multiple Regression Analysis

Stepwise multiple regression analysis was used to determine the most important relationships between fish population and environmental trends. The multiple regression analyses were done in a step-wise, top-down manner. The independent variables used in the three stages of analysis are in order of presumed importance as far as scale of effect is concerned. Thus, the most large-scale atmospheric/oceanographic variables (e.g., ENSO, PDO) that are well-described by ocean temperature were considered first, followed by more regional variables (upwelling), and then local variables (e.g., runoff and outfall mass emissions). In the first step, atmospheric/oceanographic (or temperature) variables were used as the independent variables and fish species CPUE values as the dependent variables. In the second, the regression residuals from the temperature analysis were used as the dependent variable in a regression analysis with upwelling variables. Finally, the regression residuals from the upwelling analysis were used in a regression analysis with the outfall and runoff variables as environmental variables.

The regression analysis output (see Allen *et al.* 2003) included standardized partial regression coefficients (slopes), R^2 value, p values associated with tests of the null hypotheses for the overall regression, and each independent variable. The standardized partial regression coefficients are directly comparable since these coefficients are not affected by the scale or variability of the dependent and independent variables. These coefficients are obtained if all the dependent and independent variables are first converted to z scores before analysis. When there are interaction terms among the independent variables (as is the case with the temperature data where TempPDO x TempENSO interaction is included), all variables literally need to be converted to z scores before analysis (including the computation of the interaction term), and the unstandardized regression output is used (Aiken and West 1991).

At each stage of the regression analyses of all species, regression models were computed for all combinations of lags of 0, 1, and 2 years for each of the independent variables, except that TempPDO variable already has a gradual 4-year lag built in. The regression model with the lowest p value associated with the overall regression was chosen for inclusion in the results as the basis for the next level of analysis.

If there is positive temporal autocorrelation in the residuals of the regression analysis, the regression error variances will tend to be underestimated and the regression p values will tend to be too low. The regression p values were used here for screening purposes (selecting models for further analysis and interpretation). The p value used for screening was $p = 0.05$.

Determination of the Most Influential Environmental Variables for Each Species

With many thousands of analyses comparing species trends to environmental variables in different fish databases, there was a need to select the most meaningful species trends for evaluation. Within the most representative database for each species, its population trend may have a significant correlation coefficient ($p = 0.05$ or less) with more than one environmental variable. To determine the most meaningful trend, the magnitudes of the regression coefficients were ranked, from positive to negative. Species considered to be strongly correlated with an independent variable were those with regression coefficients greater than +0.50 and less than -0.50. If a species were strongly correlated with more than one independent variable, focus was placed on the variable with the regression coefficient of greatest magnitude to limit discussion to a single variable constituting the greatest influence to a species trend.

RESULTS

A total of 298 species of fish, representing 5 classes and 109 families, was included in the impingement, trawl, and recreational fish databases used in this study (see Allen *et al.* 2003 for complete list of species). Dominant fish species differed among databases (Table 2). The power generating station impingement data and Huntington Beach Generating Station trawl data were all dominated by nearshore schooling species; species in these databases are all captured at depths less than 15 m. The recreational fish catch data (both shore and boat) were dominated by sandy bottom and pelagic species. The CSDLAC trawl data was dominated by deepwater flatfishes.

Description of Most Important Environmental Variables

Temperature Trend Variables

Several interesting patterns were apparent from the smoothed plots of the temperature variables (Figure 3). The plots of shoreline temperature (Figure 3a) and NpiPDO (Figure 3b) showed similar patterns, with below average values in the 1970s and in 1999-2001, and above average values in the 1980s and 1990s. These data suggest that, overall, atmospheric trends seem to be influencing temperature in the SCB. However, a below-average trough was apparent in the NpiPDO trend, reflecting the 1988-1989 La Niña (Figure 3b). As the smoothed shoreline temperature plot appeared to be less influenced by El Niño and La Niña events, it appeared to represent present views of the PDO pattern.

The offshore temperature plot (Figure 3c) describes a change from above-average temperatures in the late 1970s and early 1980s, a dip to below average values during the 1988-1989 La Niña, a return to above average temperatures in the mid-1990s, and a decline to below average temperatures in 1999-2001. The El Niño curve describes about seven periods of temperatures indicative of El Niños (1972, 1977-1980, 1982-1983, 1986-1987, 1992-1993, 1997-1998) during those two decades (Figure 3d). Strong El Niños occurred during 1982-1983 and 1997-1998, with moderate El Niños in 1972, 1986-1987, and 1992-1993. Strong La Niñas occurred in 1971, 1973-1976, 1988-1989, and 1999-2001. The dummy long-term PDO plot (Figure 3e) describes an idealized version of the shoreline temperature and NpiPDO plots without El Niño and La Niña effects. The dummy long-term PDO with lag effect plot (Figure 3f) is the dummy PDO, with a gradual 4-year lag to account for delayed responses in fish populations.

Table 2. Percent catch abundance of dominant fish species by database. Dominant species in each database are highlighted.

		Percent Catch Abundance by Database*					
		Recreational		Trawl		Impingement	
Scientific Name	Common Name	SH	BT	LA	HB	nS	S2/3
Seriphus politus	queenfish	3.5	1.6	0.2	18.2	44.6	32.7
Engraulis mordax	northern anchovy	--	--	1.4	50.4	8.0	22.3
Phanerodon furcatus	white seaperch	0.3	0.0	0.2	1.0	4.5	25.0
Genyonemus lineatus	white croaker	8.7	11.9	3.6	26.6	5.0	7.3
Amphistichus argenteus	barred surfperch	19.8	0.3	--	0.4	0.1	0.0
Scomber japonicus	Pacific chub mackerel	17.8	16.3	0.0	0.0	0.1	1.3
Paralabrax nebulifer	barred sand bass	0.7	12.5	0.1	0.0	0.4	0.0
Atherinopsis californiensis	jacksmelt	10.8	0.4	--	0.0	1.2	0.6
Microstomus pacificus	Dover sole	--	0.0	17.5	0.0	0.0	0.0
Citharichthys sordidus	Pacific sanddab	0.0	1.6	9.7	--	0.0	0.0
Lyopsetta exilis	slender sole	--	--	9.5	--	0.0	0.0

*SH = Shore recreational catch; BT = Boat recreational catch; LA = County Sanitation Districts of Los Angeles County monitoring trawls; HB = Huntington Beach Power Generating Station monitoring trawls; nS = non-San Onofre Power Generating Station data; S2/3 = San Onofre Power Generating Stations 2 and 3 data
Common and scienitific names used are those of Nelson *et al*. (2004).

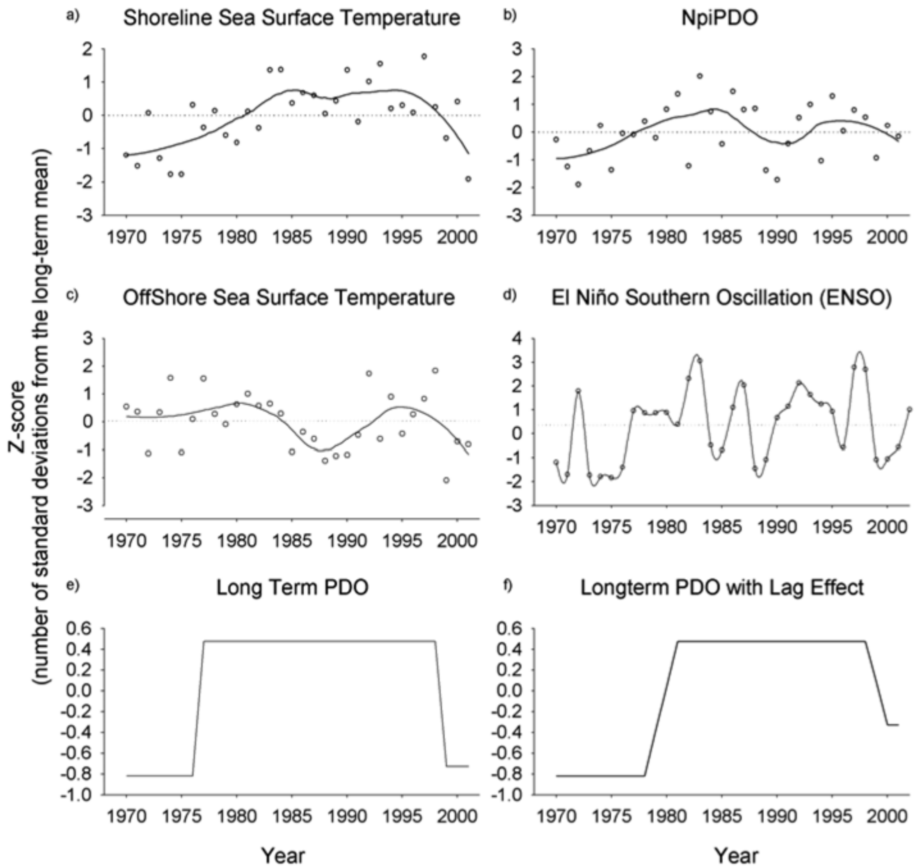


Figure 3. Smoothed temperature plots of (a) shoreline sea surface temperature, (b) atmospheric pressure indices representative of the Pacific Decadal Oscillation (PDO), (c) offshore sea surface temperature, (d) El Niño Southern Oscillation (ENSO) indices, (e) long term PDO "dummy" variable, and (f) long term PDO "dummy" variable with four-year lag effect for the Southern California Bight from 1970 to 2002.

Upwelling Trend Variables

The plots of upwelling north of Point Conception, within the SCB, and off southern Baja California Sur (Punta Eugenia to Bahia Magdalena) showed a pattern suggesting a movement of upwelling down coast (Figure 4). The upwelling north (Figure 4a) showed high upwelling in the late 1970s, low upwelling in the 1980s and early 1990s, and an increase in the late 1990s. The SCB upwelling trend (Figure 4b) was high in the early 1970s, low in the late 1970s, high (resembling the NpiPDO pattern) in the 1980s, and low throughout the 1990s. The upwelling south curve (Figure 4c) was nearly an inverse of the upwelling SCB curve (Figure 4b); it was high in late 1970s, low in the 1980s, and high in the 1990s.

Outfall Mass Emissions and Runoff Variables

The outfall (effluent mass emissions) and runoff plots showed different patterns (Figures 4d,e). Effluent mass emissions decreased until about 1990, after which it became asymptotic (Figure 4d). Runoff volume was low in the 1970s, high in the early 1980s, low in the late 1980s and early 1990s, high in the early to mid-1990s, and low in the late 1990s (Figure 4e). This curve appears to be a slightly exaggerated version of the NpiPDO curve (Figure 3b) and hence is most likely influenced by atmospheric patterns as was found with temperature.

Relationship of Fish Population Trends to Environmental Trends

Among species meeting the selection criteria (see Methods), a total of 123 species occurred in 15 or more years (50% or more of a 30-year database). Of these, 68 species (55%) were considered to be strongly correlated with an environmental variable (i.e., had regression coefficients greater than +0.50 and less than -0.50) and 55 (45%) were not correlat-

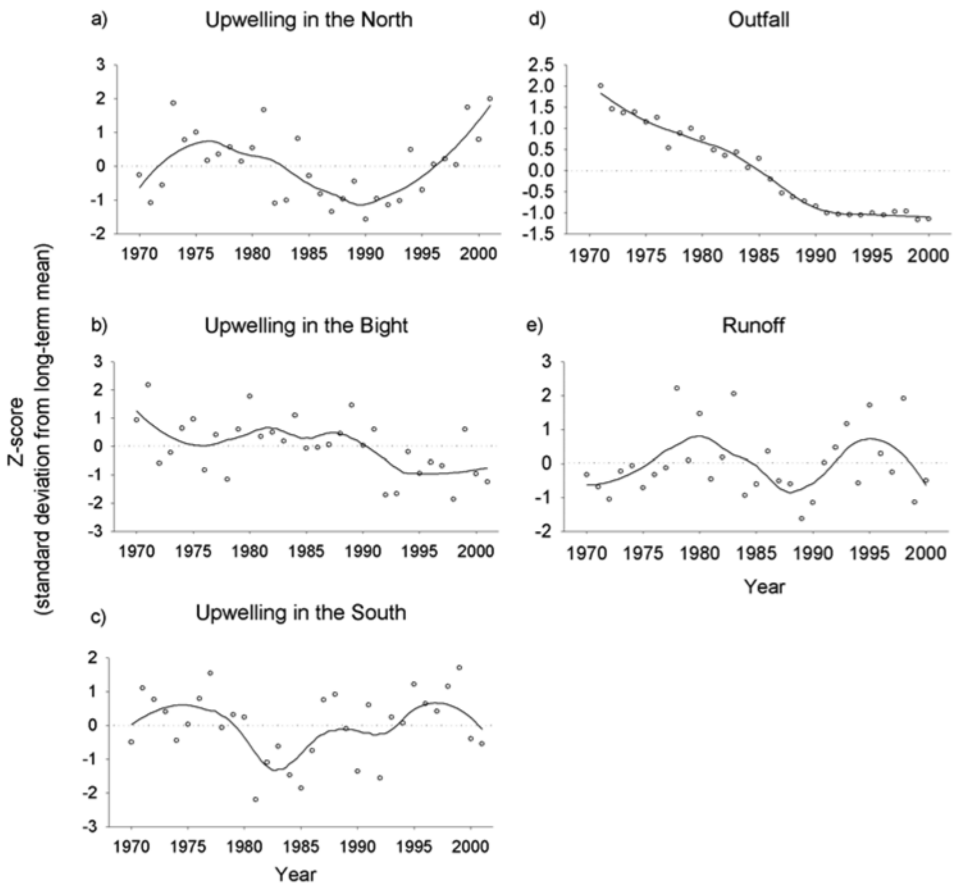


Figure 4. Smoothed temperature plots of (a) upwelling to the north of Point Conception, (b) upwelling in the Southern California Bight, and (c) south of the SCB from Punta Eugenia to Bahia Magdalena in Baja California Sur, from 1970 to 2002; (d) mass emissions of the three largest municipal wastewater treatment facilities in the Bight (Hyperion Treatment Plant, Joint Water Pollution Control Plant, and Orange County Sanitation Districts); and (e) watershed runoff volume in the Bight from 1970 to 2000.

ed or were weakly correlated with these variables (Figure 5). Of the 123 species, 28% (35 species) were correlated with the PDO, 7% (9) with upwelling in the Bight, and 7% (8) with upwelling in the south. For many of the environmental variables, some species were positively correlated and some were negatively correlated. Of these, 23 species (19%) were negatively correlated with PDO, 12 (10%) were positively correlated with PDO, and 7 (6%) were positively correlated with upwelling in the Bight. Thus, more species showed population trends correlated with environmental trends than did not, and of those with trends related to environmental variables, more were correlated with a negative PDO trend.

Species with Moderate to Strong Correlations to Environmental Variables

Correlations involving PDO were predominant in the 30-year databases (non-SONGS impingement and CSDLAC trawl databases), whereas upwelling in the SCB was predominant in the RecFIN boat data (a 20-year database). The SONGS 2&3 impingement, RecFIN shore, and Huntington Beach showed less response, largely because most species caught in these surveys were more important in either non-SONGS impingement, CSDLAC trawl, or RecFIN boat databases. For many species, the coefficients of greatest magnitude were positive, and for other species, negative (Tables 3, 4). Species with strong correlations to one variable sometimes had strong correlations with other variables (Tables 3, 4). Species with strong correlations to specific environmental variables generally have population trend

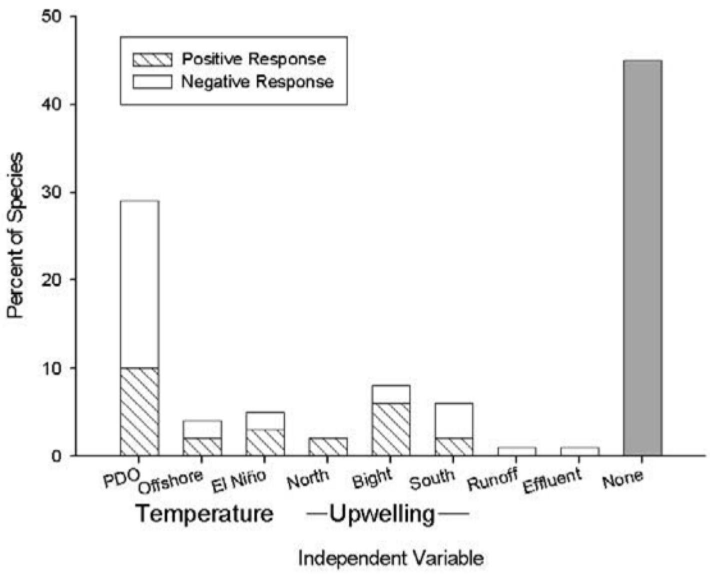


Figure 5. Percent of species responding to environmental variables (positive and negative) or showing no response to these variables in the Southern California Bight, 1972-2000. PDO = Pacific Decadal Oscillation.

curves that resemble the environmental variable trends, either as a positive relationship where the pattern varies in the same way as the variable or as the inverse (e.g., when the variable goes up, the fish population goes down).

PDO Species**.** Of 49 species with a strong positive or negative regression coefficient to PDO (disregarding number of years with data), 14 followed the positive PDO and 35 followed the negative PDO (Table 5). Restricting these to species that occurred in 50% or more of the years of occurrence in their most relevant databases, there were 12 showing positive PDO and 23 correlated with negative PDO (Table 5). Of these species, those with the highest positive correlations were spotted kelpfish (*Gibbonsia elegans*), spotted turbot (*Pleuronichthys ritteri*), and greenblotched rockfish (*Sebastes rosenblatti*). Those with the greatest negative coefficients and occurring in 50% or more of the years were ocean whitefish (*Caulolatilus princeps*), rockpool blenny (*Hypsoblennius gilberti*), and rosy rockfish (*Sebastes rosaceus*). In addition, many more species were highly correlated with the negative PDO than the positive PDO. Species important to fisheries (e.g., sablefish, *Anoplopoma fimbria*; bocaccio, *Sebastes paucispinis*; northern anchovy, *Engraulis mordax*) proved to be more correlated with the negative PDO than with the positive PDO. The response of species to different lag periods, other than a gradual 4-year lag included in the model, was not examined in PDO comparisons.

Upwelling Species. Of 32 species with strong positive or negative regression coefficients to upwelling, 17 were correlated with upwelling in the Bight, 12 with upwelling in the south, and 3 with upwelling in the north (Table 6). Restricting these to species that occurred in 50% or more of the years of occurrence in their most relevant databases, there were 9 correlated with upwelling in the Bight, 8 with upwelling south, and 2 with upwelling north. Of these species, those with the highest positive correlations for upwelling in Bight were spotfin croaker (*Roncador stearnsii*) (2-year lag), blue rockfish (*Sebastes mystinus*) (no lag), and cabezon (*Scorpaenichthys marmoratus*) (1-year lag). Those with greatest negative correlations were California butterfly ray (*Gymnura marmorata*) (1-year lag) and halfbanded rockfish (*Sebastes semicinctus*) (1-year lag). Similarly, those with the highest positive correlations for upwelling south were shortspine combfish (*Zaniolepis frenata*) (2-year lag), Pacific chub mackerel (*Scomber japonicus*) (1-year lag), and Pacific sanddab (*Citharichthys sordidus*) (no lag). Those with greatest negative correlations were yellowchin sculpin (*Icelinus quadriseriatus*) (2-year lag), blacksmith (*Chromis punctipinnis*) (no lag), and barred sand bass (*Paralabrax nebulifer*) (2-year lag). Three species had positive correlations with upwelling north. Zebraperch (*Hermosilla azurea*) (2-year lag) and brown rockfish (*Sebastes auriculatus*) (2-year lag) had the highest correlations.

Offshore Temperature and El Niños. Eight species had positive or negative correlations with offshore temperature (Table 7). In both cases, four species had positive and three had negative regression coefficients. Of those occurring in 50% or more of the years for their most relevant database, slough anchovy (*Anchoa delicatissima*) (1-year lag), bat ray (*Myliobatis californica*) (no lag), and California corbina (*Menticirrhus undulatus*) (2-year lag) had positive correlations, whereas honeycomb rockfish (*Sebastes umbrosus*) (no lag) and hornyhead turbot (*Pleuronichthys verticalis*) (no lag) had negative correlations to offshore temperature.

Seven species had positive or negative correlations with El Niños (Table 7). Species with positive correlations to El Niños included smooth stargazer

Table 3. Positive partial regression coefficients* by fish species and independent variable (Pacific Decadal Oscillation (PDO), Offshore temperature, El Niño, PDO/El Niño interaction, upwelling in the Southern California Bight and to the north and south of the Bight, outfall, and runoff) listed by greatest positive magnitude (in bold for each species).

		Temperature**			Upwelling		
Scientific Name	Common Name	PDO	Offshore	El Niño	North	Bight	South
Isurus oxyrinchus	shortfin mako	**1.36**	--	--	--	--	--
Gibbonsia elegans	spotted kelpfish	**1.28**	--	--	--	--	--
Pleuronichthys ritteri	spotted turbot	**0.92**	--	--	--	0.52	--
Sebastes rosenblatti	greenblotched rockfish	**0.85**	--	--	--	--	--
Sebastes goodei	chilipepper	--	--	--	--	**0.81**	--
Anchoa delicatissima	slough anchovy	--	**0.77**	--	--	--	0.68
Hermosilla azurea	zebraperch	--	--	--	**0.75**	--	--
Zaniolepis frenata	shortspine combfish	--	--	--	--	--	**0.73**
Cheilopogon pinnatibarbatus	smallhead flyingfish	--	--	--	--	**0.71**	--
Prionace glauca	blue shark	--	--	--	--	--	**0.70**
Kathetostoma averruncus	smooth stargazer	--	--	**0.70**	--	0.61	--
Sebastes chrysomelas	black-and-yellow rockfish	--	0.64	--	--	**0.66**	--
Myliobatis californica	bat ray	--	**0.66**	--	--	--	--
Roncador stearnsii	spotfin croaker	--	--	--	--	**0.65**	--
Sebastes mystinus	blue rockfish	--	0.63	--	--	**0.64**	--
Sebastes entomelas	widow rockfish	--	**0.63**	--	--	0.57	--
Lyopsetta exilis	slender sole	**0.63**	--	--	--	--	0.51
Hippoglossina stomata	bigmouth sole	**0.63**	--	--	--	--	--
Xenistius californiensis	salema	**0.62**	--	--	--	--	--
Halichoeres semicinctus	rock wrasse	**0.62**	--	--	--	--	--
Scorpaenichthys marmoratus	cabezon	-0.55	--	--	--	**0.61**	--
Sebastes rufus	bank rockfish	--	0.52	--	0.53	**0.59**	--
Sebastes ensifer	swordspine rockfish	--	--	--	--	**0.59**	--
Sebastes caurinus	copper rockfish	--	--	--	--	**0.59**	--
Sebastes auriculatus	brown rockfish	--	--	--	**0.58**	--	--
Leptocottus armatus	Pacific staghorn sculpin	--	--	**0.58**	--	--	--
Hydrolagus colliei	spotted ratfish	--	**0.57**	--	--	0.54	--
Embiotoca lateralis	striped seaperch	--	--	--	**0.57**	--	0.54
Sebastes eos	pink rockfish	--	--	--	--	--	**0.56**
Ophiodon elongatus	lingcod	--	--	--	--	**0.56**	--
Menticirrhus undulatus	California corbina	--	**0.56**	--	--	--	--
Xystreurys liolepis	fantail sole	**0.55**	--	--	--	--	--
Symphurus atricaudus	California tonguefish	**0.55**	--	--	--	--	--
Cheilotrema saturnum	black croaker	**0.55**	--	--	--	--	--
Scomber japonicus	Pacific chub mackerel	--	--	--	--	--	**0.54**
Lycodes pacificus	blackbelly eelpout	**0.54**	--	--	--	--	--
Rhinobatos productus	shovelnose guitarfish	--	--	--	--	**0.53**	--
Galeorhinus galeus	tope	--	--	--	--	--	**0.53**
Raja inornata	California skate	**0.52**	--	--	--	--	--
Zaniolepis latipinnis	longspine combfish	--	--	**0.51**	--	--	--
Triakis semifasciata	leopard shark	--	--	--	--	**0.51**	--
Lepidogobius lepidus	bay goby	--	--	**0.51**	--	--	--
Citharichthys sordidus	Pacific sanddab	--	--	--	--	--	**0.51**
Atractoscion nobilis	white sea bass	**0.51**	--	--	--	--	--

*$p < 0.05$, $r > 0.5$ for all partial regression coefficients listed
**There were zero positive species correlations with the PDO/El Niño interaction, outfall, and runoff variables.
Common and scientific names used are those of Nelson *et al*. (2004).

Table 4. Negative partial regression coefficients* by fish species and independent variable (Pacific Decadal Oscillation (PDO), Offshore temperature, El Niño, PDO/El Niño interaction, upwelling in the Southern California Bight and to the north and south of the Bight, outfall, and runoff) listed by greatest negative magnitude (in bold for each species).

		Temperature				Upwelling				
Scientific Name	Common Name	PDO	Offshore	El Niño	PDO/ENSO	North	Bight	South	Outfall	Runoff
Syngnathus californiensis	kelp pipefish	**-2.48**	--	--	--	--	--	--	--	--
Phanerodon atripes	sharpnose seaperch	**-1.94**	--	--	--	--	-0.59	--	--	--
Caulolatilus princeps	ocean whitefish	**-1.84**	--	--	--	--	-1.10	-0.61	--	--
Hypsoblennius gilberti	rockpool blenny	**-1.59**	0.52	--	--	-1.06	--	0.56	--	--
Ophichthus zophochir	yellow snake eel	**-1.50**	--	--	--	0.59	-0.55	-0.59	--	--
Sebastes rosaceus	rosy rockfish	**-1.46**	--	--	--	--	--	--	--	--
Micrometrus minimus	dwarf perch	**-1.43**	--	--	--	--	--	--	--	--
Amphistichus argenteus	barred surfperch	**-1.42**	--	--	--	--	--	--	--	--
Hypsoblennius jenkinsi	mussel blenny	**-1.26**	-0.65	--	--	--	--	-0.51	--	--
Sebastes atrovirens	kelp rockfish	**-1.23**	0.62	--	--	0.56	--	-0.57	--	--
Sebastes carnatus	gopher rockfish	**-1.21**	--	--	--	0.69	0.76	0.63	--	--
Anoplopoma fimbria	sablefish	**-1.11**	--	--	--	--	--	--	--	--
Acanthogobius flavimanus	yellowfin goby	--	--	--	--	-0.56	**-1.08**	--	--	--
Sebastes paucispinis	bocaccio	**-0.98**	--	--	--	--	--	--	--	--
Engraulis mordax	northern anchovy	**-0.96**	--	--	--	--	--	--	--	--
Sebastes serranoides	olive rockfish	**-0.94**	--	--	--	--	--	--	--	--
Porichthys myriaster	specklefin midshipman	**-0.94**	--	--	-0.53	--	0.51	--	--	--
Paralabrax maculatofasciatus	spotted sand bass	**-0.93**	--	--	--	--	--	--	--	--
Sebastes dallii	calico rockfish	**-0.90**	--	--	--	--	--	--	--	--
Pleuronichthys decurrens	curlfin sole	**-0.89**	--	--	--	--	--	--	--	--
Sebastes constellatus	starry rockfish	**-0.87**	0.68	--	--	--	--	--	--	--
Lepidopsetta bilineata	rock sole	**-0.77**	-0.73	--	--	--	--	--	--	--
Cymatogaster aggregata	shiner perch	**-0.73**	--	--	--	--	--	--	--	--
Radulinus asprellus	slim sculpin	**-0.71**	--	--	--	--	0.60	--	--	--
Neoclinus uninotatus	onespot fringehead	**-0.71**	--	--	--	--	--	--	--	--
Sebastes crameri	darkblotched rockfish	**-0.68**	--	--	--	0.57	--	-0.58	--	--
Rhacochilus toxotes	rubberlip seaperch	**-0.68**	--	--	--	--	--	--	--	--
Glyptocephalus zachirus	rex sole	**-0.68**	--	--	--	--	0.52	--	--	--
Artedius notospilotus	bonehead sculpin	**-0.68**	--	--	--	--	--	--	--	--
Squalus acanthias	spiny dogfish	**-0.67**	--	--	--	--	--	--	--	--
Sebastes umbrosus	honeycomb rockfish	--	**-0.66**	--	--	--	--	--	--	--
Microstomus pacificus	Dover sole	**-0.64**	--	--	--	--	--	--	--	--
Gymnura marmorata	California butterfly ray	--	--	--	--	--	**-0.64**	--	--	--
Amphistichus koelzi	calico surfperch	--	--	--	--	--	--	**-0.64**	--	--
Chilara taylori	spotted cusk-eel	-0.59	--	--	--	--	--	--	--	**-0.60**
Xeneretmus latifrons	blacktip poacher	**-0.62**	--	--	--	--	0.52	--	--	--
Oncorhynchus tschawytscha	chinook salmon	--	--	--	--	--	**-0.62**	--	--	--
Hypsoblennius gentilis	bay blenny	**-0.62**	--	--	--	--	--	--	--	--
Citharichthys xanthostigma	longfin sanddab	--	--	--	--	--	--	--	**-0.61**	--
Anchoa compressa	deepbody anchovy	**-0.61**	--	--	--	--	0.53	--	--	--
Sebastes jordani	shortbelly rockfish	**-0.59**	--	--	--	--	0.54	--	--	--
Icelinus quadriseriatus	yellowchin sculpin	--	--	--	--	--	--	**-0.59**	--	--
Pleuronichthys verticalis	hornyhead turbot	--	**-0.58**	--	--	--	--	--	--	--
Mustelus henlei	brown smoothhound	--	--	--	--	--	**-0.58**	--	--	--
Chromis punctipinnis	blacksmith	--	--	--	--	--	--	**-0.58**	--	--
Paralabrax nebulifer	barred sand bass	--	--	--	--	--	--	**-0.57**	--	--
Sebastes semicinctus	halfbanded rockfish	--	--	--	--	--	**-0.56**	--	--	--
Embiotoca jacksoni	black perch	**-0.56**	--	--	--	--	--	--	--	--
Chitonotus pugetensis	roughback sculpin	--	--	--	--	--	--	**-0.54**	--	--
Sebastes levis	cowcod	--	--	**-0.53**	--	--	--	--	--	--
Citharichthys stigmaeus	speckled sanddab	--	--	**-0.52**	--	--	--	--	--	--
Sphyraena argentea	Pacific barracuda	--	--	--	--	--	--	**-0.51**	--	--
Hypsurus caryi	rainbow seaperch	--	--	**-0.51**	--	--	--	--	--	--

*$p < 0.05$, $r > 0.5$ for all partial regression coefficients listed

Common and scientific names used are those of Nelson *et al*. (2004).

Table 5. Fish species (trends) most correlated with the PDO. Species are ranked from strong positive to strong negative coefficients; species occurring greater than 50% of the years relative to a 30-year database are highlighted.

Scientific Name	Common Name	Coeff.	Relative % FO	Database*
Isurus oxyrinchus	shortfin mako	1.36	48	recfin_b
Gibbonsia elegans	spotted kelpfish	1.28	62	imp_23
Pleuronichthys ritteri	spotted turbot	0.92	82	imp_ns
Sebastes rosenblatti	greenblotched rockfish	0.85	96	laco
Hippoglossina stomata	bigmouth sole	0.63	93	laco
Lyopsetta exilis	slender sole	0.63	100	laco
Halichoeres semicinctus	rock wrasse	0.62	72	imp_ns
Xenistius californiensis	salema	0.62	86	imp_ns
Xystreurys liolepis	fantail sole	0.55	96	laco
Cheilotrema saturnum	black croaker	0.55	96	imp_ns
Symphurus atricaudus	California tonguefish	0.55	100	laco
Lycodes pacificus	blackbelly eelpout	0.54	100	laco
Raja inornata	California skate	0.52	31	laco
Atractoscion nobilis	white sea bass	0.51	89	imp_ns
Embiotoca jacksoni	black perch	-0.56	96	imp_ns
Sebastes jordani	shortbelly rockfish	-0.59	75	laco
Anchoa compressa	deepbody anchovy	-0.61	82	imp_ns
Xeneretmus latifrons	blacktip poacher	-0.62	100	laco
Hypsoblennius gentilis	bay blenny	-0.62	34	imp_ns
Microstomus pacificus	Dover sole	-0.64	100	laco
Squalus acanthias	spiny dogfish	-0.67	65	imp_ns
Rhacochilus toxotes	rubberlip seaperch	-0.68	96	imp_ns
Sebastes crameri	darkblotched rockfish	-0.68	41	laco
Glyptocephalus zachirus	rex sole	-0.68	100	laco
Artedius notospilotus	bonehead sculpin	-0.68	13	imp_ns
Radulinus asprellus	slim sculpin	-0.71	24	laco
Neoclinus uninotatus	onespot fringehead	-0.71	20	imp_ns
Cymatogaster aggregata	shiner perch	-0.73	96	imp_ns
Lepidopsetta bilineata	rock sole	-0.77	20	recfin_b
Sebastes constellatus	starry rockfish	-0.87	62	recfin_b
Pleuronichthys decurrens	curlfin sole	-0.89	89	laco
Sebastes dallii	calico rockfish	-0.90	93	laco
Paralabrax maculatofasciatus	spotted sand bass	-0.93	65	imp_ns
Sebastes serranoides	olive rockfish	-0.94	75	imp_ns
Porichthys myriaster	specklefin midshipman	-0.94	89	imp_ns
Engraulis mordax	northern anchovy	-0.96	96	imp_ns
Sebastes paucispinis	bocaccio	-0.98	65	imp_ns
Anoplopoma fimbria	sablefish	-1.11	27	laco
Sebastes carnatus	gopher rockfish	-1.21	62	recfin_b
Sebastes atrovirens	kelp rockfish	-1.23	62	recfin_b
Hypsoblennius jenkinsi	mussel blenny	-1.26	24	imp_23
Amphistichus argenteus	barred surfperch	-1.42	62	recfin_s
Micrometrus minimus	dwarf perch	-1.43	27	imp_23
Sebastes rosaceus	rosy rockfish	-1.46	58	recfin_b
Ophichthus zophochir	yellow snake eel	-1.50	34	imp_23
Hypsoblennius gilberti	rockpool blenny	-1.59	58	imp_23
Caulolatilus princeps	ocean whitefish	-1.84	62	recfin_b
Phanerodon atripes	sharpnose seaperch	-1.94	20	recfin_b
Syngnathus californiensis	kelp pipefish	-2.48	20	imp_23

*imp_ns = non-San Onofre Power Generating Stations (Redondo, El Segundo, Huntington Beach, Ormond Beach); laco = County Sanitation Districts of Los Angeles County trawls; recfin_b = RecFIN boat data; imp_23 = San Onofre Power Generating Stations 2 & 3; recfin_s = RecFIN shore data

FO = frequency of occurrence

Common and scientific names from Nelson *et al.* (2004).

Table 6. Fish species (trends) most correlated with upwelling in the Southern California Bight, south of the Bight (from Punta Eugenia to Bahia Magdalena in Baja California Sur), and north of the Bight (north of Point Conception). For each variable, species are ranked from strong positive to strong negative coefficients. Species occurring in greater than 50% of the years relative to a 30-year database are highlighted.

Scientific Name	Common Name	coeff.	lag[a]	Relative % FO	database[b]
Upwelling in the Bight					
Sebastes goodei	chilipepper	0.81	2	44	recfin_b
Cheilopogon pinnatibarbatus	smallhead flyingfish	0.71	0	17	recfin_b
Sebastes chrysomelas	black-and-yellow rockfish	0.66	1	37	recfin_b
Roncador stearnsii	spotfin croaker	0.65	2	62	imp_23
Sebastes mystinus	blue rockfish	0.64	0	58	recfin_b
Scorpaenichthys marmoratus	cabezon	0.61	1	96	imp_ns
Sebastes rufus	bank rockfish	0.59	0	62	recfin_b
Sebastes ensifer	swordspine rockfish	0.59	0	17	recfin_b
Sebastes caurinus	copper rockfish	0.59	2	31	recfin_b
Ophiodon elongatus	lingcod	0.56	0	62	recfin_b
Rhinobatos productus	shovelnose guitarfish	0.53	0	79	imp_ns
Triakis semifasciata	leapord shark	0.51	2	58	imp_ns
Sebastes semicinctus	halfbanded rockfish	-0.56	1	93	laco
Mustelus henlei	brown smoothhound	-0.58	0	48	recfin_b
Oncorhynchus tschawytscha	chinook salmon	-0.62	2	27	recfin_b
Gymnura marmorata	California butterfly ray	-0.64	1	62	imp_23
Acanthogobius flavimanus	yellowfin goby	-1.08	1	17	imp_23
Upwelling South of the Bight					
Zaniolepis frenata	shortspine combfish	0.73	2	100	laco
Prionace glauca	blue shark	0.70	0	41	recfin_b
Sebastes eos	pink rockfish	0.56	1	34	laco
Scomber japonicus	Pacific chub mackerel	0.54	1	62	recfin_s
Galeorhinus galeus	tope	0.53	0	20	recfin_b
Citharichthys sordidus	speckled sanddab	0.51	0	100	laco
Sphyraena argentea	Pacific barracuda	-0.51	1	68	imp_ns
Chitonotus pugetensis	roughback sculpin	-0.54	2	100	laco
Paralabrax nebulifer	barred sandbass	-0.57	2	96	imp_ns
Chromis punctipinnis	blacksmith	-0.58	0	93	imp_ns
Icelinus quadriseriatus	yellowchin sculpin	-0.59	2	100	laco
Amphistichus koelzi	calico surfperch	-0.64	2	37	recfin_s
Upwelling North of the Bight					
Hermosilla azurea	zebraperch	0.75	2	58	imp_23
Sebastes auriculatus	brown rockfish	0.58	2	96	imp_ns
Embiotoca lateralis	striped seaperch	0.57	2	20	recfin_b

[a]Lag refers to the lag in years in which a fish species/independent variable relationship was most correlated.

[b]imp_ns = non-San Onofre Power Generating Stations (Redondo, El Segundo, Huntington Beach, Ormond Beach); laco = County Sanitation Districts of Los Angeles County trawls; recfin_b = RecFIN boat data; imp_23 = San Onofre Power Generating Stations 2 & 3; recfin_s = RecFIN shore data

Common and scientific names from Nelson *et al.* (2004).

(*Kathetostoma averruncus*) (1-year lag), Pacific staghorn sculpin (*Leptocottus armatus*) (2-year lag), longspine combfish (*Zaniolepis latipinnis*) (2-year lag), and bay goby (*Lepidogobius lepidus*) (2-year lag) (Table 7). Species with strong negative responses were cowcod (*Sebastes levis*) (no lag), speckled sanddab (*Citharichthys stigmaeus*) (no lag), and rainbow seaperch (*Hypsurus caryi*) (1-year lag).

Runoff and Effluent Mass Emissions. Only two species showed correlations with runoff and effluent mass emissions (Table 4). Spotted cusk-eel (*Chilara taylori*) showed a strong negative correlation to runoff (which would be similar to a negative PDO response). Longfin sanddab (*Citharichthys xanthostigma*) showed a strong negative correlation to effluent emission (i.e., its population increased with decreasing contaminant mass emissions).

Species with Weak or No Correlations to Environmental Variables

Although the emphasis here has been on species with population trends correlated moderately to strongly to the environmental variables identified in this study, a large number of species showed weak or no correlations to these variables. Of species occurring in 50% or more of the years in their most relevant database, 55 showed no or weak correlations to the environmental variables (Table 8). Many of these species are well-known to the public, such as white croaker (*Genyonemus lineatus*), kelp bass (*Paralabrax clathratus*), California halibut (*Paralichthys californicus*), California grunion (*Leuresthes tenuis*), jack mackerel (*Trachurus symmetricus*), Pacific sardine (*Sardinops sagax*), Pacific bonito (*Sarda chiliensis*), and yellowtail jack (*Seriola lalandi*). The species best represented in the databases (occurring in 100% of the years) were white croaker, plainfin midshipman (*Porichthys notatus*), California scorpionfish (*Scorpaena guttata*), splitnose rockfish (*Sebastes diploproa*), stripetail rockfish (*Sebastes saxicola*), and pink seaperch (*Zalembius rosaceus*). The population trend in California halibut in CSDLAC trawl data generally followed the positive PDO curve, but rather than dipping down in the 1990s, it inclined upwards. The trend of Pacific sardine was low in the 1970s, somewhat higher in the 1980s, and high in the 1990s.

Discussion

The population trends found in the present study differ somewhat from those of Brooks *et al.* (2002), who found decreasing trends across all species. In that study, the impingement and reef fish data extended only from 1977 to 1993, several years prior to the late 1990s cooling when some cold-regime species began to increase in abundance. For example, in the present study, northern anchovy followed a negative PDO pattern, declining in abundance from the 1970s through the 1990s, but increasing again after 1998. Many other species in common between the two studies were also negatively correlated with the PDO (Table 5), positively correlated with upwelling in the Bight, or negatively correlated with upwelling south (all of which showed decreasing trends from the early 1980s to late 1990s) (Table 6), or positively correlated to offshore temperature (which appeared to be influenced by the late 1980s La Niña, and showed a decreasing trend from the early to late 1980s and early 1990s) (Table 7). Thus, with a broader time perspective, the decreasing trends observed in Brooks *et al.* (2002) appear to reflect fish population responses to several different oceanic variables that decreased during the period examined, but which subsequently increased.

In the present study, more than half (55%) of the fish species with good representation in the databases showed correlations with independent environmental variables defined. Most of these fish species had southern California population trends that followed trends in natural oceanic variables. The most important of these were the PDO, upwelling in the Bight, upwelling off southern Baja California, offshore temperature, and the El Niño-Southern Oscillation.

The PDO, which describes multidecadal cycles of cold and warm oceanic regimes off California, had the most influence on fish population trends in 30-year fish databases. The importance of the PDO in the northeastern Pacific and beyond was recently emphasized by Chavez *et al.* (2003). This multidecadal oscillation spans several decades, and in recent history, has caused major shifts in fish populations in the Pacific. The alternation between cold and warm regimes has resulted in shifts in dominance of pelagic fish populations off California by Pacific sardine in the 1920s to 1950 (a warm regime period) to dominance by northern anchovy during the cold regime from 1950 to 1980. Interestingly, northern anchovy showed strong negative response to the

Table 7. Fish species (trends) most correlated with offshore sea surface temperature and El Niño in the Southern California Bight. For each variable, species are ranked from strong positive to strong negative coefficients. Species occurring in greater than 50% of the years relative to a 30-year database are highlighted.

Scientific Name	Common Name	coeff.	lag[a]	Relative % FO	database[b]
Offshore Temperature					
Anchoa delicatissima	slough anchovy	0.77	1	58	imp_23
Myliobatis californica	bat ray	0.66	0	96	imp_ns
Menticirrhus undulatus	California corbina	0.56	2	86	imp_ns
Sebastes entomelas	widow rockfish	0.63	2	31	recfin_b
Hydrolagus colliei	spotted ratfish	0.57	2	20	recfin_b
Pleuronichthys verticalis	hornyhead turbot	-0.58	0	100	laco
Sebastes umbrosus	honeycomb rockfish	-0.66	0	58	recfin_b
Lepidopsetta bilineata	rock sole	-0.73	0	20	recfin_b
El Niño					
Kathetostoma averruncus	smooth stargazer	0.70	1	51	laco
Leptocottus armatus	Pacific staghorn sculpin	0.58	2	89	imp_ns
Zaniolepis latipinnis	longspine combfish	0.51	2	100	laco
Lepidogobius lepidus	bay goby	0.51	2	89	laco
Hypsurus caryi	rainbow seaperch	-0.51	1	89	imp_ns
Citharichthys stigmaeus	speckled sanddab	-0.52	0	100	laco
Sebastes levis	cowcod	-0.53	0	68	laco

[a]Lag refers to the lag in years in which a fish species/independent variable relationship was most correlated.

[b]imp_ns = non-San Onofre Power Generating Stations (Redondo, El Segundo, Huntington Beach, Ormond Beach); laco = County Sanitation Districts of Los Angeles County trawls; recfin_b = RecFIN boat data; imp_23 = San Onofre Power Generating Stations 2 & 3; recfin_s = RecFIN shore data

Common and scientific names from Nelson *et al.* (2004).

PDO variable used in the present study, resulting in a decrease in population size from the 1970s (cold regime) through the 1980s and 1990s (warm regime). Pacific sardine increased in both commercial landings (Wolf *et al.* 2001) and impingement catches (present study) during the past three decades, but primarily in the 1990s rather than in the 1980s. Thus, it did not show a strong positive response to the PDO variable (low in 1970s, high in 1980s and 1990s) used in this study. Rockfish populations were higher in the cold regime and lower in the warm regime. Many species of rockfish in the present study (including bocaccio) showed strong negative correlations to the PDO, indicating their cold-regime affinity.

The PDO cycle is an important part of an atmospheric-oceanic cycle that affects oceanic climate (temperature, upwelling, productivity, precipitation, and runoff) along the Pacific Coast (Chavez *et al.* 2003). Hence, it is more than simply a shift in water temperatures between warm and cold regimes. When the Aleutian Low atmospheric pressure cell is strong, there is a warm regime off California. During the warm regime, the California Current is weak, upwelling is reduced, and nutrient levels and phytoplankton productivity are low, whereas precipitation and runoff are high. When the Aleutian Low is weak, the California Current is strong, upwelling is greater (resulting in higher nutrients and productivity of phytoplankton and zooplankton), with decreased precipitation and runoff. Thus, the shift from the cold to the warm regime results not only in a change in ocean temperature but also in reduced productivity and increased runoff.

Upwelling strength along the California and Baja California current varied between cold and warm regimes, and in southern California within the warm regime. Strong upwelling off central and northern California occurred during the cold regime, when the California Current and northerly winds were stronger. However, there also was a period of relatively strong upwelling in the Bight during the 1980s

Table 8. Fish species trends showing weak or no response to Pacific Decadal Oscillation (PDO), Offshore temperature, El Niño, PDO/El Nino interaction, upwelling in the Southern California Bight (SCB), to the north and south of the SCB, outfall, and runoff), based on study criterion. Species shown occurred at least 50% percent of the years relative to a 30- year database.

Scientific Name	Common Name	Relative % FO	% of Catch	database*
Genyonemus lineatus	white croaker	100	3.6	laco
Porichthys notatus	plainfin midshipman	100	6.2	laco
Scorpaena guttata	California scorpionfish	100	0.8	laco
Sebastes diploproa	splitnose rockfish	100	3.2	laco
Sebastes saxicola	stripetail rockfish	100	7.4	laco
Zalembius rosaceus	pink seaperch	100	1.2	laco
Anisotremus davidsonii	sargo	96	1.1	imp_ns
Atherinops affinis	topsmelt	96	0.9	imp_ns
Odontopyxis trispinosa	pygmy poacher	96	0.0	laco
Paralabrax clathratus	kelp bass	96	1.3	imp_ns
Paralichthys californicus	California halibut	96	0.2	imp_ns
Parophrys vetulus	English sole	96	0.5	laco
Phanerodon furcatus	white seaperch	96	4.4	imp_ns
Platyrhinoidis triseriata	thornback	96	0.5	imp_ns
Rhacochilus vacca	pile perch	96	0.9	imp_ns
Sebastes elongatus	greenstriped rockfish	96	0.0	laco
Seriphus politus	queenfish	96	44.6	imp_ns
Torpedo californica	Pacific electric ray	96	0.2	imp_ns
Urobatis halleri	round stingray	96	0.1	imp_ns
Argentina sialis	Pacific argentine	93	0.1	laco
Atherinopsis californiensis	jacksmelt	93	0.6	imp_ns
Citharichthys fragilis	gulf sanddab	93	0.9	laco
Heterodontus francisci	horn shark	93	0.0	imp_ns
Heterostichus rostratus	giant kelpfish	93	0.3	imp_ns
Hyperprosopon argenteum	walleye surfperch	93	5.2	imp_ns
Leuresthes tenuis	California grunion	93	0.9	imp_ns
Medialuna californiensis	halfmoon	93	0.1	imp_ns
Merluccius productus	Pacific hake	93	0.5	laco
Ophidion scrippsae	basketweave cusk-eel	93	0.2	imp_ns
Pleuronichthys coenosus	C-O sole	93	0.1	laco
Girella nigricans	opaleye	89	0.1	imp_ns
Peprilus simillimus	Pacific pompano	89	3.4	imp_ns
Brachyistius frenatus	kelp perch	86	0.2	imp_ns
Pleuronichthys guttulatus	diamond turbot	86	0.1	imp_ns
Sebastes rastrelliger	grass rockfish	86	0.1	imp_ns
Sebastolobus alascanus	shortspine thornyhead	86	1.3	laco
Oxyjulis californica	señorita	82	0.1	imp_ns
Synodus lucioceps	California lizardfish	82	1.4	laco
Trachurus symmetricus	jack mackerel	82	0.7	imp_ns
Umbrina roncador	yellowfin croaker	75	0.0	imp_ns
Sardinops sagax	Pacific sardine	72	0.6	imp_ns
Sebastes miniatus	vermilion rockfish	68	0.1	laco
Sarda chiliensis	Pacific bonito	62	6.7	recfin_b
Sebastes chlorostictus	greenspotted rockfish	62	0.8	recfin_b
Sebastes rubrivinctus	flag rockfish	62	0.4	recfin_b
Sebastes serriceps	treefish	62	0.7	recfin_b
Semicossyphus pulcher	California sheephead	62	2.6	recfin_b
Mustelus californicus	gray smoothhound	58	0.0	imp_ns
Sebastes hopkinsi	squarespot rockfish	58	0.3	recfin_b
Seriola lalandi	yellowtail jack	58	1.7	recfin_b
Physiculus rastrelliger	hundred-fathom codling	55	0.0	laco
Sebastes ovalis	speckled rockfish	55	0.1	recfin_b
Xeneretmus triacanthus	bluespotted poacher	55	0.0	laco
Oxylebius pictus	painted greenling	51	0.0	imp_ns
Sebastes pinniger	canary rockfish	51	0.0	recfin_b

*imp_ns = non-San Onofre Power Generating Stations (Redondo, El Segundo, Huntington Beach, Ormond Beach); laco = County Sanitation Districts of Los Angeles County trawls; recfin_b = RecFIN boat data; imp_23 = San Onofre Power Generating Stations 2 & 3; recfin_s = RecFIN shore data; hb = Huntington Beach Generating Station trawls

Common and scientific names from Nelson *et al.* (2004).

and weak upwelling in the Bight in the 1990s, when upwelling was stronger off southern Baja California Sur. This suggests that the warm regime off southern California consisted of two subregimes: a period with strong upwelling in the Bight and one with weak upwelling. Differences in upwelling strength in the Bight between the 1980s and 1990s appeared to affect recreational fish catches in these two periods. Catches of some recreational fish species were more abundant during the strong upwelling period of the 1980s, whereas others were more abundant in the weak upwelling of the 1990s. Fish population trends with strong positive or negative correlations to the upwelling variables were best characterized in 20-year databases (recreational fish catches for boat and shore fisheries) that covered only the period from the early 1980s to the late 1990s. Although the recreational catch database covered a shorter period, resulting in a reduced emphasis on the PDO cycle, it helped to define the importance of two upwelling periods in the Bight during the warm regime of the 1980s and 1990s.

Few species in the present study showed strong population responses to the short-term El Niño (warm) and La Niña (cold) periods. Strong El Niños occurred during 1982-1983 and 1997-1998, with moderate El Niños in 1972-1973, 1987, and 1992-1993. A strong La Niña occurred in 1988-1989. Although the period immediately following the 1997-1998 El Niño was originally thought to be a La Niña, it lasted longer than a typical La Niña and is thought to be the start of a cold regime (Chavez *et al.* 2003). Population responses were most apparent during the two strongest El Niños, but some species responded to the 1988-1989 La Niña. Those that responded to that La Niña (e.g., bat ray) were positively correlated with the offshore temperature variable (which became much colder in the late 1980s before increasing afterward).

Effluent mass emissions discharged in deep water by the three major publicly owned treatment works were high in the 1970s and decreased monotonically from then to the early 1990s (e.g., Stull 1995, CSDLAC 2002). A positive response to the early part of this trend would be similar to a negative response to the PDO, where cold regime species decreased in abundance from the 1970s through the 1980s and 1990s; however, these negative PDO species generally showed some increase in the late 1990s. A positive population correlation with this effluent trend (high in the 1970s, decreasing to the 1990s) would suggest that reductions in contamination or nutrients was detrimental to the population; whereas a negative correlation (low in the 1970s, increasing to the 1990s) would suggest that the population had benefited from the improved effluent quality. Longfin sanddab had a negative correlation to effluent mass emissions, increasing in the 1980s and particularly in the 1990s as contaminant levels decreased, suggesting that its population may have benefited from improved treatment. However, this southerly species increased throughout the southern part of the SCB during the warm regime (Allen *et al.* 2002), but decreased after 1998, suggesting its population was responding positively to the PDO trend. Although population responses to effluent mass emissions were difficult to distinguish at the regional scale from the PDO oceanic trend, positive and negative responses at local areas on the Palos Verdes shelf have been described by other studies (Allen 1977, Stull 1995, Stull and Tang 1996, CSDLAC 2002).

There is no long-term (20- to 30-year) database of contaminant loadings in runoff to the SCB, but information on precipitation and runoff does exist for this period; hence, regional fish populations can only be compared to trends in stormwater flow in runoff. Annual runoff from southern California coastal watersheds followed the atmospheric pressure trend version of the PDO (i.e., NpiPDO, which was low in the 1970s, late 1980s, and late 1990s, and high through much of the 1980s and 1990s). Precipitation is related to the PDO cycle, being low during the cold regime and high during the warm regime. Hence, a fish population trend responding positively or negatively to the runoff trend would also be responding positively or negatively to the PDO cycle (which is the cycle that results in higher or lower precipitation), thus making runoff effects on fish populations difficult to distinguish after temperature effects have been removed. Spotted cusk-eel showed a negative correlation with runoff (Table 4). As this is a relatively deepwater species that does not come close to shore, it is likely that its correlation was due to chance. As noted above, a very large number of regression analyses were conducted and it is likely that about 5% of significant correlations were due to chance.

However, some nearshore species may have responded directly to runoff rather than to temperature changes, as both increased occurring during the warm regime of the PDO. Although regional responses of fish populations to runoff cannot be distinguished from those of the PDO, local effects appear to have occurred near the Santa Clara River and in Santa Monica Bay (Allen *et al.* 2003). In some cases, local fish abundances were lower when annual runoff was high and the reverse when it was low. However, recreational fish catches in Santa Monica Bay appeared to be positively related to runoff.

It is also important to note that catch trends for several important fished species (e.g., white croaker; kelp bass; California halibut; California sheephead, *Semicossyphus pulcher*; several rockfishes and surfperches; and others) did not show a relationship with any of the environmental variables examined. These fish species require additional research to determine the causes influencing their trends. It is quite possible that fishing pressure, fishing regulation changes, habitat alteration, or some other undetermined cause is influencing the trends in these fished species. There was some suggestion that a departure in the population trend of California halibut in trawl data examined in this study from the positive PDO trend (halibut increased in abundance in the late 1990s) may reflect a response to closure of the set-gillnet fishery in southern California. Examination of such departures from trends of important oceanic variables may provide a basis for detecting such changes. Commercial and recreational fishing and habitat alteration can have regional effects, but these effects must be distinguished from natural oceanic trends.

Although fish population responses to fishing pressure or habitat alteration were not examined directly in this study, the results of this study has fishery management implications. Several fished species showed population trends that were correlated with environmental variable trends. Identifying responses of fish species to a changing environment is an important first step in determining which species are susceptible to different environmental trends. This, in turn, provides insight into expected changes in fish availability over time and management practices necessary to complement those changes. For example, of the dominant species comprising the recreational shore and boat catches (jacksmelt, *Atherinopsis californiensis*; white croaker; barred sand bass; Pacific chub mackerel; barred surfperch, *Amphistichus argenteus*), half showed responses to environmental variables. Barred sand bass and Pacific chub mackerel were positively correlated with upwelling in the SCB, and barred surfperch was negatively correlated with the PDO. For some recreational fish species, fishery independent trends (i.e., in impingement data) were similar to fishery dependent trends, with recreational catch data lagging impingement data by one or more years (Jarvis *et al.* in press). Identification of such relationships provides a basis for forecasting species responses to environmental changes and thus may facilitate adaptive management. Accordingly, fisheries managers could implement decreased bag limits for these species during predicted periods of decreased upwelling and warming temperature in southern California ocean waters. Parrish and Tegner (2001) point out that monitoring of the changing ocean environment is crucial to successively managing our fishery resources for many generations.

Although additional study is needed to assess the effects of commercial and recreational fisheries, habitat alteration, and other anthropogenic activities on these populations, the identification of the basic trends in oceanic environmental variables that affect fish populations provide a basis for assessing anthropogenic effects on fish population trends in the SCB.

Literature Cited

Ackerman, D. and K. Schiff. 2003. Modeling stormwater mass emissions to the Southern California Bight. *Journal of the Environmental Engineering* 129: 308-317.

Aiken L.S. and S.G. West. 1991. Multiple Regression: Testing and Interpreting Interactions. Sage Publications. Newbury Park, CA.

Allen, M.J. 1977. Pollution-related alterations of demersal fish communities. *American Fisheries Society, Cal-Neva Wildlife Transactions* 1977: 103-107.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg and T. Mikel. 2002. Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., R.W. Smith, E.T. Jarvis, V. Raco-Rands, B.B. Bernstein and K.T. Herbinson. 2003. Temporal trends in nearshore fish populations relative to environmental influences. Prepared for California State Coastal Conservancy, Oakland, CA, and Santa Monica Bay Restoration Commission, Los Angeles, CA. Southern California Coastal Water Research Project, Westminster, CA.

Baumgartner, T.R., A. Soutar and V. Ferreria-Batrina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. *California Cooperative Oceanic Fisheries Investigations Reports* 33: 24-40.

Brooks, A.J., R.J. Schmitt and S.L. Holbrook. 2002. Declines in regional fish populations: Have species responded similarly to environmental change? *Marine and Freshwater Research* 53: 189-198.

Chavez, F.P., J. Ryan, S.E. Lluch-Cota and M. Niquen C. 2003. From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. *Science* 299: 217-221.

CSDLAC (County Sanitation Districts of Los Angeles County). 2002. Palos Verdes Ocean Monitoring Annual Report, 2002, Chapter 4: Invertebrate and Fish Trawls. County Sanitation Districts of Los Angeles County. Whittier, CA.

Grosse, E. 1989. LOESS: Multivariate smoothing by moving least squares. pp. 299-302 *in*: Chui, C. K., and Ward, J. D. (eds.), Approximation Theory VI: Volume I. Academic Press. New York, NY.

Hare, S.R. and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography* 47: 103-145.

Herbinson, K.T., M.J. Allen and S.L. Moore. 2001. Historical trends in nearshore croaker (Family Sciaenidae) populations in southern California from 1977 through 1998. pp. 253-264 *in*: S.B. Weisberg and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1999-2000. Southern California Coastal Water Research Project. Westminster, CA.

Hollowed, A.B., S.R. Hare and W.S. Wooster. 2001. Pacific Basin climate variability and patterns of Northeast Pacific marine fish production. *Progress in Oceanography* 49: 257-282.

Hollowed, A.B. and W.S. Wooster. 1995. Decadal-scale variations in the eastern subarctic Pacific: II. Response of Northeast Pacific fish stocks. pp. 373-385 *in* R.J. Beamish (ed.), Climate change and northern fish populations. *Canadian Special Publication of Fisheries and Aquatic Sciences* 121.

Jarvis, E.T., M.J. Allen and R.W. Smith. In press. Recreational fish trends relative to environment-species relationships and fishery-independent data in the Southern California Bight (1980-2000). *California Cooperative Oceanic Fisheries Investigations Reports*.

Klyashtorin, L.B. 1998. Long-term climate change and main commercial fish production in the Atlantic and Pacific. *Fisheries Research* 37: 115-125.

Lea, R.N. and R.H. Rosenblatt. 2000. Observations on fishes associated with the 1997-1998 El Niño of California. *California Cooperative Oceanic Fisheries Investigations Reports* 41: 117-129.

Love, M.S., J.E. Caselle and K. Herbinson. 1998a. Declines in nearshore rockfish recruitment and populations in the Southern California Bight as measured by impingement rates in coastal electric power generating stations. *Fishery Bulletin* (U.S.) 96: 492-501.

Love, M.S., J.R. Caselle and W. Van Buskirk. 1998b. A severe decline in the commercial passenger fishing vessel rockfish (*Sebastes* spp.) catch in the Southern California Bight, 1980-1996. *California Cooperative Oceanic Fisheries Investigations Reports* 39: 180-1995.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* 78: 1069-1079.

Mearns, A.J. 1988. The "odd fish": unusual occurrences of marine life as indicators of changing ocean conditions. pp. 137-176 *in* D.F. Soule and G.S. Kleppel (eds.), Marine Organisms as Indicators. Springer-Verlag. New York, NY.

Nelson, J.S., E.J. Crossman, H. Espinosa-Perez, L.T. Findley, C.R. Gilbert, R.N. Lea and J.D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. American Fisheries Society, Special Publication 29. Bethesda, MD.

Parrish, R.R. and M.J. Tegner. 2001. California's variable ocean environment. pp. 21-28 *in* W.S. Leet, C.M. Dewees, R. Klingbeil and E. J. Larson (eds.), California's Living Marine Resources: A Status Report. California Department of Fish and Game. Sacramento, CA.

Radovich, J. 1960. Redistribution of fishes in the eastern north Pacific Ocean in 1957 and 1958. *California Cooperative Oceanic Fisheries Investigations Reports* 7: 163-171.

Radovich, J. 1961. Relationships of some marine organisms of the northeast Pacific to water temperatures, particularly during 1957 through 1959. California Department of Fish and Game, Fish Bulletin 112.

Sheehan, L. and R. Tasto. 2001. The status of habitats and water quality in California's coastal and marine environment. pp. 29-45 *in* W.S. Leet, C.M. Dewees, R. Klingbeil and E.J. Larson (eds.), California's Living Marine

Resources: A Status Report. California Department of Fish and Game. Sacramento, CA.

Soutar, A. and J.D. Isaacs. 1969. History of fish populations inferred from fish scales in anaerobic sediments off California. *California Cooperative Oceanic Fisheries Investigations Reports* 13: 63-70.

Soutar, A. and J.D. Isaacs. 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediments off California. *Fishery Bulletin* (U.S.) 72: 257-274.

Stull, J. 1995. Two decades of marine biological monitoring, Palos Verdes, California, 1972 to 1992. *Bulletin of the Southern California Academy of Sciences* 94: 21-45.

Stull, J.K., K.A. Dreyden and P.A. Gregory. 1987. A historical review of fisheries statistics and environmental and societal influences off the Palos Verdes Peninsula, California. *California Cooperative Oceanic Fisheries Investigations Reports* 28: 135-154.

Stull, J.K. and C.-L. Tang. 1996. Demersal fish trawls off Palos Verdes, southern California, 1973-1993. *California Cooperative Oceanic Fisheries Investigations Reports* 37: 211-240.

Thomson, C.J. 2001. The human ecosystem dimension. pp. 47-66 *in* W.S. Leet, C.M. Dewees, R. Klingbeil and E.J. Larson (eds.), California's Living Marine Resources: A status report. California Department of Fish and Game. Sacramento, CA.

Trenberth, K.E. and J.W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics* 9: 303-319.

Venables, W.N. and B.D. Ripley. 2002. Modern Applied Statistics with S. 4th edition. Springer-Verlag. New York, NY.

Wolf, P., P.E. Smith and D.R. Bergen. 2001. Pacific sardine. pp. 299-302 *in*: W.S. Leet, C.M. Dewees, R. Klingbeil and E.J. Larson (eds.), California's Living Marine Resources: A Status Report. California Department of Fish and Game. Sacramento, CA.

Zhang, Y., J.M. Wallace and D.S. Batttisti. 1997. ENSO-like interdecadal variability. *Journal of Climate* 10: 1004-1020.

Acknowledgements

This project was funded in part by the Santa Monica Bay Restoration Commission (SMBRC) and the California State Coastal Conservancy (CSCC) using state bond funds from the Safe Neighborhood Parks, Clean Water, Clean Air and Coastal Protection Act of 2000 (CSCC Proposition 12 Grant Program, SMBRP Grant Agreement No. 01-088). We thank M. Beyeler, who served as CSCC contract manager; G. Wang for providing project oversight for SMBRC; and S.B. Weisberg, for advice on this paper. We thank D. Ackerman for providing his stormwater runoff model for our use and S. Moore for assistance with maps. We thank R. Charter for assistance in obtaining California Cooperative Oceanic Fisheries Investigations data. We also thank R. Lynn for advice on the appropriate use of oceanographic data for our study as well as statistical methods for time-series analysis and recommendations of pertinent oceanographic variables. We also thank M. Lyons, G. Robertson, and M. Mengel for suggestions regarding this article.