XIV-44 California Current: LME #3

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The California Current LME is bordered by the USA and Mexico, between subtropical and subarctic LMEs. It has a surface area of around 2.2 million km², of which 1.31% is protected, and it contains 0.01% of the world's coral reefs and 1.04% of the world's sea mounts (Sea Around Us 2007). The LME shoreline is more than two thousand miles long. The LME features more than 400 estuaries and bays, including the Columbia River, San Francisco Bay and Puget Sound, which constitute 61% of the estuary and bay acreage. This LME is characterised by its temperate climate and strong coastal upwelling. Book chapters and articles pertaining to this LME include MacCall (1986), Mullin (1991), Bakun (1993), Bottom *et al*. (1993), McGowan *et al*. (1999), Brodeur *et al*. (1999) and Lluch-Belda *et al*. (2003). Additional information on this well-studied LME is available from the NMFS, Southwest Fisheries Science Center website, www.swfsc.noaa.gov.

I. Productivity

The effects of coastal upwelling, ENSO and the Pacific Decadal Oscillation (PDO) result in strong interannual variability in the productivity of the ecosystem and, consequently, of the catch levels of different species groups (Bakun 1993). ENSO events are characterised locally by an increase in temperature, a rise in coastal sea level, diminished upwelling and increased coastal rainfall (Bakun 1993). Miller (1996) reports a significant deepening of the thermocline off California, which he attributes to a weakening of the Aleutian Low (decadal scale), and to waves propagating through the ocean from the tropics (interannual scale). There is speculation as to what causes changes in the eastern bifurcation of the Subarctic Current into the California Current, and the possible effects of these changes on biological production in this LME.

The CCLME is one of the world's five LMEs that undergo seasonal upwellings of cold nutrient rich water that generate localised areas of high primary productivity that support fisheries for sardines, anchovy, and other pelagic fish species. (e.g. California Current, Canary Current, Guinea Current, Benguela Current, and Humboldt Current LMEs). The California Current LME can be considered a Class III, low productivity ecosystem (<150 $gCm^{-2}yr^{-1}$) (Figure XIV-44.3). The Pacific Decadal Oscillation (PDO) is a 20-30-year cooling and warming cycle between a cool and productive ocean regime and a warm and unproductive ocean regime. The latest warm regimes were in 1977-1998 and 2003-2006. Apparent biological consequences of these regime shifts are changes in primary and secondary production and changes in the abundance of eastern Pacific fish stocks. For example, there was a sharp decline in primary and secondary production following the 1977 regime shift (CalCOFI Atlas 35, 2002). The California Cooperative Oceanic Fisheries Investigations (CalCOFI) programme has sampled zooplankton biomass almost continuously from 1951 to present. Observed decline in zooplankton abundance related to water column stratification has been described by Roemmich & McGowan (1995a and 1995b), Haywood (1995), and McGowan *et al*. (1999). These biomass changes appear to be inversely related to those occurring in the Gulf of Alaska LME to the north (Brodeur & Ware 1995, Brodeur *et al*. 1999). For a study of interannual variability impacts on the LME, see Lluch-Belda *et al*. (2003), Peterson and Schwing (2003), and Hooff and Peterson (2006). There is a need to better understand the role of climate and seasonal change in the energy flow and population dynamics of species inhabiting the LME. For an analysis of chlorophyll and sea surface temperature changes during the El Niño/La Niña period of 1998/1999, see Kahru & Mitchell (2000). For an article on observing and modelling the California Current system, see Miller and Schneider (2000). Information on

the U.S. GLOBEC Northeast Pacific Programme is available at: http://globec.coas.oregonstate .edu/

Oceanic fronts (Belkin et al. 2009): The California Current Front (CCF) separates relatively cold, low-salinity waters of the southward California Current from warmer and saltier waters inshore (Hickey 1998) (Figure XIV-44.1). The Subarctic Front (SAF) separates the northward Subarctic Current from inshore waters. On the inshore side of the California Current, upwelling fronts develop in summer (Belkin & Cornillon 2003, Belkin *et al*. 2003). Offshore frontal filaments, sometimes a hundred km long, carry the upwelled cold, nutrient-rich water across the entire LME (Belkin & Cornillon 2003). In winter, a second and seasonal poleward current develops over the shelf and slope, giving rise to the seasonal Davidson Current Front (DCF) between warm saline subtropical waters inshore and colder, fresher temperate waters offshore. This front can be traced from off southern California (35°N) to the northern Washington coast (48-49°N).

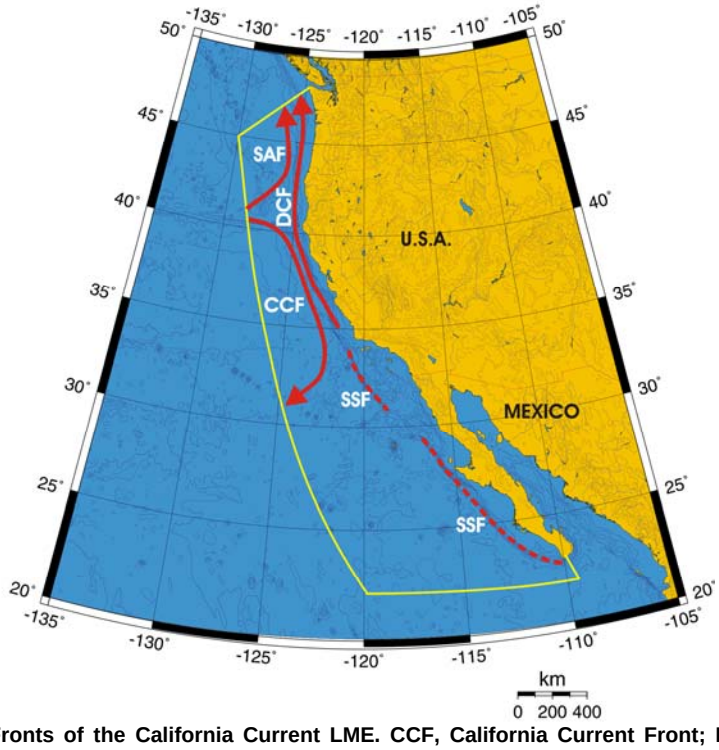

Figure XIV-44.1. Fronts of the California Current LME. CCF, California Current Front; DCF, Davidson Current Front (winter only); SAF, Subarctic Front; SSF, Shelf Slope Front; Yellow line, LME boundary. After Belkin et al. (2009).

California Current LME SST (Belkin 2009)(Figure XIV-44.2).
Linear SST trend since 1957: 0.32°C.
Linear SST trend since 1982: -0.07°C.

Like the East Bering Sea and Gulf of Alaska LMEs, the California Current cooled dramatically, by nearly 2°C, from 1958 to 1975, then warmed by 1977 as a result of the North Pacific regime shift (Mantua et al., 1997), and remained relatively warm up to 1998. Cooling was again observed from 1999-2002, then warming in 2003-2006. The absolute minimum of 1975 was synchronous with the absolute minima in two other LMEs of the East Pacific, the Gulf of California and Pacific Central American. The absolute maximum of 18.3°C in 1997 is attributable to El Niño, whereas the dramatic 1.8°C cooling in 1999 was associated with La Niña. The California Current LME and the Humboldt Current LME

have experienced a slight cooling over the last 25 years. Both LMEs are situated in similar oceanographic regimes of East Pacific wind-induced coastal upwelling systems. These regimes feature strong and persistent alongshore winds directed towards the Equator, causing Ekman offshore transport of warm surface waters and upward flux of cold subsurface waters (coastal upwelling). The above-noted long-term cooling in these areas is suggestive of a long-term increase in the upwelling intensity, which in turn may have resulted from a long-term increase in the strength and/or persistence of upwelling-favorable along-coast winds. This hypothesis is supported by observed data and numerical modeling experiments (Schwing and Mendelsson, 1997; and GLOBEC at www.usglobec.org). There is no significant time lag between major thermal events in the California Current, Gulf of Alaska and East Bering Sea LMEs. The observed synchronicity among these regions suggests ocean-scale – if not global – forcing in the Northern and Northeast Pacific. The North Pacific regime shifts of 1976-1977 and 1999-2002 were broad scale events.

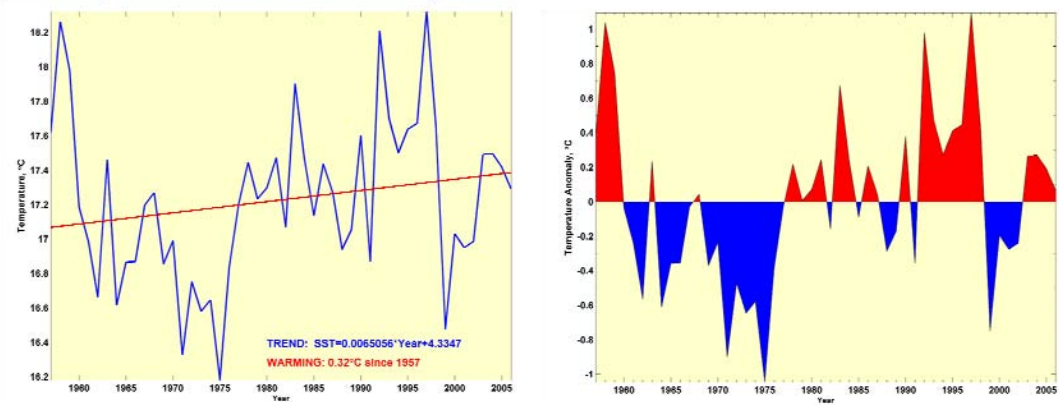

Figure XIV-44.2 California Current LME annual mean SST (left) and SST anomalies (right) based on Hadley climatology. 1957-2006. After Belkin (2009).

California Current LME Chlorophyll and Primary Productivity: The California Current LME is a Class III, low productivity ecosystem (<150 $gCm^{-2}yr^{-1}$)(Figure XIV-44.3).

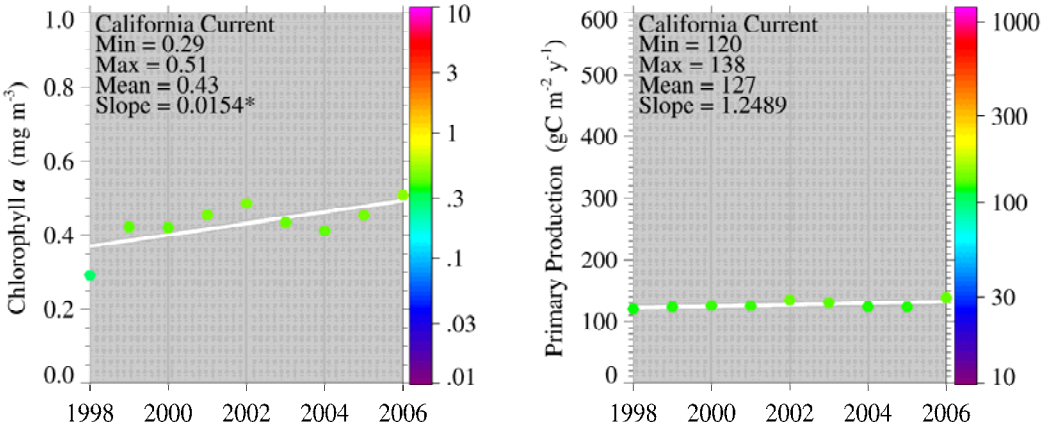

Figure XIV-44.3. California Current LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume..

II. Fish and Fisheries

Fisheries resources in the California Current LME include salmon, pelagic fisheries, groundfish, and invertebrates. Salmon fisheries harvest 5 species of salmon (Chinook, coho, sockeye, pink, and chum). The abundance of salmon stocks fluctuates considerably. Chinook and coho are harvested recreationally and commercially in Puget Sound and in freshwater rivers. Fisheries management for salmon is complex, with conflicting jurisdictions and salmon originating from several rivers. For all salmon species there is excess fishing power and overcapitalization of the fishing fleet. For coho and Chinook there is a sharp decline in abundance that has led to the closure of all salmon fisheries off the coasts of Oregon and California. Small pelagic resources in the LME are Pacific sardine, northern anchovy, jack mackerel, chub (Pacific) mackerel, and Pacific herring. Sardine, anchovy and mackerel are mostly harvested off California and Baja California. Sardine and anchovy fluctuate widely in abundance (NMFS 2009). Natural environmental change and intensive fishing are causing long-term shifts in their abundance in this LME. The CalCOFI programme was initiated to examine the reasons for the decline of the Pacific sardine and to study its physical and biotic habitat (CalCOFI 1990 results at www.calcofi.org). The collapse of the Pacific sardine has had cascading effects on other ecosystem components including marine birds. The variability in abundance levels of sardine and anchovy spawning biomass from 1930 to 1985 is analysed in MacCall (1986). Sardine catches declined after World War II, and the stock collapsed in the late 1950s. The sardine crash is one of the earliest well documented major fishery crashes (Radovich 1982) and is attributed to overfishing that accelerated a long term pattern of natural decline. Sardines today are taken for human consumption, bait, and aquaculture feed. Consumer demand for canned anchovy is low. Anchovy are harvested for reduction into fishmeal, bait, human consumption and oil. In recent years, low prices and market problems continue to prevent a significant anchovy fishery. The endangered brown pelican depends on anchovy as an important food source, and the wellbeing of the ecosystem is an important factor in resource management. Mackerel supported a major fishery in California but the stock collapsed in the 1970s. It has since reopened under a quota system. Sardine, anchovy, and mackerel are transboundary stocks exploited by both US and Mexican fleets. Squid is an important fishery in California in terms of revenue and tons landed. The vast majority is frozen for human consumption and exported to China, Japan and Europe. Landings depend on cyclical oceanographic regimes, with increases when relatively warm water events are displaced by cool water. Herring landings declined with an El Niño episode. Groundfish fisheries include sole, thornyheads, sablefish, rockfish, lingcod and cabezon, flatfish, and Pacific hake. Harvest rates have been reduced in recent years and gear designs to reduce bycatch. Nearshore fisheries are for invertebrate species including crabs, shrimps, abalones, clams, scallops and oysters (NMFS 2009). A recent compilation of species inhabiting the nearshore California Current LME can be reviewed at the California Department of Fish and Game site at: www.dfg.ca.gov/mrd/.

Total reported landings peaked at 710,000 tonnes in 1987 (Figure XIV-44.4). The value of reported landings peaked in 1970 at US$540 million (in 2000 US dollars) with a similar level recorded in 1988 (Figure XIV-44.5). The major commercial fish species are Pacific salmon, hake, albacore tuna, Pacific sardine (also known as South American pilchard), northern anchovy, jack mackerel, chub (Pacific) mackerel, Pacific herring, and Pacific halibut. Shrimp, squid, crab, clam and abalone have high commercial value.

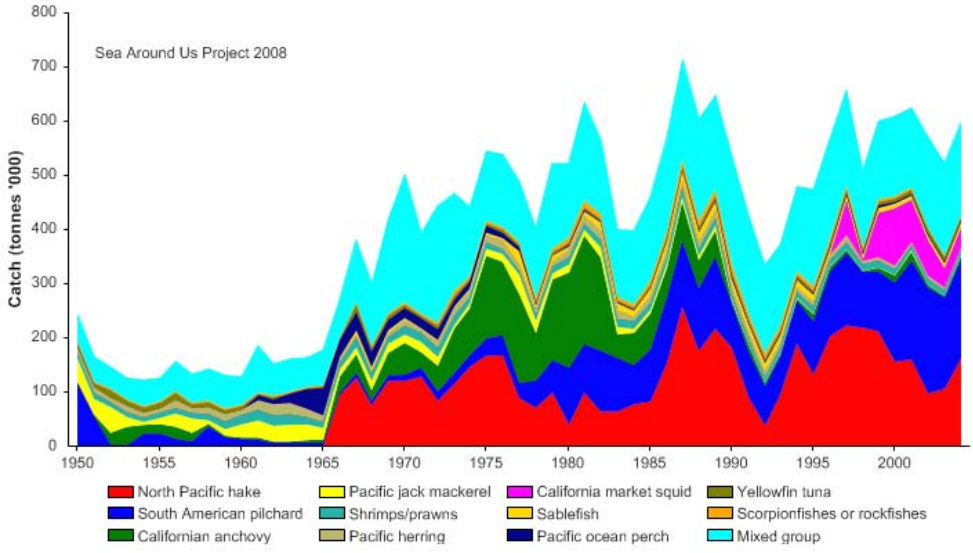

Figure XIV-44.4. Total reported landings in the California Current LME by species (Sea Around Us 2007).

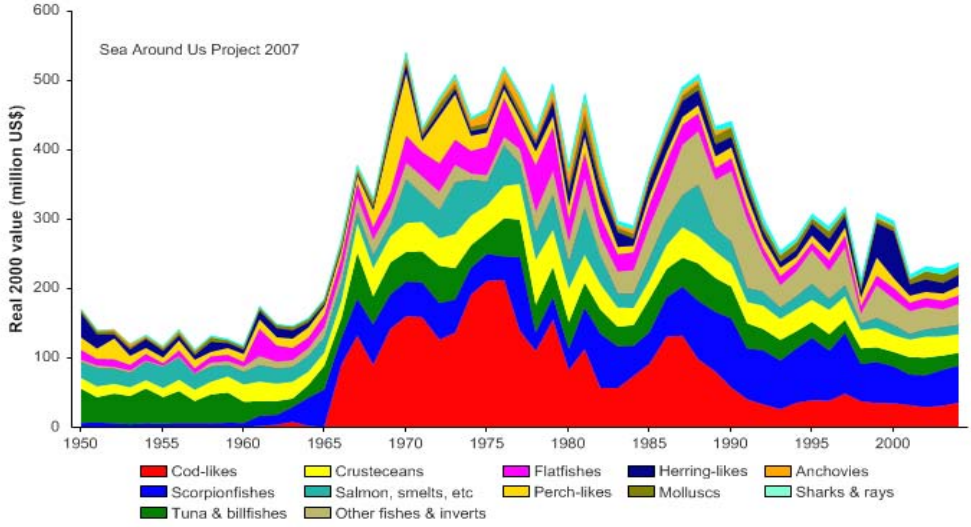

Figure XIV-44.5. Value of reported landings in the California Current LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR) (Pauly & Christensen 1995) to sustain reported landings in this LME reached 16% of the observed primary production in the late 1980s, and has fluctuated between 7 to 15% in recent years (Figure XIV-44-6). The USA has the largest share of the ecological footprint in the LME.

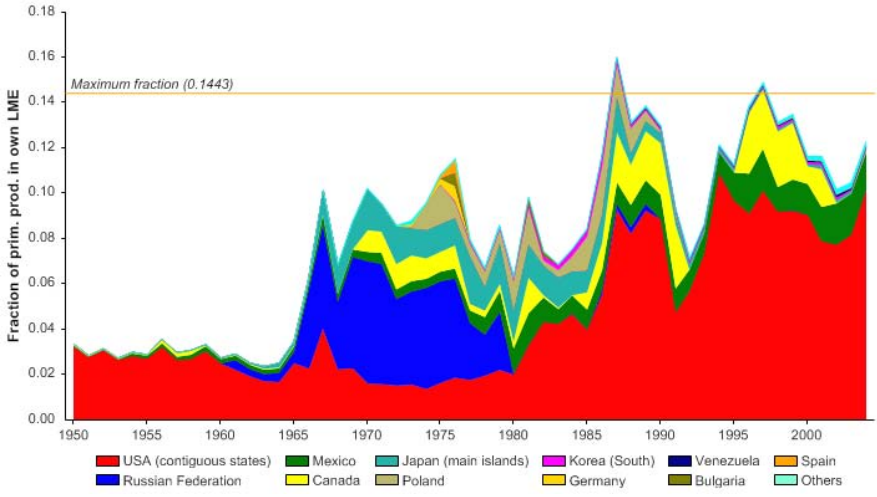

Figure XIV-44.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the California Current LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

Both the mean trophic level of the reported landings (Pauly & Watson 2005; figure XIV-44.7, top) and the Fishing-in-Balance index (Figure XIV-44.7, bottom) show considerable fluctuation over the reported period with no clear trend, except for the initial increase in the FiB index corresponding to a growth in fisheries during the 1960s.

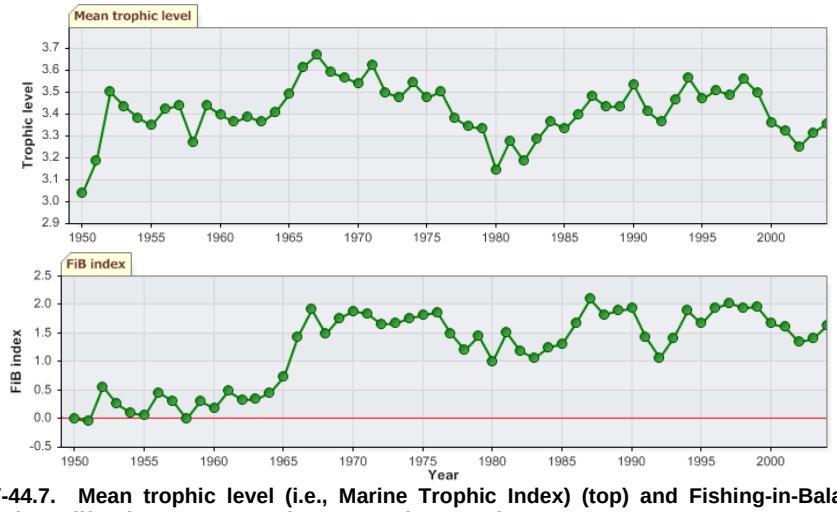

Figure XIV-44.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the California Current LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that over 80% of the stocks in the LME have collapsed or are currently over-exploited (Figure XIV- 44.8, top). Half of the reported landings biomass is still supplied by fully exploited stocks (Figure XIV-44.8, bottom). The US National Marine Fisheries Service (NMFS) includes "overfished" but not "collapsed" in its stock status categories. Currently overfished are Chinook and coho salmon, thought to be impacted by environmental conditions resulting in poor ocean survival. The other salmon species are considered fully exploited. Six other overfished species are among

groundfish stocks. Hake and lingcod have been rebuilt to target levels. Jack mackerel and northern anchovy are underutilized species (NMFS 2009).

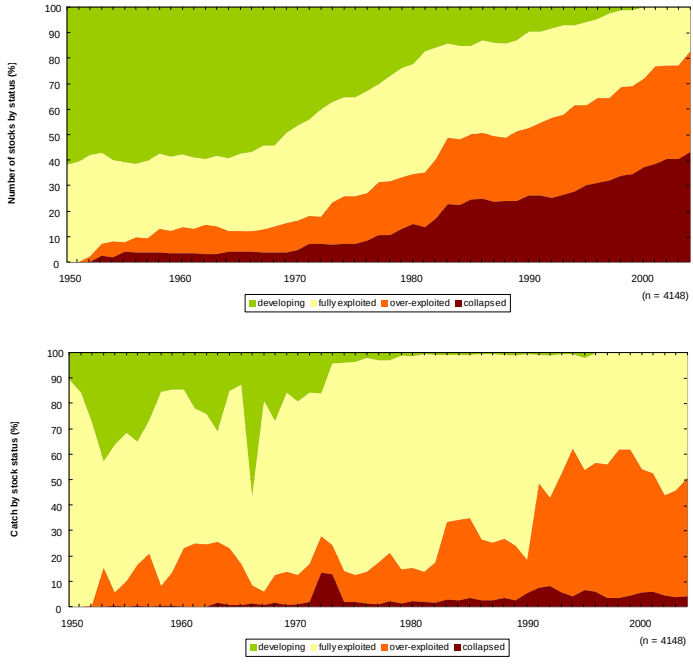

Figure IV-44.8. Stock-Catch Status Plots for the California Current LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only includes taxonomic entities at species, genus or family level. Higher and pooled groups have been excluded (see Pauly *et al*, this vol. for definitions).

Comprehensive plans for the management of marine resources in this LME are being developed. Efforts are underway to implement ecosystem management in this LME. There is a need to know more about competitive and predatory interactions, and about climate effects on the fish stocks.

III. Pollution and Ecosystem Health

The major stressors in this LME are the effects of shifting oceanic climate regimes, the intensive harvesting of commercial fish, releases of captive-bred salmon, and low-level, chronic pollution from multiple sources (Bottom *et al*. 1993). Population growth rates suggest that human pressures on coastal resources will increase substantially in many coastal areas (EPA 2004). Hypotheses concerned with the growing impacts of pollution, overexploitation and environmental changes on sustained biomass yields are under investigation. Pacific salmon in the California Current LME depend on freshwater habitat for spawning and rearing of juveniles. There are concerns about the interactions of hatchery and natural wild salmon regarding the genetic integrity of native stocks and productivity levels. The quality of freshwater habitat is largely a function of land management practices. Coastal habitat degradation and shoreline alteration have resulted from dam construction, logging, agriculture, increased urbanisation, grazing and atmospheric pollution. In 1990-2000, the coastal areas experienced a loss of 1720 acres, a low figure compared with other regions of the country but high in relation to existing wetlands in the California Current LME. Ecological conditions in West Coast estuaries, a

valuable resource in this LME, are considered fair to poor (EPA 2004). Eighty seven percent of estuaries assessed are impaired by some form of pollution or habitat degradation. Some estuaries have extensive areas with elevated phosphorus concentrations and decreased water clarity. Considerable areas have poor light penetration. DIN concentrations in estuaries are rated good. Summer wind conditions result in an upwelling of nutrient rich deep water that enters estuaries during flood tides (EPA 2004). DIP concentrations in estuaries are rated fair. Chlorophyll a concentrations in estuaries are rated good.

The EPA rated water clarity and dissolved oxygen as good, benthos and fish tissue as fair, and coastal wetlands, eutrophic condition and sediment as poor in this LME (EPA 2001). In 2004 the EPA assessed the water quality index as fair, the sediment quality index slightly improved, and the coastal habitat index and fish tissue index as poor (EPA 2004). The primary problem in California Current estuaries continues to be degraded sediment quality, with 14% of estuaries exceeding thresholds for sediment toxicity or sediment contaminants. Seventeen different contaminants were responsible for fish advisories in this LME in 2002. Toxic sediments in Puget Sound were contaminated with DDT and metals. For a study of water quality and one on sediment contamination in Puget Sound, see EPA 2004. High concentrations of metals and PAHs were observed in the Los Angeles harbour. The potential for benthic community degradation and fish contamination is increasing. A decline in seabirds such as the sooty shearwater has been observed. The LME contains a large seabird and marine mammal population (Bakun 1993) that includes sea lions and elephant seals. Since the late 1970s, pinnipeds have been increasing and are consuming large quantities of fish (DeMaster 1983; California Department of Fish and Game 2005). For more information on marine mammals as indicators of LME health, see NOAA (1999, p. 238). Of 274 coastal beaches, 178 were closed or under an advisory for some period of time in 2002.

IV. Socioeconomic Conditions

Three major estuaries, the San Francisco Bay, the Columbia River and Puget Sound, contribute to the local economy and enhance the quality of life of the inhabitants. Human population pressures are increasing in Puget Sound, the Seattle-Tacoma region, San Francisco Bay and southern California. California's population approached 37.7 million persons on January 1, 2007 (www.dof.ca.gov), up almost 3.8 million persons from the 2000 census. The coastal population increased by 45% between 1970 and 1980 (U.S. Census Bureau 1996). Forty seven coastal and estuarine counties bordering the California Current LME increased their population by 13% between 1990 and 2000 (U.S. Census Bureau 2001). In 2008 the combined population increase of San Diego, San Bernardino, Orange and Riverside counties in California was estimated at 12 percent of the total U.S. coastal population increase (www.oceanservice.noaa.gov). These pressures require continued environmental monitoring to ensure that environmental indicators currently demonstrating fair condition do not deteriorate. The California Current LME supports important commercial and recreational fisheries. All salmon species are harvested by Native American tribes for subsistence and ceremonial purposes. The value of recreational catches is not easily measured. Recent prices for salmon have declined due to market competition from record landings of Alaskan salmon and increasing aquaculture production. Northern anchovy landings fluctuate more in response to market conditions than to stock abundance. Commercial fishing is heavily regulated in an effort to achieve sustainability. In 1998 there were 9,843 commercial fishermen licensed to fish in California waters, down from 20,363 in 1980-1981. In 2006, there were 6,354 commercial fishing licenses purchased (California Department of Fish and Game Statistics, online at <www.dfg.ca.gov/licensing/statistics>). Recreational fishing in California generates US$4.9 billion and supports 43,000 jobs paying US$1.2 million in salaries and wages (Bacher 2007). An increase in the demand for oil, gas and mineral

resources (e.g., chromite-bearing black sands and titanium sands off the Oregon and Washington coasts; sand and gravel dredging) has stimulated an exploration of the non-living resources of the LME.

V. Governance

Some critical issues requiring management include wild salmon stocks and significant loss of their spawning and nursery habitats (EPA 2001, p.153). The Pacific Fishery Management Council (PFMC) is responsible for managing fisheries off the coasts of California, Oregon and Washington, with cooperation form states and tribal fishery agencies. Within Puget Sound and the Columbia River, fisheries for Chinook and coho salmon are managed by the states and tribes. The Pacific Salmon Commission, the State of Washington, and tribal fishery agencies manage fisheries for pink, chum, and sockeye salmon. All species of pink salmon have been listed as threatened or endangered under the US Endangered Species Act. There is a legally mandated tribal allocation of Coho salmon. The Pacific Salmon Treaty with Canada determines the share of Canada and the US in the transboundary stock (NMFS 2009). There are more than 80 species managed under the Pacific Coast Groundfish Fishery Management Plan (FMP) of the PFMC, no less than eight of which have been declared overfished. Many groundfish stocks have geographic ranges that extend beyond the US EEZ into Canada and Mexico. Groundfish stocks support many commercial, recreational, and Indian tribal fishing interests in state and Federal waters off the coasts of Washington, Oregon, and California. Groundfish are also caught incidentally in other fisheries, such as the trawl fisheries for pink shrimp and ridgeback prawns. Current management measures include trip limits, bag limits size limits, time/area closures, and gear restrictions. A trawl permit buy-back program was implemented in 2003 to reduce the capacity of the groundfish fishery. NOAA Fisheries Service, in cooperation with the PFMC, is assessing the impacts of groundfish fisheries on the human, biological and physical environment. A preliminary set of alternatives will be developed to take into account new stock assessments for 23 of the groundfish species managed under the FMP (NOAA Fish News 2005). For information concerning the San Francisco Bay Estuary Project, see www.abag.ca.gov/. In Northern California, commercial, recreational, and Native American fishermen have recently targeted both State and Federal water management on the Klamath River and in the California Delta charging that historic fish runs in Northern California have been destroyed by illegal pumping in the Delta area and by hydroelectric dams (Bacher, 2007).

Since the passage of the Marine Mammal Protection Act in 1972, populations of seals and sea lions have increased. Killer whales are listed as an endangered species. In the south, the Mexican portion of the LME has minimal fisheries regulation, with limited fauna and marine mammal protection. The Mexican part of this LME falls within a non-UNEP administered Regional Seas Programme, the North-East Pacific Region, which covers 8 central American countries (Colombia, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama). The Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the North-East Pacific (Antigua Convention) was signed in 2002. The governments also approved an Action Plan detailing how the countries concerned will improve the environment of the North-East Pacific for the benefit of people and wildlife. The Action Plan's secretariat is COCATRAM (Central America Marine Transport Commission). For information on PICES, see the East China Sea LME (Chapter X). The States of California, Oregon, and Washington are developing and implementing a network of marine protected areas.

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